ecaart12

The 12th European Conference on Accelerators in Applied Research and Technology

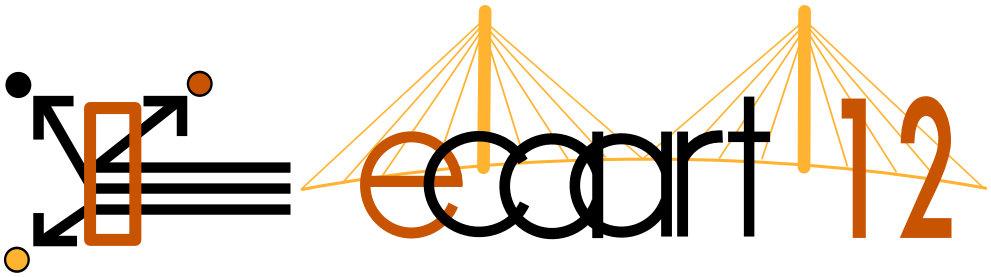
Abstract book

3 - 8 July 2016

UNIVERSITY OF JYVÄSKYLÄ

12th European Conference on Accelerators in Applied Research and Technology

ABSTRACT BOOK AND PROGRAMME



July 3–8, 2016
Jyväskylä, Finland

Abstract book
12th European Conference on Accelerators
in Applied Research and Technology

July 3–8, 2016, Jyväskylä, Finland

Editors: Kai Arstila, Elina Leskinen, Timo Sajavaara

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Welcome

Dear colleague,

We welcome you to join us at the 12th European Conference on Accelerators in Applied Research and Technology (ECAART12) hosted by the Department of Physics of the University of Jyväskylä, Finland, on 3rd – 8th July, 2016.

The first ECAART conference was held in Frankfurt (1989) and over almost three decades it has kept its status as a high level conference reporting latest developments in the field of particle accelerators and their applications. The previous ECAART conferences were organized in Florence (2007), Athens (2010) and Namur (2013), and in 2016 ECAART is the first time organized in Scandinavia. The Accelerator Laboratory in Jyväskylä is a national research infrastructure in the field of nuclear and accelerator based physics with two cyclotrons, a 1.7 MV Pelletron and a 20 MeV electron LINAC. The research covers many of the ECAART topics and therefore we are especially proud to have the conference site in Agora, only some hundred meters from the laboratory.

Following the tradition, there are no parallel sessions in ECAART12. There will be all together 13 invited talks, 29 contributed talks, and more than 110 poster presentations. The posters are divided into Tuesday and Thursday sessions and they are visible also the day before the session. There is one special session on Tuesday morning celebrating 40 years of elastic recoil detection analysis (ERDA) and we are proud to have professor Jacques L'Écuyer, the first author of 1976 ERDA paper as an invited speaker in this session. On Wednesday before the lunch and outing there is a special discussion session about the current status of the ion beam technology roadmap, an initiative by the IAEA.

Excellent science is an important part of a scientific meeting but equally important it is to meet old friends and make new ones. We are convinced that Jyväskylä, a lively city with one of the biggest universities in Finland in the middle of the Finnish Lake District will promote all of this. During the social program also the clean nature, short midsummer nights and, of course, Finnish sauna will become familiar to the conference participants.

We will do our utmost to make sure that you will feel at home and together we will make this conference a productive and engaging one.

Prof. Timo Sajavaara
Chair of the local organizing committee of ECAART12

Exhibitors and sponsors

Organisation and contact details

Local organizing committee of ECAART12

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- Dr. Kai Arstila (vice-chair), kai.arstila@jyu.fi
- Dr. Ari Virtanen (vice-chair), ari.j.virtanen@jyu.fi
- Dr. Arto Javanainen, arto.javanainen@jyu.fi
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- Dr. Mikko Laitinen, mikko.i.laitinen@jyu.fi
- Dr. Olli Tarvainen, olli.tarvainen@jyu.fi

For help, contact the info desk, write an e-mail to ecaart12@jyu.fi, or talk to the conference staff (in blue band). For urgent matters, call + 358 50 581 8351.

If you have questions concerning registration, payments, receipts, etc., please contact: Tavicon Oy (+358 3 233 0400, ecaart12@tavicon.fi). Tavicon Oy is responsible for the registration. Tavicon representatives are present on Sunday and Monday at the info desk.

In case you need any medical assistance at the conference venue, please contact + 358 50 581 8351. In case of an emergency, please call 112.

E-mail: ecaart12@jyu.fi
WWW-pages: www.ecaart12.fi, Twitter: #ecaart12_jyu or #ecaart12

International Committee:

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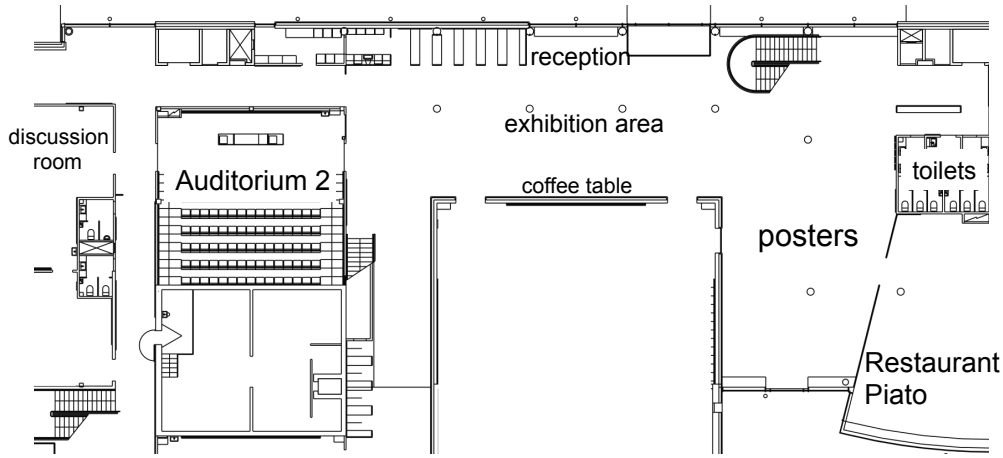
General information

Conference location

Auditorium 2, Agora building of the University of Jyväskylä (see the floorplan below)
WGS84 coordinates lat: 62.23217° lon: 25.73669°
Street address: Agora, Mattilanniemi 2, 40100 Jyväskylä, Finland



Conference registration/info desk

The registration desk will be open on Sunday 3rd of July from 16 until 21. The registration/info desk will be open during all the conference days from 8.30 in the morning until conference activities are over in Agora for that particular day. See daily schedule for details.

Oral presentations

Oral contributions are scheduled in 20-minute (30-minute for invited speakers) time slots and we strongly encourage a presentation of no more than 15 minutes (25 minutes) to allow questions from the audience during the remaining five minutes. The time limits will be strictly enforced to ensure a smooth running of the conference. The oral presentations in either PDF or PowerPoint format have to be uploaded to the organizer's computer before the session. The presentations are best displayed in 4:3 ratio, not wide screen.

Poster presentations

The poster sessions are organized on Tuesday July 5th (session A) and Thursday July 7th (session B) in the main hall of the Agora building. Poster boards with 97×135 cm of space (fits A0 in portrait orientation) are available for mounting the posters. The posters can be mounted on the day before the presentation and should be unmounted immediately after the poster session. The posters are mounted on the boards using double-sided tape provided by the organizers. The best young presentation award will be given in the conference dinner.

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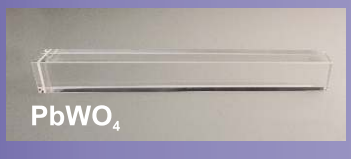
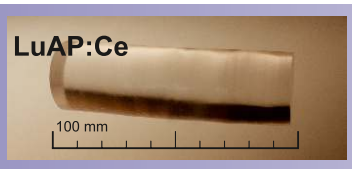
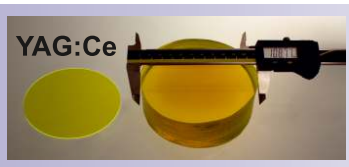
RADIATION HARD MATERIAL





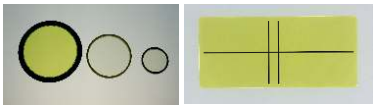


RADIATION DETECTION AND MONITORING

Scintillation detectors

α, β, γ, neutron

Scintillation screens for accelerators and synchrotrons



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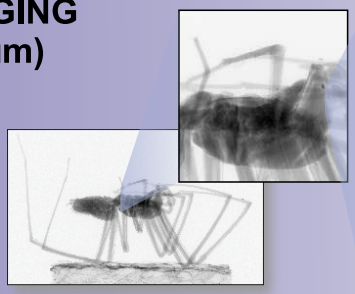

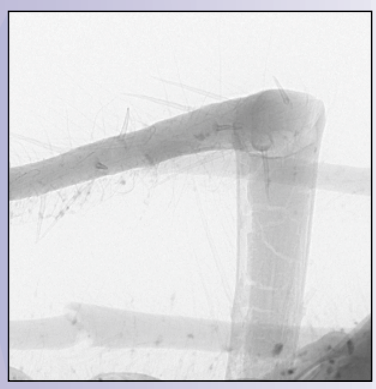

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Lunches and coffee breaks

All coffee breaks and lunches during conference are included in the conference fee. You will find vouchers for the lunches in your conference bag. Lunch will be available in the restaurant Piato. Piato is located on the ground floor of the Agora building. At the Piato the voucher can be used to obtain a full menu including a main course (meet, fish or vegetarian), a salad, a drink, bread and dessert coffee or tea. Remember to wear the conference badge throughout the conference.

Conference Proceedings

ECAART12 proceedings will be published by Elsevier Science Publishers B.V. in a special issue of Nuclear Instruments and Methods in Physics Research, section B, Beam Interactions with Materials and Atoms (NIM B). The manuscripts need to be submitted to the Elsevier online submission system before 15 of July 2016 for peer-review process. Submitted papers should be an original work associated with the symposium topics, which has not been previously published. There is no official template for the NIM B. The final formatting will be done by the editors. Nevertheless, we recommend the use of templates available at the ECAART12 website for preparing the paper. Please contact Timo Sajavaara (timo.sajavaara@jyu.fi) for proceedings related questions.

Internet Access and printing

The University of Jyväskylä is part of the eduroam (education roaming) network. The configuration instructions are specific for your institution. If your device is not yet configured, please go to www.eduroam.org or contact your institution's IT staff.

WiFi access at the university is also possible through specific congress accounts. To access the University WLAN-network you will need username and password, which you will get in your conference bag. In Agora there is also an open free WiFi access (agora-open).

If you like to use University computers, you will need username and password. With user name and password you are able to log on to public computers all over the campus areas. Computers can be found in every building.

- Username: phys-guest1
- Password: Ecaart123!

If you need to get something printed, please contact the info desk.

Conference Photo

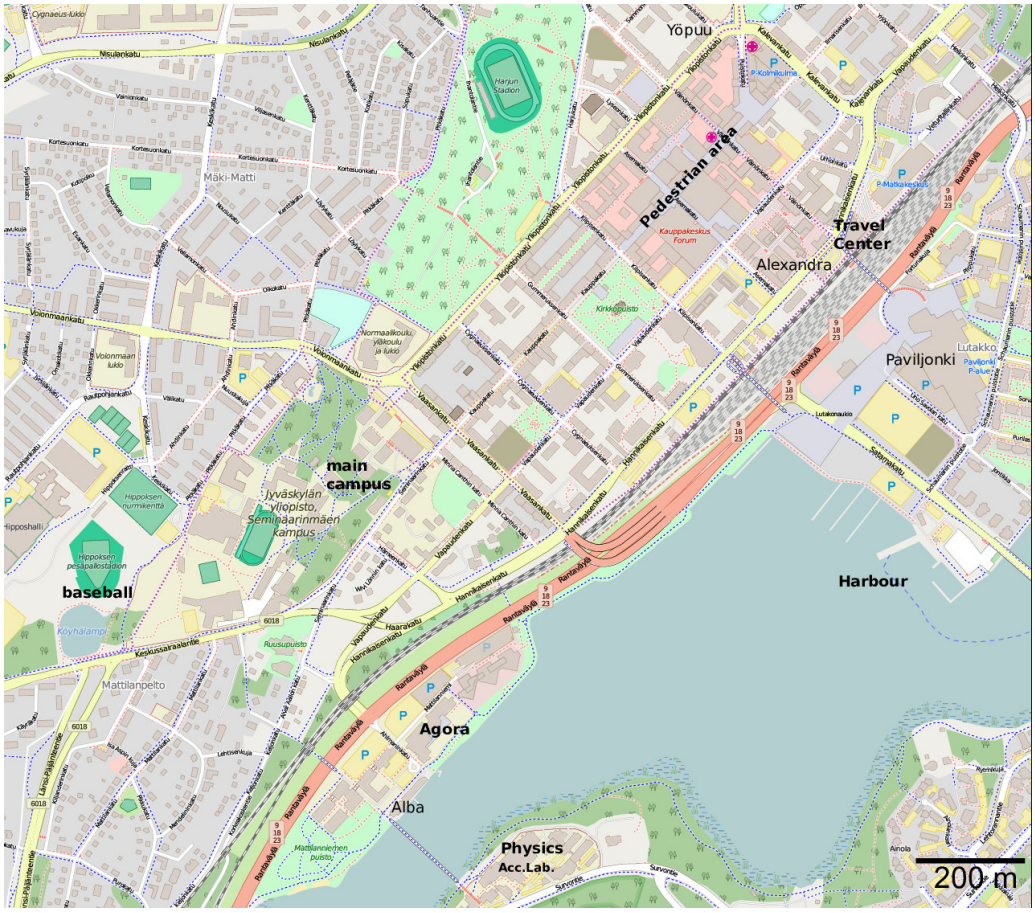
The conference photo will be taken on Monday 4th of July after the second session at 12.30, just before the lunch.

Accelerator Laboratory visit

On Monday at 16.20 we will gather between Agora and Lake Jyväsjärvi and then walk (5 min.) in five groups across the lake to visit the Accelerator Laboratory.

Jyväskylä city map

The map shows the most relevant places in the ECAART12 conference. The city center with most of the restaurants and stores is around the pedestrian area. ©OpenStreetMap contributors



Hiisi denotes a sacred and mythological
place for Baltic-Finnic people.
HIISI is also a brewery
in central Finland.

HIISI
JYVÄSKYLÄ

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Social programme

Our social programme will enable you to discover our town as well as its beautiful surrounding area. In addition to the social program, there are a lots of happenings in Jyväskylä! Go and see the museums, visit a football or a Finnish baseball game or enjoy the music provided by many events in Jyväskylä summer. You may also enjoy the clean nature of Finland by having a picnic in a park, playing some frisbee or football at the grass or swimming in the lakes.

Welcome Reception

The congress welcome reception offers delegates a perfect opportunity to relax and enjoy informal drinks with colleagues and associates as part of the warm welcome to the 12th European Conference on Accelerators in Applied Research and Technology. High Voltage Engineering Europa B.V. is gratefully acknowledged for sponsoring this event.
Time: Sunday 3rd of July, 2016 at 19:00 – 21:00.
Location: Agora hall.
Inclusions: Beverages and canapés.

City tour with city guide

For accompanying persons walk to the center of the city showing the main museums, attractions and shopping areas on Monday morning. Learn about the history and architecture of the campus and city of Jyväskylä.
Time: Monday 4th of July, 2016 at 10:30 – 12:30.
Location: Departure in front of the Agora at 10:30. Transportation back to the Agora at 12:30.

Monday and Tuesday evenings

There is no fixed program for these two evenings but there is much to do in Jyväskylä. There will be several companies presenting their outdoor activities during the welcome reception of Sunday. There is also a possibility to see top level Finnish baseball (our national sport) on Tuesday evening, please sign in at the info desk. The baseball match will be free for the conference participants, other activities are at own expense.

Conference outing: The Varjola Holiday Center

Varjola farm has a wide range of activities and organised experiences in beautiful Finnish countryside. You will have a wonderful chance to enjoy Finnish culture, spend time outdoors. Possibilities for walks in the nature, white water rafting and games. In Varjola area the traditional Finnish Smoke saunas offer you a relaxing experience that you will never forget.
Time: Wednesday 6th of July, 2016 at 13:30–22:00
Location: Busses will take us there from Agora at 13:30, please be on time. There is bus transportation back to the Travel Center and Agora after the dinner at 21:30.
Inclusions: Beverages and dinner.
Dress: Suitable clothes for outdoor activities. If you do the white water rafting, and we strongly recommend that, you might want to bring some extra dry clothes with you.
Sauna: There will be separate saunas for women and men, towels will be provided. If you want to go swimming from the sauna, as Finns normally do, bring your swimming suit with you.

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Cruise and Conference Dinner at Savutuvan Apaja

Finland is the country of thousands lakes and Jyväskylä lies at the very center of the Finnish Lake District. The conference participants will be offered an opportunity to enjoy the peaceful lake scenery with typical Finnish summer cottages along the shore by taking an evening cruise on Lake Päijänne, the second largest lake in Finland. After cruising about an hour on the lake, the boat will come ashore at Savutuvan Apaja where the dinner will be served in a unique atmosphere. Savutuvan Apaja consists of over 30 peasant buildings, the oldest of which is over 200 years old. The yard with its historic buildings built of timber let you experience what it was like living in Central Finland in the past.
Time: Thursday 7th of July, 2016, 16:45–24:00
Location: M/s Suomen Suvi cruise ship will take us Savutuvan Apaja from Hotel Alba at 16.45 and Jyväskylä harbor at 17:00 so please be on time. There is bus transportation back to the Agora with a stop at the Travel Center after the dinner at 24:00.
Inclusions: Beverages and dinner. Live music throughout the night presented by Pallomeri.
Dress: The night can get bit chilly, so you better have some warmer clothes with you.

Visitor information

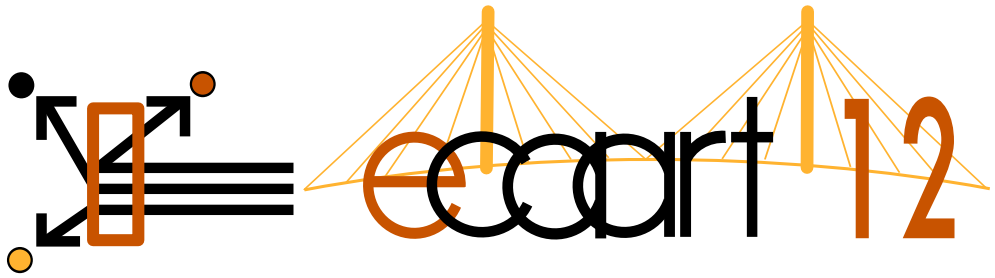
The info desk offers information about the city and its sights, events, restaurants, souvenirs and services. Get the tips and advice for making the most of your conference.

Thank you

We would like to thank you in advance for participating in the 12th European Conference on Accelerators in Applied Research and Technology (ECAART12). We wish that you, just like us, will have an interesting week with lots of new insights and fun as well. Hopefully we have given you a good impression of University of Jyväskylä and city of Jyväskylä.

If you want to share your photos or videos, please send them to ecaart12@jyu.fi as we will create a Dropbox account. You will receive an invitation to join this account in August.

Organisation of ECAART12



Scientific Program

Monday 4.7.2016

8:45 – 9:00	**Opening remarks**	
Medical, biological and environmental applications	**Chair: Iva Bogdanović Radović**	
9:00 – 9:30	**M.Q. Ren** *National University of Singapore, Singapore* Analytical Possibilities of Highly Focused Proton Beam in Biomedical Field	I-1
9:30 – 9:50	**Koji Noda** *National Institute of Radiological Sciences, Japan* Recent progress and future plan of heavy-ion cancer radiotherapy with HIMAC	O-1
9:50 – 10:10	**Cátia Santos** *Universidade Nova de Lisboa, Portugal* Measurement of the Ca/P ratio of samples with Paget's disease of bone and osteoporosis by PIXE, PIGE and micro-XRF	O-2
10:10 – 10:30	**Roger P. Webb** *University of Surrey, UK* Ambient Pressure Mass Spectrometry of Fingerprints: An Opportunity for MeV-SIMS	O-3
10:30 – 11:00	**Coffee**	
Ion beam modification and radiation effects	**Chair: Jyrki Räisänen**	
11:00 – 11:30	**Arto Javanainen** *University of Jyväskylä, Finland* Radiation effects in electronics – featuring power devices	I-2
11:30 – 11:50	**Leonard C. Feldman** *Rutgers University, USA* Ion Beam Science Applied to Silicon Carbide Technologies	O-4
11:50 – 12:10	**Shavkat Akhmadaliev** *Helmholtz-Zentrum Dresden-Rossendorf, Germany* Depth profiled ion implantation doping using an energy filter based on Si membrane	O-5
12:10 – 12:30	**Jakub Cajzl** *University of Chemistry and Technology, Prague, Czech Republic* Erbium doped nanocrystalline diamond thin films	O-6
12:30 – 14:00	**Lunch**	
Accelerator mass spectrometry	**Chair: Alfred Dewald**	
14:00 – 14:30	**Caroline Welte** *ETH Zurich, Switzerland* Laser Ablation – Accelerator Mass Spectrometry: rapid and spatially resolved radiocarbon analyses of carbonate archives	I-3
14:30 – 14:50	**Peter Steier** *University of Vienna, Austria* The ILIAS project – Isobar suppression in AMS by laser photodetachment	O-7
14:50 – 15:10	**Klaus Wilcken** *ANSTO, Australia* Accelerator Mass Spectrometry on SIRIUS: new 6 MV spectrometer at ANSTO	O-8
15:10 – 15:30	**Markus Schiffer** *University of Cologne, Germany* A dedicated AMS setup for medium mass isotopes at the Cologne FN-Tandem Accelerator	O-9
15:30 – 15:50	**Vesa Palonen** *University of Helsinki, Finland* Biofraction measurements of methane for environmental and metrological applications	O-10
15:50 – 16:20	**Coffee**	
16:20 – 18:00	**Lab visit**	

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Tuesday 5.7.2016

Elastic Recoil Detection Analysis 40 years	Chair: Max Döbeli	
9:00 – 9:40	**Jacques L'Écuyer** The development of ERDA	I-4
9:40 – 10:10	**Stephan Eschbaumer** *Universität der Bundeswehr München, Germany* An angular sensitive time of flight setup for heavy ion ERD	I-5
10:10 – 10:30	**Timo Sajavaara** *University of Jyväskylä, Finland* Conceptual study of high-performance heavy-ion-ERDA spectrometer for energies below 6 MeV	O-11
10:30 – 11:00	**Coffee**	

Applications to art and archeology	Chair: Miguel A. Respaldiza	
11:00 – 11:30	**Claire Pacheco** *Centre de Recherche et de Restauration des Musées de France, Paris, France* From AGLAE to New AGLAE	I-6
11:30 – 11:50	**Lucile Beck** *LMC14, Saclay, France* Analysis and dating of the Preuchdorf hoard (Alsace, France) by IBA and AMS	O-12
11:50 – 12:10	**Iva Bogdanović Radović** *Ruđer Bošković Institute, Zagreb, Croatia* Identification and imaging of modern paint materials using MeV-SIMS	O-13
12:10 – 12:30	**Alexandre Subercaze** *Subatech, Nantes, France* Thick multi-layers analysis with high energy PIXE	O-14
12:30 – 14:00	**Lunch**	

Ion source and accelerator technology	Chair: Leonard C. Feldman	
14:00 – 14:30	**Victor Malka** *CNRS, Ecole Polytechnique, France* Manipulating Electrons with Intense Laser Pulses	I-7
14:30 – 14:50	**Matthias Klein** *High Voltage Engineering Europa B.V., Amersfoort, Netherlands* Technical improvements and performance of the HVE AMS sputter ion source SO110	O-15
14:50 – 15:10	**M.V. Mores** *National Electrostatics Corp., Middleton, Wisconsin, USA* Recent Projects and Future Collaborations at National Electrostatics Corp.	O-16
15:10 – 15:30	**Taneli Kalvas** *University of Jyväskylä, Finland* Application and development of ion source technology for electronics radiation effects testing	O-17
15:30 – 15:50	**Kenichiro Mizohata** *University of Helsinki, Finland* Accelerators of University of Helsinki on the IAEA Ion Beam Technology roadmap	O-18
15:50 – 16:20	**Coffee**	
16:20 – 18:00	**Poster session A**	

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Ionplus covers the entire range of dedicated ^{14}C laboratory equipment. Our instruments are designed for fast and efficient sample processing with a very high degree of automation. We offer fully automated graphitization systems – AGE 3, gas interface systems for unattended gas measurements of small samples – GIS, automated carbonate handling systems – CHS, and a range of peripheral devices. High-precision $\delta^{13}C$ and $\delta^{15}N$ values can be conveniently obtained online during graphitization and gas measurements with a newly implemented IRMS instrument.

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info@ionplus.ch

Wednesday 6.7.2016

Fundamentals and simulations	**Chair: Kai Arstila**	
9:00 – 9:30	**Jeremy M C Brown** *Queen's University Belfast, United Kingdom* Applications of Geant4 to ion beam and synchrotron science	I-8
9:30 – 9:50	**M. Mayer** *Max-Planck-Institut für Plasmaphysik, Garching, Germany* Computer Simulation of Backscattering Spectra from Paint	O-19
9:50 – 10:10	**Michael Kokkoris** *National Technical University of Athens, Greece* CSIM – A new code for the simulation of channeling EBS/RBS spectra	O-20
10:10 – 10:30	**Guy Terwagne** *University of Namur, Belgium* Development of an ultra-low background detection facility	O-21
10:30 – 11:00	**Coffee**	
Ion beam technology and industry	**Chair: Ian Vickridge**	
11:00 – 11:30	**J. Meersschaut** *Imec, Leuven, Belgium* High-throughput ion beam analysis in an industrial environment	I-9
11:30 – 12:30	**Ion Beam Technology roadmap**	
12:30 – 13:30	**Lunch**	
13:30 – 22:00	**Conference outing**	

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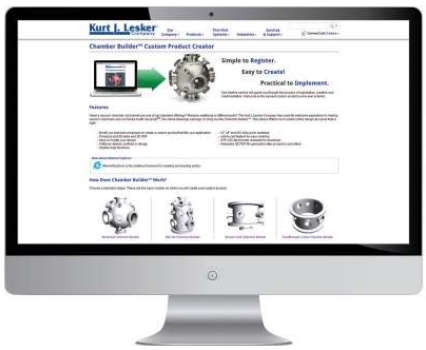

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Thursday 7.7.2016

Instruments and techniques for materials research	Chair: Ferenc Ditrói	
9:00 – 9:30	**Simo Huotari** *University of Helsinki, Finland* Recent developments in synchrotron light sources and new possibilities for materials research	I-10
9:30 – 9:50	**Charles-Olivier Bacri** *CNRS-CSNSM, Orsay, France* SCALP, a platform for synthesis and characterization of materials	O-22
9:50 – 10:10	**M. Fonseca** *Universidade Nova de Lisboa, Portugal* Quantitative analysis of Li by PIGE technique	O-23
10:10 – 10:30	**Victor Alarcon-Diez** *Sorbonne Universités, France* Charge Collection Efficiency in Segmented Semiconductor Detector interstrip region	O-24
10:30 – 11:00	**Coffee**	

Analysis and modification using heavy ions	Chair: Roger Webb	
11:00 – 11:30	**Zdravko Siketić** *Ruđer Bošković Institute, Zagreb, Croatia* Two modes for molecular imaging using MeV-SIMS at the heavy ion microprobe	I-11
11:30 – 11:50	**Toshio Seki** *Kyoto University, Japan* Chemical analysis under ambient conditions using swift heavy ion beams	O-25
11:50 – 12:10	**Kenji Morita** *Nagoya Industrial Science Research Institute, Japan* In-situ Depth Profiling of Li in Solid State Li Ion Battery under Charging by Means of ERDA and RBS Techniques with 9 MeV O^{+4} ion	O-26
12:10 – 12:30	**Florent Moisy** *CIMAP, Caen, France* Point defects and structural modifications in $Al_xGa_{1-x}N$ nitride semiconductors under heavy ion irradiation	O-27
12:30 – 14:00	**Lunch**	
14:00 – 15:50	**Poster session B**	
16:45 – 24:00	**Cruise and conference dinner**	

Pelletron Systems

MATERIALS ANALYSIS

National Electrostatics Corp. offers tandem and single ended Pelletron systems with all hardware and software for **RBS, channeling, PIXE, ERD and NRA** data collection. Software is included for RBS and PIXE data analysis

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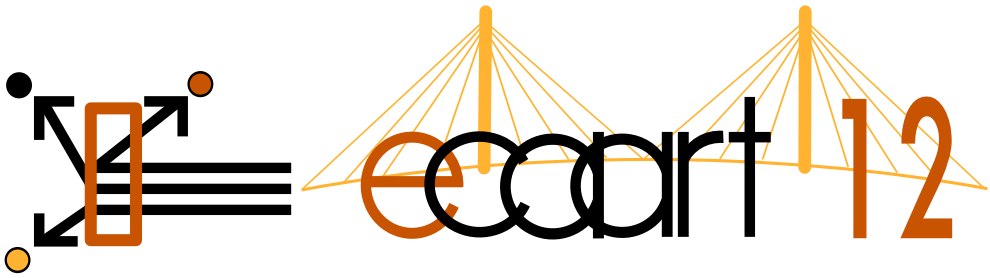
Friday 8.7.2016

Accelerator technology and radiation hard materials	Chair: Ari Virtanen	
9:00 – 9:30	**Markus Strobl** *ESS ERIC, Lund, Sweden* ESS – the promises of an accelerator in the service of neutron science	I-12
9:30 – 9:50	**Alexandre Bosser** *University of Jyväskylä, Finland* R2RAM project: Development and characterization of a radiation-hard resistive random-access memory	O-28
9:50 – 10:10	**Tianjue Zhang** *China Institute of Atomic Energy, Beijing, China* mA Beam Acceleration Efforts on 100 MeV H^- Cyclotron at CIAE	O-29
10:10 – 10:30	**Coffee**	
Quality assurance in IBA	**Chair: Timo Sajavaara**	
10:30 – 11:00	**Chris Jeynes** *University of Surrey Ion Beam Centre, United Kingdom* RBS as a new "primary direct reference method" for measuring Quantity of Material	I-13
11:00 – 11:30	**Concluding remarks**	
11:30 – 11:45	**Closing of the conference**	
11:45 – 13:00	**Lunch**	

Tuesday 5.7.2016 – Poster session A

Thursday 7.7.2016 – Poster session B



Abstracts

Invited Talks

Analytical Possibilities of Highly Focused Proton Beam in Biomedical Field

*MQ Ren, SK Vajandar, ZH Mi, JA van Kan, F Watt, T Osipowicz

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The novelty of fast ion beam is its ability of traversing through matter with well-defined straight path having very little lateral spread, for example, 2 MeV proton beam can penetrate 5 μm into polymer PMMA with only 25 nm lateral spreading. This unique characteristic has been demonstrated in various applications, especially in the field of biological tissue and single whole cell imaging using the Nuclear Microscopy (NM) facility in the Center for Ion Beam Applications, National University of Singapore.

Probing into thin biological tissue and single whole cell without slicing the cell into thin sections at high spatial resolutions is not easy: conventional light microscope can't resolve features smaller than 250 nm due to the limitation of fundamental diffraction limits of visible light; electron microscopy has nanometer resolution but is limited to viewing only surface features because electrons are easily scattered. The NM facility in the National University of Singapore has the state-of-art performance of probing thin tissue section with 0.5–1 μm and single whole cells with sub-100 nm fine proton beam and alpha beam. It has also been used for material modification to create different nano and micron structures for various applications.

My talk will include an introduction to the-state-of-art NM facility operated using fast ions (protons and alpha particles) and its various applications by using the combination of nuclear techniques such as scanning transmission ion microscopy (STIM) for providing detailed density contrast images of thin biological tissue and single whole cell with and without NanoParticles, Rutherford Backscattering Spectrometry (RBS) for determining the depth of NanoParticles from the surface to inside the cells, proton induced X-ray emission (PIXE) for trace elemental mapping and quantification measurements, proton induced fluorescence (PIF) for imaging the fluorescence dye to which cell-nucleic acid or other cell organelles might be sensitive, etc.

We believe the NM facility in CIBA has great potential to extract more information from thin section of biological materials and inside single whole cells in a much more unique way, and will be complementary to other types of microscopy widely used in the imaging world.

Radiation effects in electronics – featuring power devices

*Arto Javanainen[1,2]

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All electronic systems are under a constant threat due to radiation. On the ground the threat is less evident than in space, but nevertheless the threat exists. Many of the radiation-induced problems, especially in logic devices, can be (and are) mitigated by using various software and/or hardware techniques, such as error-detection-and-correction, or redundancy, etc. Also, for critical applications, the components can be designed to tolerate radiation, which is called RadHard-by-Design or RHDB. However, these precautions are not always feasible, due to budget or performance contraints. For many applications it is more cost-effective, and more efficient to use commercial off the shelf (COTS) components rather than the RadHard components. In any case, the radiation response of the devices needs to be assessed before devices can be used in the final applications in harsh radiation environment. Typically in radiation hardness assurance testing, two types of radiation effects are studied: (1) cumulative effects, which include total ionizing dose (TID) and displacement damage (DD), and (2) prompt effects, so-called Single Event Effects (SEE). This presentation will focus on SEE testing by using energetic heavy ion beams.

The talk will give introduction to the relevant radiation environments in space and on ground, and the most common types of radiation effects occurring in electronics. Also the RADiation Effects Facility (RADEF) [1] in the Accelerator Laboratory of the University of Jyväskylä will be introduced. The radiation testing specifications will be briefly discussed with focus on SEE and particularly those in power devices. As a case-study, the radiation response of modern power technologies, based on GaN and SiC, will be compared to that of silicon-based power devices. The implication of the different radiation response in SiC and GaN technologies on their utilization in space applications is discussed.

[1] https://www.jyu.fi/fysiikka/en/research/accelerator/radef

Laser Ablation – Accelerator Mass Spectrometry: rapid and spatially resolved radiocarbon analyses of carbonate archives

*Caroline Welte[1,2], Lukas Wacker[1], Bodo Hattendorf[2], Marcus Christl[1], Joachim Koch[2], Christiane Yeman[1], Jens Fohlmeister[3], Sebastian F.M. Breitenbach[4], Allen H. Andrews[5], Laura F. Robinson[6], Jesse R. Farmer[7], Detlef Günther[2], Hans-Arno Synal[1]

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[7]*Earth and Environmental Sciences and Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, USA*

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Spatially resolved radiocarbon (^{14}C) profiles in carbonate archives (e.g. corals, speleothems, shells) are difficult to accomplish due to tedious multi-step sample preparation required for conventional ^{14}C measurements, employing accelerator mass spectrometry (AMS). Furthermore, producing a highly resolved ^{14}C record implies processing a large number of subsamples, which is very time consuming.

A novel setup [1, 2, 3] has been developed at ETH Zurich that combines high spatial resolution of laser ablation (LA) with the sensitivity of AMS, enabling rapid in-situ determination of ^{14}C in carbonate samples. An ArF-excimer laser beam (λ = 193 nm) is focused on the carbonate sample, generating CO_2 that is directly introduced into the AMS gas ion source. Pressed carbonate powder reference materials (IAEA C2, CSTD, in-house standards) and marble have been used to investigate the analytical behavior of the new LA-AMS system including sensitivity, accuracy, background and cross-contamination. Best measurement conditions were reached using a carbon flow into the ion source of about 3 µg/min, resulting in negative ion currents up to 20 µA, a detection limit of about 1% of the modern ^{14}C concentration, and a reproducibility of reference materials within counting statistics. Different sampling strategies are compared using a stalagmite sample comprising the ^{14}C bomb pulse. The applicability of the setup for other materials such as corals and shells is demonstrated.

The continuous sampling of the LA-AMS setup offers great flexibility with regard to analysis time, spatial resolution and measurement precision: several cm per hour can be scanned, providing rapid overview screening of the ^{14}C abundance in a sample. A resolution of 100 µm and measurement precision of 1% is achievable for modern samples. A detailed overview of the todays' performance of the setup will be given and implications on new possible applications will be reviewed.

[1] Welte, C., Wacker, L., Hattendorf, B., Christl, M., Koch, J., Synal, H.-A., Günther, D., Radiocarbon 2016 (accepted for publication).
[2] Münsterer, C., Wacker, L., Hattendorf, B., Christl, M., Koch, J., Dietiker, R., Snyal, H.-A., Günther, D., Chimia 2014, 86, 215.
[3] Wacker, L., Münsterer, C., Hattendorf, B., Christl, M., Günther, D., Synal, H.A., NIM B 2013, 294, 287.

The development of ERDA

*Jacques L'Écuyer

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In this presentation, the author will explain how the elastic recoil detection method was developed. He will show that this development came from the close collaboration of two groups of scientists coming from different horizons: one group was composed of surface scientists and the other of nuclear physicists. This led to the development of ERDA and to the solution of a difficult technical problem: the corrosion of internal walls of nuclear reactors. The author will use original documents to describe the different steps of this development. He will show that the power of ERDA was rapidly recognized by the scientific community. He will also discuss some of the problems that he met during this development and draw some conclusions from this experience.

An angular sensitive time of flight setup for heavy ion ERD

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Elastic recoil detection analysis (ERD) is performed using heavy ion beams provided by the Munich Tandem Accelerator utilizing a Q3D magnetic spectrograph in order to obtain high resolution depth profiles (< 1 nm depth resolution) of a single element in a single run [1]. For simultaneously monitoring multiple elements of the sample and to quantify the high resolution profiles a TOF-E setup has been installed at the Q3D scattering chamber.

The depth resolution in the TOF-E measurements however is affected through kinematics by the solid angle of detection of 0.4 msr (dE/E_{Kin} = 3.3 %, scattering angle α = 40°, $\Delta\alpha$ = 1.1°) and by the enlarged effective beam spot size due to an incident angle of typically 4° (with respect to the sample surface) which is required for optimal depth resolution for the Q3D measurements. This additional kinematic contribution $dE/E_{Spotwidth}$ is in the range of 0.6 %. In order to correct both kinematic contributions an angular measurement of every recoil ion trajectory is required.

For determination of the true scattering angle two position measurements are necessary. One position measurement is carried out by a position sensitive gas ionization chamber serving as energy detector within the TOF-E setup. The second position determination is realized by the start detector of the TOF setup. Therefore, a new TOF detector has been developed which is based on secondary electron emission/detection from both sides of a carbon foil. A straight detector geometry is used to detect the emitted electrons by two MCP stacks for separate position and time measurement. A position resolution of < 0.6 mm FWHM as well as an intrinsic timing resolution of 96 ps FWHM is achieved [2].

The performance of the individual detectors within the setup as well as the performance of the entire TOF-E setup for ERD measurements will be shown.

[1] G. Dollinger, A. Bergmaier, L. Goergens, P. Neumaier, W. Vandervorst, and S. Jakschik. High resolution elastic recoil detection. Nucl. Instr. and Meth. B 219-220, 333-343, (2004)
[2] S. Eschbaumer, A. Bergmaier, G. Dollinger, A position sensitive time of flight detector for heavy ion ERD, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 371 (2016) 125 – 131

From AGLAE to New AGLAE

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Since its settlement in the premises of Le Louvre in 1988, the Grand Louvre Accelerator for Elemental Analysis – alias AGLAE – has been continuously developed on instrumental and methodological aspects so as to improve its performance in IBA for Cultural Heritage objects with their very specific issues and constraints.

Laureate of the French Future Investment – EQUIPEX programme, the New AGLAE project has been devised in the same perspective. As a matter of fact, proposals for AGLAE beamtime are more numerous, which has motivated the first aim of the project consisting in the automation of the beamline in order to run experiments night and day. Moreover, if most materials, mainly inorganic as glass, ceramics, metals, stones, etc. can be non-invasively directly analyzed without any preparation, some fragile artifacts, typically paintings composed by inorganic pigment and organic binder, can be irreversibly modified by the beam. For that reason, a multi-detector enabling systematic mapping is being developed in the framework of this project.

The state of progress of the *New AGLAE* project will be presented, especially the automation of the beamline and the prerequisite stabilization of the beam. Original IBA applications to Cultural Heritage objects will illustrate the talk.

[1] J.C. Dran, J. Salomon, Th. Calligaro, Ph. Walter, Ion beam analysis of art works: 14 years of use in the Louvre, NIMB, June 2004, 219-220, 7-15

Manipulating Electrons with Intense Laser Pulses

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Laser Plasma Accelerators (LPA) rely on the control of the electronic motion with intense laser pulses [1]. The manipulation of electrons with intense laser pulses allows a fine mapping of the longitudinal and radial components of giant electric fields that can be therefore optimized for accelerating charged particle or for producing X rays. To illustrate the beauty of laser plasma accelerators I will show, how by changing the density profile of the gas target, one can improve the quality of the electron beam, its stability [2] and its energy gain [3], or by playing with the radial field one can reduce its divergence [4]. I'll then show how by controlling the quiver motion of relativistic electrons intense and bright X-rays beam are produced in a compact and elegant way [5,6]. Finally I'll show some examples of applications [7].

[1] V. Malka, Phys. of Plasmas **19**, 055501 (2012).
[2] E. Guillaume *et al.*, Phys. Rev. Lett. **115**, 155002 (2015).
[3] C. Thaury Scientific Report, 10.1038, srep16310, Nov. 9 (2015).
[4] C. Thaury *et al.*, Nature Comm. **6**, 6860 (2015).
[5] K. Ta Phuoc *et al.*, Nature Photonics **6**, 308-311 (2012).
[6] S. Corde *et al.*, Review of Modern Phys. **85** (2013).
[7] I. Andriyash *et al.*, Nature Comm. **5**, 4736 (2014).

Applications of Geant4 to ion beam and synchrotron science

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Geant4, a toolkit for simulating the passage of particles through matter, is the result of a world wide collaboration of over 100 scientists and software engineers spanning the last 20 years. Since the development of its original implementation, a total of nine additional versions have been released. With each release the core tracking, geometry and hits collection architecture has been incrementally improved and optimised. At the same time new particle types and physics models, including electromagnetic, hadronic and optical processes, spanning energies of a few eV to hundreds of TeV have been added to increase the functionality of Geant4. In this talk I will present an overview of Geant4, outline its capabilities for accelerator science, and discuss a few select Geant4 based ion beam and synchrotron science studies.

High-throughput ion beam analysis in an industrial environment

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The semiconductor industry faces significant challenges to continue increasing the performance and the functionality of information processing. A true revolution in the semiconductor technology has occurred with the replacement of the SiO_2 gate dielectric by high-k dielectric materials in conjunction with a metallic gate. As the semiconductor industry moves to silicon nanoelectronics and beyond, new materials are being developed and investigated, and novel technologies are being pursued.

Strong metrology and characterization approaches are required to probe the novel materials and devices that will advance the semiconductor technology. Ion beam analysis has traditionally been recognized for its capability to characterize the thickness and crystal structure of sub-nanometer thin films. In order to keep relevance to the semiconductor R&D environment, it is imperative that the ion beam techniques can analyze standard test structures, that it can handle large numbers of samples, and that it allows for a short turn-around time.

The experimental set-up at imec has been optimized to enable the analysis of large volumes of samples with Rutherford backscattering spectrometry (RBS) and ToF-E elastic recoil detection analysis (ERDA). Both the end-stations, for RBS and ERDA, allow one to load a series of samples to be measured un-attended. We will present the hardware configurations of the experimental end-stations. Besides, we will present the architecture of a novel software platform (WASP) that facilitates the scheduled and unattended data-acquisition for RBS and ERDA.

The analysis, interpretation and reporting of RBS and ERDA requires a considerable time and effort of a skilled person. We will present the procedures and algorithms developed at imec to optimize the efficiency of the RBS and ERDA data-analysis, and to attain a good traceability and reproducibility.

We will illustrate the contribution of ion beam analysis at imec to the development of emerging semiconductor technologies through selected cases: the analysis of MX2 materials, of laterally confined fins, and of Li- containing compounds for battery applications.

Towards the future, we envisage ion beam analysis to remain a reliable characterization approach in the semiconductor R&D environment. We will present further developments and strategies to achieve this.

Recent developments in synchrotron light sources and new possibilities for materials research

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The new generation of synchrotron radiation sources is upcoming with the development of the novel concepts of a diffraction limited storage ring design. Leading the way are e.g. the MAX-IV Laboratory in Lund, Sweden, and the EBS (Extremely Brilliant Source) upgrade of the European Synchrotron Radiation Facility, in Grenoble, France.

The recent status and the new possibilities offered by the new synchrotron light sources are reviewed. Focus areas on materials research are emphasized.

Two modes for molecular imaging using MeV-SIMS at the heavy ion microprobe

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Time of flight Secondary Ion Mass Spectrometry (TOF-SIMS) is a well-established technique used for the identification of molecular ions released from the sample surface by primary ion beam. The choice of the primary ion for TOF-SIMS is critical because it determines detection sensitivity for certain molecular ion. Contrary to the keV-SIMS, where secondary molecular ions are ejected from the sample surface due to the dominant nuclear sputtering (collision cascade), ejection of secondary molecular ions with MeV primary ions is a consequence of electronic sputtering mechanism that dominates the MeV ion energy deposition process and causes desorption of intact large secondary molecular ions. Therefore, several orders of magnitude larger yields as well as less fragmentation are expected for larger molecular masses when MeV ions are used for the excitation. This is especially important for imaging of organic samples with a micrometer lateral resolution.

In case when organic material is analysed, energy deposited at the surface by the primary ion has to be high enough to desorb substantial number of intact molecules, with low fragmentation rate, keeping at the same time chemical damage very low (static regime). Among the all mass spectrometry techniques, there are only few of them, like TOF-SIMS using C-60 and Ar cluster primary beams or MALDI, which fulfil those requirements and are suitable for the molecular imaging of delicate biological samples.

For MeV-SIMS measurements at the Ruđer Bošković Institute, the most commonly used primary beams are oxygen and silicon with energies between 5 and 20 MeV. In order to obtain a sufficiently narrow width of the timing pulse (<5 ns), which is essential for high mass resolution imaging, current of the primary focused heavy ion beam has to be greater than 100 pA. To fulfil this condition, large opening of the object and collimator slits is needed limiting lateral beam resolution to ~10 μm. This lateral resolution is however not sufficient for molecular imaging of single cells. In order to improve the beam lateral resolution, we have decided to use continuous primary ion beam with significantly lower currents (< 1 fA) instead of the pulsed beam. Trigger for the timing signal was provided by the primary ion detector, which was placed behind the thin transmission target. With this approach using the same primary ion current beam lateral dimension was reduced by an order of magnitude. This high-resolution mode (transmission MeV-SIMS, continuous mode) can be used only for targets, which are transparent for primary ions such as thin tissue sections or single cells grown on thin Si_3N_4 windows. For thick samples, such as cultural heritage samples, MeV-SIMS in low-resolution mode using pulsed primary ion, can be applied. Results obtained with both imaging modes as well as the role of the proper ion beam selection for MeV-SIMS analysis will be also discussed.

ESS – the promises of an accelerator in the service of neutron science

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The European Spallation Source is currently under construction in Lund in Sweden (Fig. 1). The ESS is a 2 GeV proton accelerator driven spallation neutron source planned to be the brightest neutron source for material research worldwide. Hence, the accelerator will serve the neutron science community and in particular the European material science community and in some cases also industry directly. Rather than on the accelerator itself the presentation shall focus on the specific advantages of using an accelerator driven source for neutron science as well as on the scientific capabilities in material science, which such approach enables. The specific focus will indeed be on the expected performance and capabilities of the ESS facility in this respect, outlining neutron science applications and the expected advantages of the accelerator driven ESS neutron source, which will be the world's first long pulse spallation neutron source.

Figure 1: Current status of ESS construction with the accelerator tunnel nearly completed (top right of center) in Lund, Sweden.

RBS as a new "primary direct reference method" for measuring Quantity of Material

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RBS is well suited in principle to being a highly accurate primary reference method since the interaction cross-section is given analytically. This is why Anthony Turkevich claimed it was "1% accurate" in his report on the analysis of Moon rocks following the landing of Surveyor V in 1967 [1]. But transparent evidence for such accuracy was not available until 2012 [2].

The Surrey ion implantation Quality Assurance protocol qualifies ion fluence at 1%, using RBS (reproducible at 0.33%, see Figure) to absolutely determine the retained ion dose [3]. The RBS accuracy is traceable to a certified reference material [4] through the stopping power, measured at 0.8% [5]. This work was a longitudinal study of implanter behaviour over four years, with 1.5% electrical characterisation of sheet resistance by four-point-probe.

We also show how to directly measure the beam energy (at 0.03%), independently establishing the EBS resonance at 3038 keV for ^{16}O [6], consistently with the nuclear physics compilations [7]. Accurate RBS also depends on linearising the spectrometry by taking account of the pulse height defect [8]. 1% accurate RBS has been accredited [9] as conforming to the ISO 17025 standard, the first such accreditation of any lab for RBS. The analytical power of "Ion Beam Analysis" (RBS, EBS, ERD, NRA, PIXE) is dramatically enhanced by a synergistic use of multiple techniques (so-called "Total-IBA" [10]).

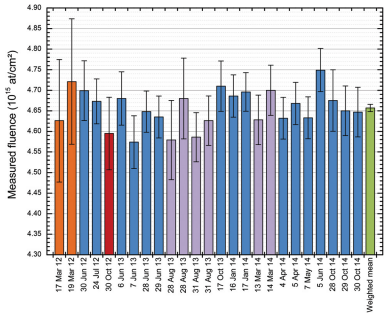

Figure 1: Repeated independent RBS of the implanted dose in the same sample, with mean and standard combined standard uncertainties (Fig.7 of ref.3)

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[3] J.L. Colaux, C. Jeynes, K.C. Heasman, R.M. Gwilliam, Analyst, 140 (2015) 3251-3261
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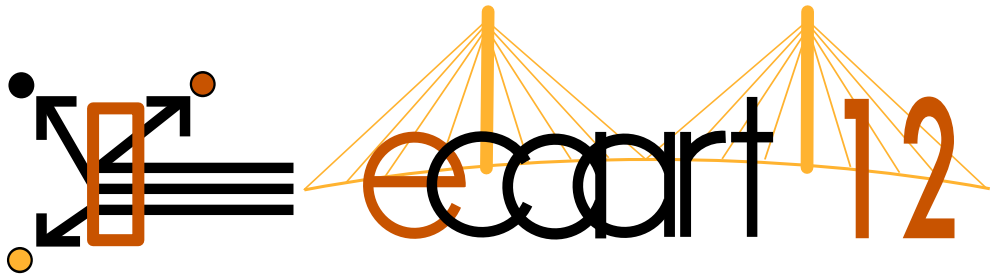

Abstracts

Contributed Talks

Recent progress and future plan of heavy-ion cancer radiotherapy with HIMAC

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The HIMAC clinical study has been conducted with a carbon-ion beam since June 1994. The total number of patients treated was around 10,000 as of March 2016. As a new treatment research project [1], NIRS has developed both the accelerator and beam-delivery technologies for the sophisticated heavy-ion radiotherapy since 2006, which brings both the static and moving-tumour radiotherapy technologies by the fast 3D scanning. The fast 3D scanning with a pencil beam, which is called NIRS-scanning, has been carried out for the static-tumour treatment since May 2011, while the moving-tumour treatment since March 2015. In the NIRS-scanning, further, the variable-energy operation from 430 to 56 MeV/u by the HIMAC synchrotron itself, instead of energy-degraders, has been performed for the depth scanning since September 2015. At the present, a heavy-ion rotating gantry has been successfully developed with the superconducting technology and is in a beam-commissioning stage. As a future plan, we just start a study of the LET-painting with a carbon-ion beam, which will be realize combining the NIRS-scanning and the rotating gantry. The multi-ions operation will bring more sophisticated LET-painting, which will be realized by a time-sharing operation of the HIMAC accelerator complex. Further, we just start the design study for a superconducting synchrotron with a diameter less than 10 m for more compact heavy-ion radiotherapy machine. The recent progress and the future plan of the heavy-ion cancer radiotherapy with HIMAC is reported.

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Measurement of the Ca/P ratio of samples with Paget's disease of bone and osteoporosis by PIXE, PIGE and micro-XRF

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Bone diseases such as osteoporosis and Paget's Disease of Bone (PDB) have harmful effects in the patient quality of life. An earlier and precise diagnosis is important to improve treatment. The relative content of Ca and P is critical for sustaining mineral homeostasis and bone metabolism and has been investigated as a possible biomarker for the assessment of bone health. [1]

Ion Beam analytical techniques, PIXE (Particle Induced X-ray Emission) and PIGE (Particle Induced Gamma-ray Emission), and micro-X-Ray Fluorescence Spectroscopy (μ-XRF) were employed in this work both for measuring the Ca/P ratio and for quantitative analysis of major and trace elements, of femoral head bone samples affected with PDB and with osteoporosis, and also of an healthy bone sample for comparison, in order to find some characteristic abnormalities of these bone diseases. The analysis of PDB sample revealed high concentrations of Lead, a toxic element that affects bone metabolism acting directly on bone cells (osteoblasts and osteoclasts). One previous publication found similar results [2].

The analysis was performed in different points of each sample with μ-XRF (Brukers M4 Tornado), in two different conditions of operation (50 kV, 100 μA, no filter and 50 kV, 600 μA, Al/Ti/Cu filter), and with PIXE and PIGE (3 MV tandem accelerator installation) with a proton beam of 2800 keV. The results for Ca/P ratio and for trace elements concentrations for both techniques are shown. The main purpose is essentially the attempt of understanding the differences between heathy and diseased bone and how this information may be related to the etiology of PDB, that remains unknown.

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[2] 2. Lesley M Egden, Khanh Nguten, David R Chettle, Richard Butler, Michael J Inskip, Colin E Webber (2015), X-ray fluorescence of archived bone samples: are raised Pb levels a chance finding or an association with Paget's disease?, X. Ray Spectrometry, 44, 221-225

Ambient Pressure Mass Spectrometry of Fingerprints: An Opportunity for MeV-SIMS

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Ambient pressure mass spectrometry of latent fingerprints provides a potential route to the secure, high throughput and non-invasive detection of, amongst other things, drugs of abuse. We have shown that it is possible to detect both the drugs of abuse as well as the excreted metabolites in the fingerprints using ambient mass spectrometry. A recent press release on this work reported in the Analyst received a large amount of media interest around the world. We report here on the preliminary study employing MALDI, SIMS, DESI and paper spray backed up by GC-MS of oral fluids. The study shows that ambient mass spectrometry can detect cocaine, benziylecgonine (BZE) and methylecgonine (EME) in the fingerprints of drug users. The results provide exciting opportunities for the use of fingerprints a new sampling medium for secure, non-invasive drug detection. The mass spectrometry techniques used offer a high level of selectivity and consume only a small area of a single fingerprint, allowing repeat and high throughput analyses of a single sample. However the conventional techniques described here mostly destroy or consume the fingerprint evidence in the analysis. Consequently a fast ambient pressure mapping technique capable of this analysis would have substantial benefits. The merits of MeV-SIMS in this context will be discussed.

Ion Beam Science Applied to Silicon Carbide Technologies.

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Wide band-gap, single crystal has sparked the interest of multiple investigators because of its many forefront uses including: new device science for power MOSFETs, in quantum systems associated with the atomic properties of the silicon vacancy, and as an ideal platform for the fabrication and study of graphene. In all of these technologies we have used ion beam science to further the ultimate goal. 1) Until recently the 4H-SiC power MOSFET has displayed limited performance due to a high interface defect density. A significant improvement has been achieved with the use of unusual passivating species such as N, P and Sb, and, to some extent, hydrogen. Combining MeV ion scattering, channeling, nuclear reaction analysis, SIMS and XPS our studies provide quantitative understanding of these effect of these passivating agents and the structural nature of the passivating interface. These findings are correlated with the device properties to reveal a practical and workable structure, although still less than ideal. Approaches to still improved performance will also be discussed. 2) The silicon vacancy in SiC has been recognized as a viable single photon source for quantum computing. The realization of large area, highly perfect SiC wafers is one advantage in this SiC path to a quantum computing system. Proton ion bombardment is one way to achieve the required defect. Our group has recently used Coherent Acoustic Phonon scattering (CAP) in combination with proton bombardment to determine the optical modifications to proton irradiated silicon carbide. Using CAP we extract the real and imaginary parts of the modified index of refraction and compare to the expected distribution via defect creation. An interesting, and still unexplained observation is the difference in the depth distribution of the modified real and imaginary components of the index. 3) Silicon sublimation from the surface of SiC is an established technique for graphene production. New properties of graphene may be revealed by the creation of nano-scale structures. We report the use of the Rutgers Helium Ion Microscope as a unique SiC lithography tool to achieve an innovative approach to patterned graphene. The essential element is the recognition of the large volume expansion (low density) of a-SiC which permits a unique approach to patterning. The limits of this process will be discussed in terms of fundamental ion scattering physics. New results on basic ion beam-surface interactions in SiC underpin many of these results.

This report is the result of a number of significant collaborations including the groups of: Prof. N. H Tolk Vanderbilt University; Prof. T. Gustafsson, Rutgers University; Prof. S. Dhar, Auburn University; Prof. P. Cohen, Univ. of Minn.; Prof. E. Conrad, Ga. Tech and Prof. S. V. S. Nageswara Rao, University of Hyderbad. All, including the many students, have made significant contributions to this work.

Depth profiled ion implantation doping using an energy filter based on Si membrane

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An important step during fabrication of modern semiconductor devices is doping of the material by means of ion implantation. For some applications in power or optoelectronics also special non-Gaussian shaped buried implantation profiles are required. The conventional way to create accurate shaped doping profiles by using multiple implantations of mono-energetic ions with subsequent thermal annealing is quite time consuming. An alternative approach is the application of an ion beam exhibiting the desired energy and flux distribution. For applications of less accuracy metallic foils with various thicknesses have been applied as energy filters (EF). A relatively new method is a filter made of micro-mechanically manufactured silicon membranes with modulated thickness which changes the energy of the initially mono-energetic ion beam from an accelerator and converts quasi-Gaussian shaped implantation profile into the specified one [1]. An example of such an EF shown in Fig.1 which can be used for homogeneous buried box-like doping profiles covering a doping depth of several micrometers. The ions with equal energies E_o will have different energies after the filter depending on the local thickness of the material and the resulting ion ranges are in different depth in the substrate. There are some challenges by using this technique. Besides the reliable and reproducible fabrication of the energy filter, aspects like thermal stability, ion beam sputtering or geometrical constrains have to be considered. Another difficulty of this method is the monitoring of the ion flux after the EF in order to control the implanted dose. A Faraday cup setup cannot be directly applied because of the recharging of the ions by the EF and their undefined charge state after the filter, so the process needs precise calibration for each ion type and energy. A Si EF fabricated at Ernst-Abbe Hochschule was calibrated and taken for the doping of 4" wafers using the wafer-handler with the mechanical scanning system at 3 MV tandem accelerator at Helmholtz-Zentrum Dresden-Rossendorf [2]. The experiments deliver promising results and demonstrate the possibility of application this method for doping purposes.

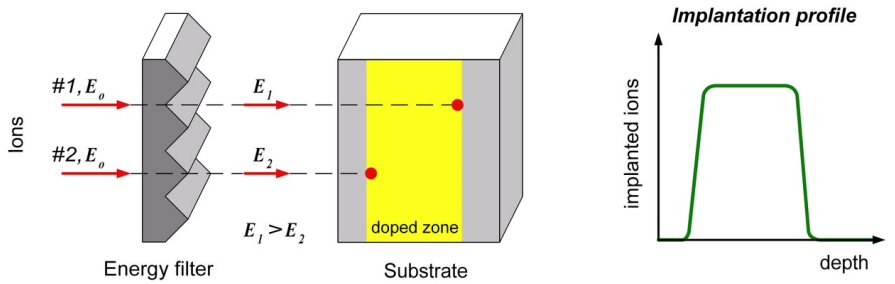

Figure 1: Principle of the energy filter.

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Erbium doped nanocrystalline diamond thin films

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Diamond exhibits outstanding physical and chemical properties such as extremely high thermal resistance, the highest hardness and thermal conductivity among all materials, and also a biocompatibility due to the carbon nature of the material. In photonics diamond is mainly used due to its high refractive index and low optical absorption scattering. Nanocrystalline diamond (NCD) represents a novel material that retains the outstanding material properties of single-crystal diamond. Moreover, thin NCD films, when deposited on a silica glass or a silica-on-silicon, can be used as high-index-contrast (HIC) waveguides. The photoluminescence in diamond can be enabled thanks to the colour-defect centres created by doping with various ions, e.g. Si, N, Cr, Eu, Er. In our study we investigated the doping of the diamond crystal structure with Er. The main motivation was to create diamond HIC optical waveguides with erbium that can amplify a guided optical signal.

Here, we present a basic study of the preparation and characterization of the Er ion implantated NCD waveguiding thin films. We used NCD prepared by a linear-antenna microwave plasma-enhanced chemical vapour deposition (MW PECVD) on different substrates – namely Corning glass, SiO_2 on Si, and pure SiO_2. Samples were doped with erbium using ion implantation with an energy of 190 keV and fluences ranging from 1×10^{14} to 5×10^{15} ions/cm^2. The changes of Er-concentration depth profiles (by Rutherford Backscattering Spectrometry – RBS) as well as the degree of structural damage/ordering (RBS/Channeling), diamond structure character investigation (Raman spectroscopy) and surface morphology (Atomic Force Microscopy – AFM) were studied in detail. Prepared Er-doped NCD samples exhibited optical waveguiding in the range of 633–1552 nm and revealed measurable luminescence at around 1530 nm. Further, to enhance the luminescence properties and consolidate the structure of samples we applied subsequent thermal annealing. Annealing was done using temperatures between 400 and 800 °C in vacuum or Ar atmosphere. Results showed substantial differences both in structural and luminescence properties between samples doped with different Er ion implantation fluences.

Acknowledgements: We acknowledge the Czech Science Foundation project GA 14-05053S and the CANAM (Center of Accelerators and Nuclear Analytical Methods) LM2011019 infrastructure.

The ILIAS project – Isobar suppression in AMS by laser photodetachment

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Stable isobars are the greatest challenge for accelerator mass spectrometry. Novel techniques for isobar separation will allow access to numerous new trace isotopes and a vast range of applications.

The ILIAS project at the University of Vienna was initiated in 2010 to explore isobar suppression by selective laser photodetachment. A gas-filled radio frequency quadrupole (RFQ) is used to decelerate and cool negative atomic and molecular ion beams from a cesium sputter source and extend the ion-laser interaction time, thereby substantially increasing the efficiency of photodetachment and isobar suppression. Following successful development and characterization at a purpose-built test bench, the RFQ cooler is currently moved to a new injector beamline at VERA for first applications of this novel technique at a state-of-the-art AMS facility.

This talk will give an overview of the project, with highlights on the experimental results including the suppression of a $^{63}Cu^-$ test beam by more than 99.999% with a 532 nm laser, optical filtering of MgO^- and AlO^- beams, and comprehensive measurements of the ion residence time inside the RFQ cooler. Also the new setup, and hopefully first benchmark measurements, will be presented.

Accelerator Mass Spectrometry on SIRIUS: new 6 MV spectrometer at ANSTO

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As a part of Australian Federal Government funding in 2009 to establish a centre for accelerator science a new 6 MV state of the art accelerator – SIRIUS – was purchased. The system is now commissioned and comprises ion sources and beam lines to cater for a wide variety of both IBA and AMS applications. The ion source used for AMS (MC-SNICS) is the latest incarnation followed by 45 degree spherical ESA (R=0.3 m) and double focusing injection magnet (R=1 m, ME=20) prior the accelerator. At the terminal we have a choice of 2 stripper gasses and/or stripper foils. The high-energy spectrometer for AMS consists of a 1.27 m radius analyzing magnet with ME=176, 45 degree ESA (R=3.81m), followed by a switching magnet and 3 beam lines: one with a standard multianode ionization chamber; one with an absorber cell in front of the detector; whereas the third beam line has a time-of-flight detector. Details of the instrument design and performance data for ^{10}Be, ^{26}Al and ^{36}Cl will be presented.

A dedicated AMS setup for medium mass isotopes at the Cologne FN-Tandem Accelerator

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Following demands for AMS measurements of medium mass isotopes, especially for ^{53}Mn and ^{60}Fe, we started to build a dedicated AMS setup at the Cologne FN-Tandem accelerator. This accelerator with a maximum terminal voltage of 10 MV can be reliably operated at a terminal voltage of 9.5 MV which corresponds to energies of 95-100 MeV for ^{60}Fe or ^{53}Mn beams using the 9^+ or 10^+ charge state. These charge states can be obtained by foil stripping with efficiencies of 30% and 20%, respectively. With second-foil-stripping we can increase the energy to 130 MeV.

The suppression of the stable isobars ^{60}Ni and ^{53}Cr will be done by a gas filled magnet and a focal plane detector. Additionally (dE/dx) techniques, using combinations of energy degrader foils and dispersive elements like an electrostatic analyzer and a time of flight (TOF) system, can be used to increase the suppression.

In this contribution we will report on details of the setup and the expected features of the new AMS system. Especially the first measurements concerning efficiency, transmission and background will be presented.

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Biofraction measurements of methane for environmental and metrological applications

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Reducing the use of fossil fuels is one of the most important means to mitigate the climate change. The reduction of fossil fuels is typically achieved by mixing biogenic fuels (solid, liquid, or gaseous) with fossil fuels. However, the biogas content of gas networks and fuelling stations cannot be accurately determined at present. On the other hand, methane is 20 times more effective greenhouse gas than carbon dioxide. Therefore, studies of natural methane emissions are strongly on the scientific agenda of the Integrated Carbon Observation System (ICOS).

Within this framework and based on our previous work on CO_2 sampling, we have developed and commissioned a set-up to allow for collecting and storing methane samples in laboratory and from field for AMS radiocarbon measurements. The system includes gas purification for possible CO_2 contaminant by molecular sieves, combustion of remaining methane with Pt catalyst and storing of the resulting AMS radiocarbon sample as CO_2 in a molecular sieve cartridge. The complete process chain includes conversion of the stored sample to AMS graphite targets with our HASE facility and an eventual AMS radiocarbon measurement with the Helsinki AMS. This contribution presents results of this development including – particularly – laboratory tests for methane combustion and biofraction measurements of methane gas mixtures of fossil and biogenic origin.

Conceptual study of high-performance heavy-ion-ERDA spectrometer for energies below 6 MeV

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Elastic recoil detection analysis (ERDA) is well established and its value among the techniques especially in the thin film analysis is not questioned. Today the ERDA measurements can be roughly categorized in two groups. In the first group a low energy (<2.5 MeV) helium beam is used to probe the hydrogen isotopes from the samples, the scattered He ions are stopped by a polymer foil before the silicon detector. The second group uses higher energy (>10 MeV) heavy ions (HI) to probe the material and different elements or masses are separated by means of more sophisticated detector setup. The most used setups are combinations of time-of-flight (TOF) and energy detectors.

The use of low energy very heavy ions, like ^{127}I and ^{197}Au is possible with gas ionization chamber energy detector, and has been thoroughly discussed before [1]. The main benefits of using very heavy ions are reduced beam damage due to enhanced scattering cross-sections and increased depth resolution. The small incident energy and multiple scattering limit the probing depth. Also quantification of hydrogen is difficult because of the low recoiling energy.

In the concept we propose, the low current (< 1 nA) 3–6 MeV ion beam could come from single-ended accelerator as doubly or triply charged Ar ion. Alternatively, the same energy range can be reached with electron cyclotron resonance (ECR) ion source and 500 kV implanter. This concept is tested (Fig. 1) by measurements of Li-based energy storage materials with 3–6 MeV ^{39}K ions from a 1.7 MV tandem accelerator with the Jyväskylä TOF-ERDA setup [2,3]. A design optimized for detecting both hydrogen and heavier elements with low energy incident Ar ions will be presented.

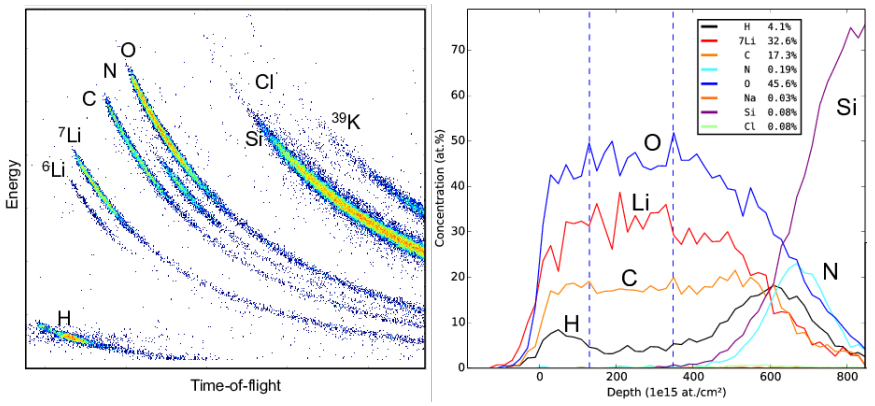

Figure 1: A TOF-ERDA histogram (left) and depth profiles (right) from 57 nm thick Li_2CO_3 film grown by atomic layer deposition. Incident beam was 5.1 MeV $^{39}K^{2+}$.

[1] M. Döbeli et al., Nucl. Instr. Meth. B 241 (2005) 428.
[2] M. Laitinen et al., Nucl. Instr. Meth. B 337 (2014) 55.
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Analysis and dating of the Preuchdorf hoard (Alsace, France) by IBA and AMS

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The hoard of Preuchdorf, discovered in 2005, contains 7270 silver-copper coins. They seem to have been struck over more than a century, between the end of the 15th and the beginning of the 17th century. This hoard is an exceptional find composed of a large quantity of coins from various periods, areas and contexts. It is also remarkable by the presence of unknown official coins and counterfeit coins.

IBA was used to analyse the silver content of the official coins by combining PIXE and RBS (Beck et al, NIMB 266, 2008). The fineness was found to be between 12 and 40 % according to the mint place and an unexpected subdivision of the values has been revealed. For the counterfeit coins, the analyses were able to bring to light different elaboration processes: amalgam with two various contents of mercury and electrochemical coating. Very few examples of amalgam silvering are known for this period.

Finally, although coins are usually used to provide dates on archaeological findings, the deposition time of the hoard is not clear since most of the coins have a long time span without changes in the issues (same marks and no date). Only 617 coins have a date, covering the period 1516-1601. Based on the representations, most of the other coins are in the same range, but some coins are older (around 1300) and others could have been struck until 1610-1620. The hoard was buried in a pot and some very small fragments of textile were still attached to the coins (see Figure). The linen fibers have been prepared for AMS radiocarbon dating. The combination of the coin dates with the radiocarbon result could indicate if the hoard was a deposition at one moment in time or if it was consisted of long term collection.

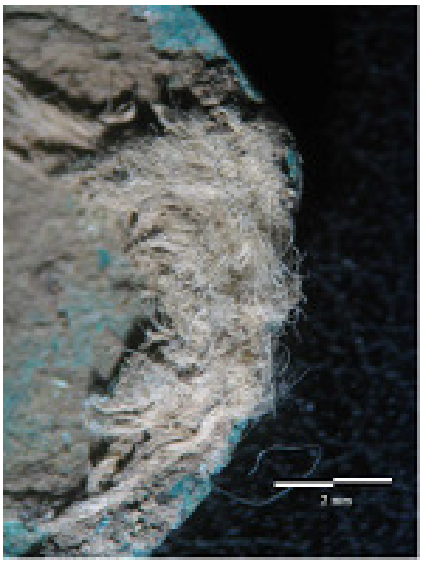

Figure 1: Textile fragments from the bag containing the coins of the Preuchdorf hoard (15th-17th c.)

Identification and imaging of modern paint materials using MeV-SIMS

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Development of the industry in the twentieth century caused appearance of many new synthetic organic pigments (SOPs) and binders, which started to be extensively used by the artists. Behaviour of such materials as well as their degradation under the different environmental conditions is not well known. Those materials are usually studied using different chemical and physical characterization techniques, but especially important are analytical techniques that can provide information about the molecular structure such as Gas Chromatography Mass Spectrometry (GC/MS), Pyrolysis-GC/MS, FTIR or Raman spectroscopy. Compared to those methods MeV Secondary Ion Mass Spectrometry (MeV-SIMS), a new mass spectrometry technique that employs MeV ions, has some advantages. There is no need for sample preparation prior to the analysis as well as identification of SOPs and binders can be done in the same mass spectrum. Furthermore, the sample is not consumed during the measurement, thus still remaining for the complementary measurements. Another benefit of the MeV-SIMS is surface sensitivity, which is important concerning that possible material degradation occur mostly in the uppermost layers and this area is usually not accessed by chromatographic methods coupled to MS. Finally, the MeV primary ion beam causes a so-called ”soft ionization” of organic molecules, which means that large intact organic molecules or larger molecular fragments are desorbed from the outermost surface of the sample instead of the smaller fragments which makes identification of SOPs and binders much easier. In the present work potential of the MeV SIMS technique for the identification and imaging of synthetic organic materials used for the modern paints materials is explored using MeV-SIMS spectrometer installed at the heavy ion microprobe in Zagreb [1]. Several types of synthetic organic paint materials were analysed: pure pigments, self prepared mock-ups, commercial paints and samples taken from the real contemporary art objects placed in the outdoor conditions. We will demonstrate that different synthetic organic pigments and binders can be easily identified by their molecular masses with MeV-SIMS. Also, results of the molecular imaging of paint cross sections to study chemical composition of different paint layers will be presented.

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Thick multi-layers analysis with high energy PIXE

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High-energy PIXE is suitable to analyze thick target due to the larger penetration range of the energetic ion and the excitation of the energetic K X-rays. Another advantage is the low energy loss per unit length of high energy incident ion allowing reduced radiation damage. This is well suited to cultural heritage applications, such as characterization of ancient paintings [1] and metallic archaeological objects [2]. The latter can be analyzed without removing the patina layer on the surface. To identify the pigment composition, sequencing and the thickness of paint-layers, K and various L X-rays from heavy elements (like Pb) and K lines for lighter elements (like Fe) are used. A comparison between the measured intensities ratios Kα/Kβ, Lα/Lβ and Lα/Kα, influenced by absorption, give information on the depth of the emitting layer. With this technic, several questions remain to be treated such as how many layers can be analyzed and how to resolve a repeated layer in depth (complex multi-layer). In addition, resolving the analysis of a thick multi-layer target is a good starting point to be able to determine the concentration profile of an element as a function of the depth.

We have developed an experimental set-up for high energy PIXE and PIGE at ARRONAX cyclotron (Nantes-France) with proton and alpha ions of 68MeV [3]. It includes two X-ray detectors and one gamma ray detector. We have made several experiments with known multi-layer samples (simple and more complex). For each one, we irradiated with multiple angles between the target and the beam. During this talk, a description of the experimental setup will be presented together with examples on simple and complex thick multi-layers targets solved with PIXE at high energy using information given by the measured X and gamma rays.

Depending on the specifications of the samples, different strategies must be applied: For layers with medium and heavy elements, the use of ratio of the K and L X-ray intensities allows to locate each layer and to determine their thicknesses. For layers with light elements, due to absorption of the low energy of the X-rays, it is important to get additional information from gamma rays emitted by the interaction of the beam with the samples. In case of more complex multi-layers, we used the variation in the ratio of the K and L lines intensities according to the irradiation angle and the intensities of emitted gamma rays.

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[2] Influence of corrosion layers on quantitative analysis, A. Denker et al, Nuclear Instruments and Methods in Physics Research Section B, 239, 2005, 65-70
[3] Development of a PIXE method at high energy with the ARRONAX cyclotron, D. Ragheb et al, Journal of Radioanalytical and Nuclear Chemistry, 301, 2014, 895-901

Technical improvements and performance of the HVE AMS sputter ion source SO110

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The AMS systems developed and manufactured by High Voltage Engineering Europa B.V. (HVE) are equipped with Cs sputter ion sources model SO110. This is a hybrid ion source, well suited for measurement of solid and gaseous CO_2 samples [1]. The operator can remove the source head sideways from the source housing for maintenance. All cleaning and servicing can be done on a work bench, and no alignment is necessary when inserting the source again. HVE modified the design for the use of volatile sample materials, resulting in model SO110-B. For this model, cross-talk between samples is very low, and chlorine samples need no effortful embedding in a AgBr backing [2].

For increased source outputs HVE introduced the model SO110-C (see figure). Distances between parts of different potentials have been increased for improved voltage holding capability, allowing silent operation up to 12 kV target voltage at the required high cesium inflow. Compared to its predecessors, model C is less sensitive to corrosion, resulting in much longer life-time. It is known that the ionizer alignment is critical for source performance, especially for small samples. We have therefore changed the concept of ionizer mounting. Precise alignment is now ensured and no longer depending on a critical alignment procedure or on operator skills. The Cs beam spot at the sample surface is now defined within 0.2 mm.

In factory tests, the source showed its capability of producing $^{27}Al^-$ outputs up to 2 µA, $^{9}BeO^-$ outputs of more than 30 µA and stable $^{12}C^-$ current above 400 µA. In this contribution, we present the design of the new model ion source and present results of the tests.

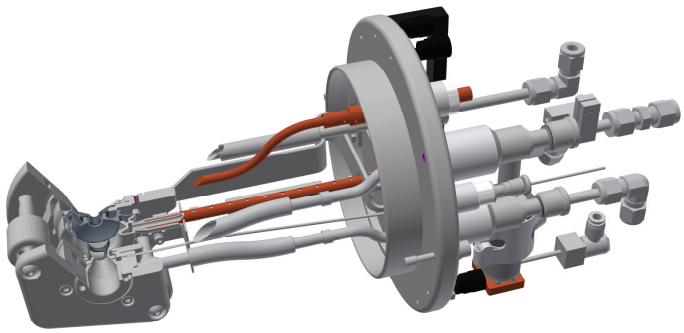

Figure 1: HVE SO110-C source head

[1] Mous et. al, Radiocarbon, Vol 40, No 1, 1998, 283-288
[2] R. Finkel et. al, Nucl. Inst. And Meth. B 294 (2013) 121-125

Recent Projects and Future Collaborations at National Electrostatics Corp.

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National Electrostatics Corp. (NEC) recently celebrated its 50th anniversary in providing accelerators to national laboratories, government agencies, universities, and private companies around the world. While continuing to provide standard low voltage systems for AMS and IBA, NEC has recently finalized projects related to two customized state-of-the-art multi-isotope 6 MV AMS/IBA systems (ANSTO and Tsukuba University), verified calcium measurements on a 1 MV AMS system, and completed a 400 kV implanter installation in China. Custom projects in progress include a 400 kV implanter capable of combining two ion beams into a transmission electron microscope (TEM) and a 4 MV single ended Pelletron with a liquid metal ion source, among other projects. This presentation will describe recent projects and future collaborations at National Electrostatics Corp.

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[2] Sasa et al, The new 6 MV multi-nuclide AMS facility at the University of Tsukuba, NIMB, Volume 361, 15 October 2015, Pages 124-128

Application and development of ion source technology for electronics radiation effects testing

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Studies of heavy ion induced radiation effects on space electronics are necessary to verify the operation of the components in the harsh radiation environment. These tests are conducted in several accelerator laboratories around the world. The high-energy heavy-ion beams used in the tests for simulating the radiation environment of space are produced by accelerating so-called ion cocktails, containing several ion species to cover a wide range of linear energy transfer (LET) values in the target material. The cocktails are carefully designed to contain ions with similar m/q fractions, which enables fast switching between the ion species during the tests. The beam intensities required for the tests are low — about 10^6 s^{-1} or 100 fA is usually sufficient from the ion source

In most cases the use of a very large accelerator is not justified for radiation effect studies. The same high energies can be reached more economically using for example a medium sized cyclotron and relatively high charge state beams. Two well developed ion source types exist for production of high charge states: The electron beam ion source EBIS and the electron cyclotron resonance ion source ECRIS. The EBIS ion sources can reach higher charge states (even fully stripped heavy ions) and therefore higher energies, which makes them attractive for the application. Unfortunately their operation is pulsed, which makes the average beam intensity lower than with ECRIS. ECR ion sources provide continuous beams of relatively high charge states with sufficient intensity for the application. ECR ion sources are also available in most cyclotron laboratories, which has made the ECR ions sources the standard tool for production of ion cocktails.

The Accelerator Laboratory at the University of Jyväskylä has performed radiation effects testing since 1998 using a K130 cyclotron and ECR ion sources. Currently most of the tests in Jyväskylä are done at 9.3 MeV/A energy which is achievable with the charge states produced by the 14 GHz ECRIS of the laboratory. The radiation effects community has shown a strong desire to reach 15 MeV/A, which is approaching the limits of what can be achieved without super conducting ECR technology using the K130 cyclotron. The desire for the high charge states has initiated a project to push the performance of regular conducting ECRIS by building an 18 GHz ion source HIISI [1]. The new ion source under development features a high volume plasma chamber and an innovative refridgerated permanent magnet hexapole to reach higher magnetic field necessary for the production of the very high charge states needed in the application. In this paper the suitability of the ion source types and their future prospects for use for radiation effects studies are discussed.

[1] H. Koivisto, O. Tarvainen, T. Kalvas, K. Ranttila, P. Heikkinen, et al., Proc. of the 21st International Workshop on ECR Ion Sources, pp. 99–103, 2014.

Accelerators of University of Helsinki on the IAEA Ion Beam Technology roadmap

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According to the initial draft (2015), the Ion Beam Technology (IBT) roadmap[1] is proposed to cover scientific and technological developments of Ion Beam Techniques defined both by the nature of the accelerators that are used, and the ways in which the ion beams are used. The main purpose of our presentation is to show where and how the electrostatic accelerators KIIA and TAMIA of the Department of Physics of the University of Helsinki are located on the proposed IBT road(map). We review the steps and leaps taken during the process to achieve the current status and also discuss the planned future developments.

Our accelerators cover almost completely the "eight-fold" scope of the IBT roadmap with 1) acceleration voltages from less than 100 kV to 5 MV, 2) ions from hydrogen to lead, 3) science from fundamental to applied, 4) applications from analysis to radiation effects, 5) beam intensities from single ions to continuous beams, 6) length scales from micro to macro, 7) dimensions from 1D to 4D, and 8) environment from UHV to ambient.

Among the key elements in achieving this wide coverage have been 1) the implementation of the modern control and automation system, 2) fast logging of accelerator parameters, and 3) fast ion beam diagnostics employing simultaneous measurement of beam profiles at several locations along the beam path. Together they allow fast and reliable beam optimization and fully unattended remote operation of the accelerators.

[1] https://nucleus.iaea.org/sites/accelerators/IBT_Roadmap/SitePages/Home.aspx

Computer Simulation of Backscattering Spectra from Paint

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Ion beam analysis (IBA) methods are often applied for the quantitative analysis of objects from cultural heritage, such as paintings. Paint consists of color pigments (for example lead white $(PbCO_3)_2 \cdot Pb(OH)_2$) embedded in oil and binder. The diameter of the pigments can vary between several 100 nm and several 10 µm. Popular simulation codes for the evaluation of IBA spectra [1], however, neglect the microstructure of paint and assume atomic mixing of all elements. The distribution of elements is assumed to be homogeneous in lateral direction (i.e. parallel to the surface) and to vary only with depth (i.e. perpendicular to the surface). But it has been already demonstrated in [2] that the analysis of backscattering spectra from such multi-phase materials like paint can get ambiguous and extracted depth profiles can get inaccurate if a multi-phase material is approximated to be laterally homogeneous. This is a potentially serious problem for the quantitative application of IBA methods to cultural heritage objects like paintings.

The program STRUCTNRA [2] allows the simulation of charged-particle IBA spectra (RBS with Rutherford or non-Rutherford cross-sections, ERDA, NRA and MEIS) from arbitrary two-dimensional sample structures taking all correlations between incident and exit trajectories into account. Sample structures are imported as optical microscopy, scanning electron microscopy or transmission electron microscopy images of sample cross-sections or as artificial sample drawings created by any graphics software. The well-known SIMNRA program [3] is used as simulation kernel. Stopping and energy-loss straggling effects are calculated precisely, multiple and plural scattering can be taken into account approximately.

An idealized model of paint has been implemented in STRUCTNRA. Paint is represented as a three-dimensional random distribution of non-overlapping color pigments embedded in a matrix of oil and binder. The pigments are assumed to be spherical and may be either equal sized, or may have a Gaussian-like distribution of diameters. Two different surface models are available representing sample surfaces generated by cutting or by submersion. The first model is suitable for samples originating from a multi-phase solid-state material manufactured by a cutting process like sawing, grinding, or polishing. The second model is proposed for paint.

For sufficiently small diameters of the pigments (where small is relative to the penetration depth of the ion beam) the calculated backscattering spectra are identical to spectra from atomically mixed materials. For larger pigments the shape of the spectra depends on their diameter. If these spectra are evaluated assuming atomic mixing the concentrations of elements may get inaccurate. Accurate quantitative evaluation of backscattering spectra from paint therefore requires taking the correct microstructure into account.

[1] E. Rauhala et al., Nucl. Instr. Meth. B 244 (2006) 436
[2] M. Mayer, Nucl. Instr. Meth. B 371 (2016) 90
[3] M. Mayer, Nucl. Instr. Meth. B 332 (2014) 176

CSIM – A new code for the simulation of channeling EBS/RBS spectra

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This work represents an attempt to solve a long-standing problem in material analysis with ion beams, namely, the successful quantification of channeling EBS/RBS spectra, for which a new phenomenological simulation code – CSIM – has been developed. Successfully quantified c-EBS/RBS spectra open new possibilities for these IBA techniques to be used for the determination of low concentration profiles of light elements implanted or generally present as interstitial impurities in heavier crystalline matrices, or for the detection of heavier trace elements at higher depths, whose yield in standard EBS/RBS spectra overlaps with the matrix-induced background. The advantages of the c-EBS/RBS technique over the commonly used NRA in these situations are related to: a) The fact that the differential cross-sections for elastic scattering are usually much larger than the corresponding NRA ones, thus improving the MDLs of the elements under study and b) the use of protons and alpha particles as probing beams, thus avoiding the neutron background, commonly associated with d-NRA.

CSIM is a computer code written in C++, which assumes that the phenomenological channeling process can be described by only three extra parameters. Two parameters, namely the dechanneling rate and range, are used to describe the Gompertz-type sigmoidal dechanneling process, since already dechanneled ions, which are subsequently backscattered, are the main yield contributors in c-EBS/RBS spectra. The third parameter describes the energy loss in the channeling mode, and, more specifically, the channeling to random mode energy loss ratio. These three parameters can be either manually set by the user or obtained via the χ^2 minimization MINUIT routine from experimental data. CSIM has been successfully tested in reproducing 1-2 MeV proton c-EBS spectra of virgin crystals, like [110] Si (in the past) [1] and [100] diamond (recently). CSIM also gives the opportunity for obtaining amorphization and concentration profiles (user supplied differential cross-sections in the customary .r33 format are supported) from c-EBS/RBS spectra, whose channeling parameters have already been determined. More specifically, CSIM has been successfully used in obtaining amorphization profiles in the cases of 4 MeV Si^{3+} ions implanted in Si and 4 MeV C^{3+} ions in diamond, with the implantation being carried out in the channeling orientation, in order to reduce the induced crystalline damage in the trace region of implanted ions. There are also very promising preliminary results related to concentration profiles in the cases of implanted Si ions in diamond and C ones in Si. A user-friendly visual interface is currently being developed, and thus, CSIM will soon be available to the scientific community for downloading, evaluation and testing.

[1] M. Kokkoris, G. Perdikakis, S. Kossionides, S. Petrovic and E. Simoen, Eur. Phys. J. B, vol. 34, p. 257, 2003.

Development of an ultra-low background detection facility

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Stellar nucleosynthesis occurs in stars during the process of stellar evolution. Fusion process is responsible of the formation of light elements between C and Ca. The main fusion reactions in stars cooler than Sun are included in the p-p chain while CNO cycle is dominant for stars hotter than the Sun. Those nuclear reactions occurring in the core of stars are produced in the Gamow energy window, which is below the energy of the Coulomb barrier where the cross sections are very low. It is necessary that nuclear physicists measure the reaction cross sections at very low energies and thus be sensitive to very low reaction rates. In particular for radiative capture reactions, we must determine the optimal experimental conditions to detect the gamma rays. This means performing very low background measurements. The present project gives the usual constraints and the solutions we have chosen for the particular $^{13}C(p,\gamma)^{14}N$ resonant reaction that is involved in the CNO cycle and which plays a key role in the nucleosynthesis of heavy elements in AGB stars. The reverse kinematics reaction $^{1}H(^{13}C,\gamma)^{14}N$ have been studied by bombarding an hydrogenated silicon sample with ^{13}C ions in the energy range which corresponds to energies around the 511 keV resonance in the CM system.

The experimental set-up consists of a HPGe detector (123% efficiency) or a 4x4 inches NaI(Tl) well detector installed in a passive shielding. The detector is placed near the target in a lead castle of ultra-low background material, which is covered with a plastic scintillator to detect muons produced in the high atmosphere of Earth. The efficiency of the muons detector has been measured and exhibits lower background in the energy region of interest of the gamma rays detector. The HPGe detector placed in the lead castle detects 8 MeV gamma-rays emitted from the capture reaction $^{1}H(^{13}C,\gamma)^{14}N$, which is the reverse kinematics of the proton capture by ^{13}C occurring in the CNO cycle of stars. In order to reduce the background the gamma rays detector is in anti-coincidence with the muons detector placed above the lead castle. First results using this very low background facility will be shown and the efficiency of the anti-coincidence technique will be explained in detail. Recently the active shielding has been upgraded to reduce the background due to muons and to measure the $\cos^2(\theta)$ distribution.

SCALP, a platform for synthesis and characterization of materials

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SCALP (Synthesis and Characterization using ion AcceLerators for Pluridisciplinary research) is a platform dedicated to characterization and modification of materials using ion beam. Located at CSNSM, Orsay-France, it is constituted, for one side, by a 2 MV Tandem accelerator and a 190 keV implanter, both possibly coupled with a Transmission Electron Microscope. Moreover, ion beam analysis, such as RBS, RBS/C, ERDA, and PIGE are currently performed in order to complete the developed studies, enabling a complete characterization of the samples. On another side, 50 kV implanter is dedicated to magnetic isotopic separation and enable to manufacture mono-isotopic targets (purity of the order of ppm), either by implantation or by deposition.

The Tandem is equipped with a Penning ion source used for the single-ended mode and a SNICS ion source for the Tandem mode. The two implanters are equipped by a Bernas-Nier source, allowing to deliver a very large range of ions, from Z=1 to Z= 83.

Studies related to structural properties of materials, to simulation of their damage under nuclear reactor conditions and to synthesis of out-of-equilibrium systems are developed. The precise characterization, down to the nano-metric scale of the defaults and structures synthetized in situ by implantation/ionization allows to have access to elementary mechanisms governing material behavior under ion beams.

Thanks to this multi-purpose platform, beam is delivered both for the academic community, and for industrial purposes, the latest being mainly focused on spatial, energy and electronic

Main activities of the platform will be discussed, emphasizing on the originalities of the installations. New ongoing developments will also be presented. They are related to:

- high energy (~ 16 MeV) gamma source, for gamma efficiency measurements or calibration of nuclear physics detectors,
- concentration measurement of different isotopes,
- development of a micro-PIXE line,
- development of thin layers by ion deposition or implantation,
- study of the mechanisms underlying the targets (thin layers) weakening under ion beam.

Quantitative analysis of Li by PIGE technique

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The booming sales of clean energy vehicles is increasing the demand for lithium ion batteries and is intensifying the production of new sources of lithium raw materials. The prices of the industrial chemical, lithium carbonate used in lithium ion batteries have increased suddenly 47 percent in 2016. Hence, the mining companies, the auto industry and industrial technology, would gain with the ability to determine with accuracy the concentration of lithium in a variety of samples.

For most of the detectors employed for Proton-induced X-ray analysis (PIXE), lithium is not detectable and Proton-induced γ-ray analysis (PIGE) may be an advantageous alternative.

The sensitivity and the multielemental character of PIGE bulk analysis increase with energy, so in this work we continued the extension of the cross sections for PIGE to a higher energy range. For this purpose, the cross section of the reactions ^{7}Li(p,pγ)^{7}Li (γ – 478 keV) at the proton energy range 2.0 to 4.0 MeV was measured [1]. The measurements were carried out at the 3 MV Tandem Accelerator at the CTN/IST Laboratory in Lisbon. In order to quantify the light elements present in the samples, we used a standard free method for PIGE in thick samples, based on a code – Emitted Radiation Yield Analysis (ERYA), which integrates the nuclear reaction excitation function along the depth of the sample [2].

To validate the obtained results, calculated gamma-ray yields were compared, at several proton energy values, with experimental yields for thick samples made of inorganic compounds containing lithium. The agreement is better than 5%. We also demonstrated the capacity of the technique for analysis of Li ores, as Lepidolite and Spodumene.

[1] R. Mateus, A.P. Jesus, B. Braizinha, J. Cruz, J.V. Pinto, J.P. Ribeiro. Nuclear Instruments and Methods in Physics Research B 190 (2002) 117–121
[2] R. Mateus, A. P. Jesus, J.P. Ribeiro. Nuclear Instruments and Methods in Physics Research B 229 (2005) 302–308

Charge Collection Efficiency in Segmented Semiconductor Detector interstrip region

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Charged particle semiconductor detectors have been used in Ion Beam Analysis (IBA) for over four decades without great changes in either design or fabrication. However one area where improvement is desirable would be to increase the detector solid angle so as to improve spectrum statistics for a given incident beam fluence. This would allow use of very low fluences opening the way for example to increased time resolution in real-time RBS or analysis of materials that are highly sensitive to beam damage. In order to achieve this goal without incurring the costs of degraded resolution due to kinematic broadening or large detector capacitance, a single-chip segmented detector (SEGDET) was designed and built within the SPIRIT EU infrastructure project. In this work we present the Charge Collection Efficiency (CCE) in the vicinity between two adjacent segments focusing on the interstrip zone. Microbeam Ion Beam Induced Charge (IBIC) was used to perform X-Y mapping of CCE with different ion masses and energies, as a function of detector operating conditions (bias voltage changes, detector housing possibilities and guard ring configuration). We show the CCE in the active area edge region and have also mapped the charge from the interstrip region, shared between adjacent segments. The results indicate that the electrical extent of the interstrip region is very close to the physical extent of the interstrip and guard ring structure with interstrip impacts contributing less than 8% to the complete spectrum. The interstrip contributions to the spectra can be substantially reduced by an offline anti-coincidence criterion through the list mode data analysis, which should also be easy to implement directly in the data acquisition software.

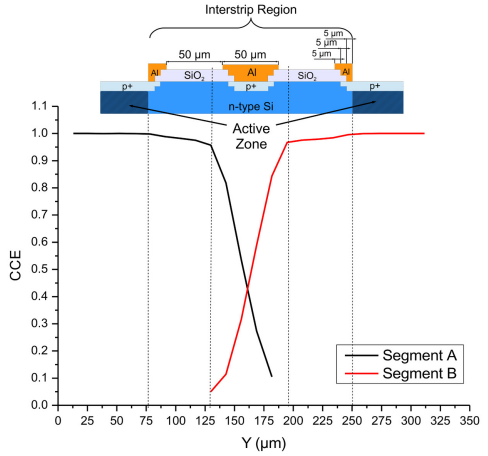

Figure 1: Interstrip region schema (top) and Charge Collection Efficiency of 4.5 MeV protons for 30 V detector bias and floating guard ring, between two adjacent segments (A and B) including the interstrip region (bottom).

Chemical analysis under ambient conditions using swift heavy ion beams

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Secondary ion emission under swift heavy ion impacts provides unique opportunities not only for insights into ion collisions but also for material analysis. The yield of secondary molecular ion emission with swift heavy ions is much higher than that with conventional keV monomer ion beams, because of the dense electronic excitation of the molecules during ion impact.

Secondary ion mass spectrometry (SIMS) using swift heavy ion beams, known as "MeV-SIMS," opens new possibilities for investigating chemical composition, structure as well as for imaging, which are very important for organic and biological materials. We have demonstrated molecular imaging of a rat brain and a single animal cell with the MeV-SIMS technique.

Furthermore, swift heavy ion beams (>MeV) have a high transmission capability in matter, which allows their use for the analysis of volatile samples such as liquids, solid–liquid interfaces and wet samples under atmospheric pressure. As most of the liquid molecules are organic and have a high vapor pressure, it is hard to use conventional surface analysis technique. A schematic diagram of "Ambient-SIMS" is depicted below. Current challenges and future prospects of the MeV-SIMS technique will be discussed along with its possible applications.

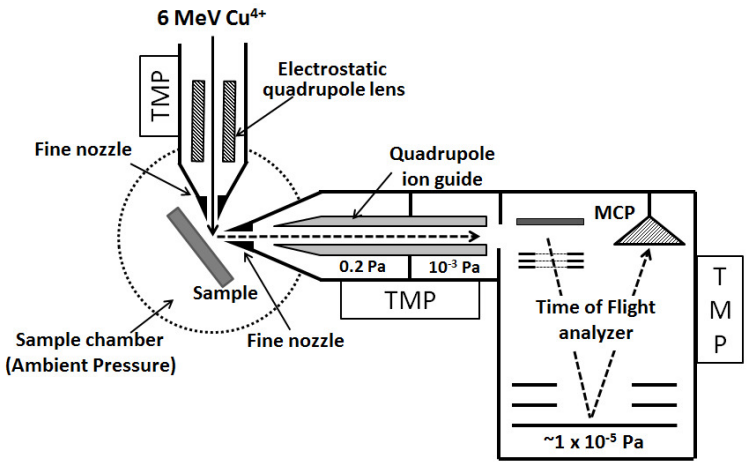

Figure 1: Schematic diagram of "Ambient SIMS" system. A high-energy ion accelerator is combined with an orthogonal acceleration time-of-flight mass spectrometer (oa-ToF-MS)

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In-situ Depth Profiling of Li in Solid State Li Ion Battery under Charging by Means of ERDA and RBS Techniques with 9 MeV O^{+4} ion

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Thin-film stacked solid sate Li ion micro-batteries composed of metal/anode/electrolyte/cathode/metal have been developed to facilitate the integration of high capacity energy storage devices into micro-electronics. Since Fermi levels of each constituent film are different from each other, space charge (or enrichment and depletion of Li) is induced at their interfaces, which plays an important role as a barrier for Li transport. To understand the Li transport throughout the battery, it is essentially crucial to know how Li ions are distributed throughout the battery stack and to get insight into Li mobility. In this paper, for the first time, we report the experimental results on Li depth profiles in $Au/LiCoO_2/LATP/Pt$ ($LATP=Li_{3.1}Al_{0.83}Ti_{1.17}Ge_{1.27}P_{1.73}O_{12}$)specimens under charging have been in-situ measured by means of ERDA and RBS techniques.

ERDA spectra at each bias normalized to no bias, for close inspection of change in Li depth profiles by charging, are shown in Fig.1(a) and(b), which have been measured from both surfaces of Au and Pt, at several stages of the biasing. Fig.1(a) was obtained on biasing + voltage to Au against Pt at earth potential and Fig.1(b) was on biasing – voltage to Pt against Au at earth potential. For the former case, up to +1.3 V no Li depletion in $LiCoO_2$ was not observed. As seen Fig.1(a), Li is uniformly depleted over the whole depth above +1.3 V and the depletion is extended into LATP up to 200 nm deep from the interface. On the other hand, for the latter case, it is seen from Fig.1(b) that Li in LATP near the interface with Pt is enriched over the depth of 200 nm deep with increasing the bias voltage. The depletion and enrichment of Li in both figures are seen to correspond qualitatively well with each other. The characteristic curve of Li composition in $LiCoO_2$ vs bias voltage is found to correspond well with the electro-chemical data.

Acknowledgement: This work is partly supported by Grants-in-Aid, Scientific Research (C25420762), JSPS and Global Research Center for Environment and Energy based on Nano-materials Science(GREEN). This work was also performed under the co-operative program of Tandem Accelerator at the Quantum Energy Science and Engineering, Education and Research Center, Kyoto University. We are grateful to Mr. T. Sasaki for his technical support.

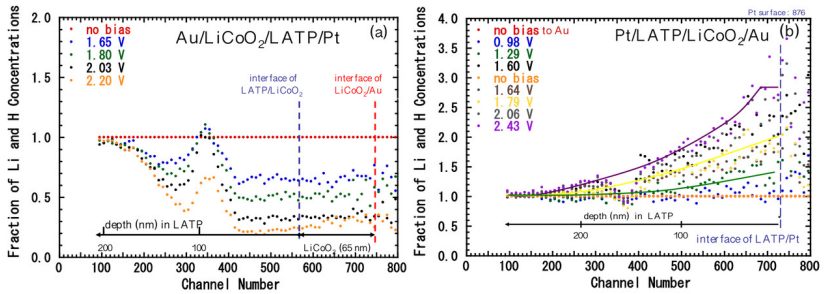

Figure 1: Fig.1 (a) and (b) Change in Li depth profiles in Li ion battery measured from both surfaces of Au(a) and Pt(b).

Point defects and structural modifications in AlxGa1-xN nitride semiconductors under heavy ion irradiation

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Swift Heavy Ions (SHI) irradiation experiments in materials are useful to reproduce radiation conditions of extreme environments like the outer space or nuclear plants. It is particularly interesting for nitride semiconductors due to their potential radiation exposition during their life cycle and their strong correlation between defects and properties.

In this work, AlxGa1-xN (with x=0; 0.1; 0.3; 0.5; 0.7; 0.85 and 1) nitride semiconductors have been irradiated with SHI at GANIL facility. Induced modifications are thereafter studied by different techniques such as Transmission Electron Microscopy (TEM), UV-visible spectroscopy and Raman spectroscopy. Using different irradiation conditions, the mechanisms of formation of these modifications are investigated, particularly the role of electronic and nuclear energy losses.

In this communication, influence of the composition on optical absorption results will be discussed. UV-vis spectra show absorption bands, related to point defect formation in these materials after irradiation. In GaN, Ga vacancies have been identified and nuclear collisions alone seem to explain their formation, since the evolution of the area of the absorption band (related to the number of created point defects) follows a linear rule as a function of the number of displacements per atom (dpa) : figure 1a. On the contrary, for alloys with x from 0.5 up to AlN, absorption bands related to N-vacancies were highlighted and an unexpected synergy between nuclear and electronic processes has been found to explain their formation [1,2] (figure 1b).

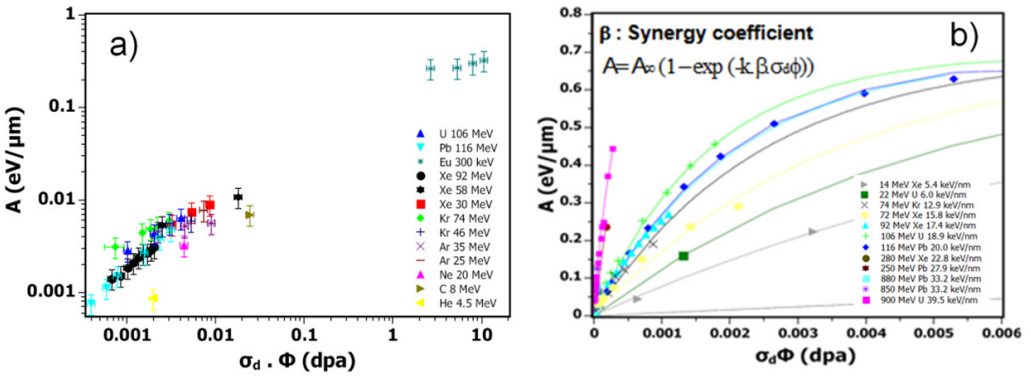

Figure 1: Absorption band area as a function of the number of dpa for different projectiles in (a) GaN and (b) AlN. In GaN, this area seems to follow a linear rule versus the number of dpa whearas in AlN (and for alloys with x>0.3), a synergy between dpa and Se has been demonstrated.

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R2RAM project: Development and characterization of a radiation-hard resistive random-access memory

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Over the past decades, the constant miniaturization of electronic components, and in particular electronic memories, has enabled a steady improvement in their performance, pow-er consumption and storage density. However, a major drawback of this miniaturization is that current technologies are sensitive to radiation, and data corruption and/or device failure may result from individual particle strikes (Single-Event Effects, SEE) or long-term dose accumulation (Total Ionising Dose, TID) generating parasitic charge in the memory component. This threat to memory reliability has become a major concern in several fields of application, particularly in space engineering, where components are expected to per-form reliably for several years in very harsh environments.

In recent years, a considerable effort from the semiconductor industry, has been dedicated to the development of new technologies to produce enduring, low-power and rad-hard non-volatile memories, all of which are critical qualities for space applications. However, most technological advances have focused on improving the storage elements, while for a variety of reasons, the peripheral circuitry in these devices is still designed and fabricated with legacy CMOS technology, which is inherently vulnerable to radiation. Consequently, most of these new technologies are not truly radiation-hard when their peripheral circuitry is active.

This presentation introduces the R2RAM project, which aims at filling this technological gap by designing, manufacturing and characterizing a new type of memory. The storage elements will be based on Resistive Random-Access Memory technology (RRAM), whose operating principle is based on chemical redox reactions and has proven to be practically immune to SEE and TID effects [1]. The memory's peripheral circuitry will implement innovative designs and algorithms to ensure a reliable operation in a radiation environment, such as gate-enclosed transistor layout and differential memory array architecture [2]. Prototype memory devices will be produced over the course of this project, which will be tested with particle beams at the University of Jyväskylä's RADEF facility to assess their effective radiation vulnerability.

Funding for this project is provided by the European Union's Horizon 2020 research and innovation programme.

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mA Beam Acceleration Efforts on 100 MeV H^- Cyclotron at CIAE

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Various technologies for high current compact H^- cyclotron have been developed since 1990s. 375 μA proton beam was extracted from a 30 MeV compact H^- cyclotron CYCIAE-30 [1] at the end of 1994. A central region model cyclotron CYCIAE-CRM [2] was developed for the design verification of a 100 MeV high current compact H^- cyclotron CYCIAE-100 [3,4]. It is also a 10 MeV proton machine as a prototype for PET application. 430 μA beam was achieved in 2009. After the construction of CYCIAE-100 and the first beam was extracted from the machine on July 4, 2014 [5], the operation stability have been improved and beam current have been increased gradually. 720 μA beam was got on the internal target at the beginning of this year. The effort for mA beam is continuing till now.

In this paper, the effort on several aspects for mA beam development will be presented, including the multi-cusp source, buncher, matching from the energy of the injected beam, vertical beam line and central region, beam loading of the RF system and instrumentation for beam diagnostics etc.

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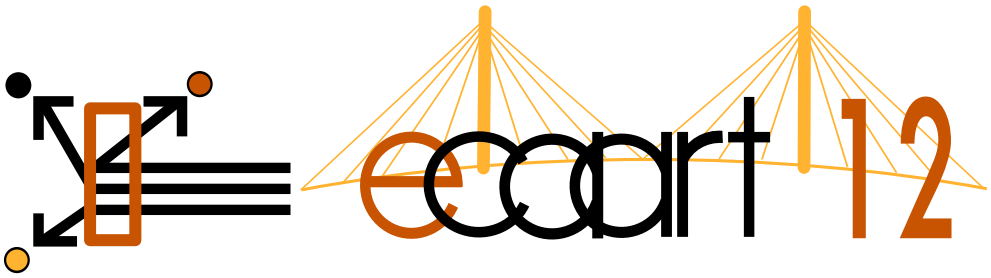

Abstracts

Posters

Session A, Tuesday

Identification of optimisation parameters for enhancement of ion yield in Ambient Pressure MeV SIMS

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Ambient Pressure MeV Secondary Ion Mass Spectrometry (AP MeV SIMS) uses primary ion beams in MeV range to sputter secondary species from a surface which are then being analysed by Mass Spectrometry. In comparison to keV primary ions, MeV's can penetrate into air where they can retain a sub micron focus for up to few millimeters, hence giving a possibility to perform analysis under full ambient conditions. This ambient analysis minimizes or completely avoids sample preparation and implies both decreased cost and time consumption of the analysis. An ambient analysis also bypasses the negative vacuum influence on samples, making it more relevant to "real life" over non-ambient ones and spreading the interest of the wide scientific community for the Ambient Mass Spectrometry [1]. In AP MeV SIMS an MeV beam of heavy ions is extracted through a 100 nm thin Si_3N_4 window and hits a target at normal incidence. Desorbed species are then pushed into a capillary attached to a QTOF mass spectrometer with support from a He flow coming out of a second capillary which is placed opposite the inlet capillary of the mass spectrometer. Some of the factors which increase sputtering yield in SIMS, such as incident angle of the beam [2], charge state [3] and choice of ion beam species [4] are well known from earlier research. In AP MeV SIMS where contributions from ambient background signals dominant and hinder peaks which originate from the target, some additional parameters need to be defined and optimised in order to achieve most efficient secondary ion transportation into and through the mass spectrometer and increase the signal to ambient signal ratio.

The experiments carried out at University of Surrey Ion Beam Centre, supported with numerical simulations, has proven the dependence of ion yield in AP MeV SIMS on positions of the capillaries, sample distance, gas carrier (He) flow rate, heating and applying bias on the mass spectrometer capillary. Difficulty of obtaining and identifying the target signal in AP MeV SIMS, a set of optimisation data having an emphasis on fine tuning of He capillary angle in regards to the target plane and He flow rate, as well as the first fully ambient MeV SIMS setup commissioned at University of Surrey Ion Beam Centre, will be described in this work.

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Proton-induced gamma-ray production cross sections and thick target yields for boron, nitrogen and silicon

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Particle-Induced Gamma-ray Emission (PIGE) is a powerful analytical technique based on the measurement of characteristic prompt γ-rays. It is applied often to determine the subsurface light element composition of the samples. However its light element depth profiling power and capability for standardless analysis of complex samples is limited by the lack of appropriate γ-ray production cross section data.

In this work, the excitation functions for the reactions ^{14}N(p,p'γ)^{14}N, ^{28}Si(p,p'γ)^{28}Si and ^{29}Si(p,p'γ)^{29}Si were measured at an angle of 55° by bombarding a thin Si_3N_4 target with protons in the energy range of 3.59 – 6.92 MeV. The deduced γ-ray production cross section data is compared with available literature data relevant for ion beam analytical work. Thick-target γ-ray yields for boron, nitrogen and silicon were measured at 4.0, 4.5, 5.0, 5.5, 6.0 and 6.5 MeV proton energies utilizing thick BN and Si_3N_4 targets. The measured yield values are put together with available yield data found in the literature. The experimental thick target yield data has been used to cross-check the γ-ray production cross section values by comparing them with calculated thick-target yields deduced from the present and literature experimental excitation curves. All values were found to be in reasonable agreement taking into account the experimental uncertainties.

Extension of the evaluation of the $^{nat}S(p, p_0)$ differential cross section up to E_p = 4.6 MeV

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The evaluated differential cross sections, being produced by incorporating the available experimental data within a unified theoretical approach, provide the most reliable values to be used in analytical EBS studies. The existing evaluated datasets for proton elastic scattering on sulfur, provided by SigmaCalc calculator (http://sigmacalc.iate.obninsk.ru), cover the energy range up to 4 MeV. The cross-section for higher energy proton elastic scattering is very important for the quantitative investigation of sulfur concentration at large depth. A strong and overlapping resonant structure is observed at higher energies according to the very limited corresponding available experimental data in literature. Our previous detailed experimental study on ^{nat}S(p,p), presented at the last IBA 2015 conference in Opatija (Croatia), made it possible to extend the evaluation over the energy region up to 4.6 MeV. The evaluated cross section at lower energy was also revised. In particular, a resonance at 3.7 MeV missed in the previous evaluation because of the lack of sufficient experimental information was included in the theoretical calculations.

The applied procedure involved the compilation and critical assessment of all the available experimental data. The parameters of the used model including also the spectroscopic information concerning the formed compound nucleus ^{33}Cl were adjusted to fit the theoretical calculations to the available experimental data. The R-matrix code was used for the corresponding calculations, while valuable feedback and validation were provided by additional cross-section measurements and thick target yield spectra. The overall methodology followed, the obtained results compared to the available experimental data and the claimed accuracy, are presented and analyzed.

Electron Linear Accelerator System for Natural Rubber Vulcanization

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Development of an electron accelerator system, an irradiation instrumentation and a methodology for natural rubber vulcanization is underway at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. This project is carried out with the objectives to improve the qualities of the natural rubber latex and to provide a solution for protein and chemical allergy problems, which may occur in natural rubber products. The system consists of a DC thermionic electron gun, three cells standing-wave radio-frequency (RF) linear accelerator and an electron beam irradiation system. It is able to produce electron beams with the energy range of 0.5 to 4 MeV, the pulse current of 10 to 100 mA, and the electron dose of about 0.4 to 4.4 Gy-sq.m/min. The research focuses firstly on study of accelerator properties and beam dynamic simulations of electron beam travelling from the thermionic cathode through the electron gun and the whole accelerator system. The simulations in this step are conducted by using simulation codes SIMION 6 and ASTRA. Then, Monte Carlo simulations are performed with the program GEANT4 to estimate the depth of electron beam in the rubber latex, distributions of electron dose and the influence of accelerated electrons on rubber vulcanization mechanism. The results from this research are used in design and development of instruments and the procedure to define optimal conditions for natural rubber vulcanization with different electron beam energies and doses.

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New measurements on ionization cross sections for high energy PIXE

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PIXE (Particle Induced X-ray Emission) has previously found extensive use in non-destructive multi-elemental analysis technique using low energy protons. Several attempts to perform PIXE using high energy protons have been performed in the past for quantitative analysis of archeological and art objects [1]. The use of high energy projectiles allows to benefit from K-X ray emission to analyze medium and heavy elements in thin (µm), thick (mm) and multi-layer samples.

HE-PIXE is under development at the ARRONAX facility [2] but additional K shell ionization cross section measurements are necessary for quantitative analysis. Indeed, if at low energy experimental values for different elements exist [3], there are only few experimental data above 10 MeV.

Therefore at our facility, we have started an experimental campaign to measure K-shell ionization cross sections for various elements. The first experiments have been conducted to measure these cross sections for titanium, copper, silver and gold targets impinged by a 68 MeV proton beam. An attention has been paid on a good control of the experimental parameters. Particularly, an effort has been made on the efficiency of our HPGe X-ray detector. The outcomes of the experiment were compared with the measurements of A. Denker et al [4] for the same protons energy. Also new experiments at lower energies (30, 42 and 54 MeV) are being analyzed that will allow to complement the databases.

In the same vein, a study of the theoretical model ECPSSR (Energie-loss Coulomb-repulsion Perturbed-Stationary-State Relativtic theory) based on the plane wave Born approximation (PWBA) [5] has been performed to check its validity at high energy.

During this talk, a review on the theoretical model ECPSSR will be presented, followed by a description of our experiment (beam, detector and target). Finally, I will present a comparison of our experiments data with the ECPSSR model.

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Complementary analysis using PIXE and RBS for thin films

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CuInTe is one of important materials used for conductive bridging random access memory. It is necessary to quantify the material composition to recognize the characteristic. On the other hand, determination of composition of In and Te is quite difficult by Rutherford backscattering spectrometry (RBS) because In and Te signals are interfered completely due to those close atomic numbers. Particle induced X-ray emission (PIXE) is one of IBA techniques with better elemental resolving power for heavy elements. On the other hand, PIXE is no straightforward absolute quantification.

Shariff *et al.* use the H_{el} value as an absolute correction factor of interest elements (el) to calibrate PIXE quantification. The H_{el} value is the product of solid angle and ratio between PIXE and theoretical areal density, thus the H_{el} value includes uncertainties of experimental parameters like detector solid angle, collected charge, etc. Due to those uncertainties, the quantification using the H_{el} value is accuracy to ~10%. To avoid this problem, we used new correction factor $h_{\mathrm{el/ref}}$ value as a relative correction factor. The $h_{\mathrm{el/ref}}$ values are defined as a ratio of the H_{el} and H_{ref} values from standards that contain both the elements of interest as well as reference elements (ref). By estimating the areal densities from single spectrum by PIXE and RBS, the uncertainties of experimental parameters are canceled out and do not propagate to the uncertainty of the h value.

To define the composition of CuInTe, we estimated the $h_{\mathrm{In/Cu}}$ by using both PIXE and RBS. PIXE was carried out with 2.0 MeV H^+ accelerated by the 5SDH-2 Pelletron in KU Leuven. The angle between a sample normal and incident beam is set to 45°. The X-ray detector for PIXE is a 30 mm^2 HPGe detector (Canberra) located at 45° from the incident beam. The 75 µm mylar film was set in front of the detector. We used software GUPIX to simulate PIXE spectrum. RBS was performed with 1.5 MeV He^+ accelerated by the 6SDH tandem accelerator in imec. The angle between the sample normal and the incident beam is 10° and the PIPS detector located at a scattering angle 170°. We measured CuIn (60 nm)/ SiO_2 (100 nm) / Si sub. for estimating the $h_{\mathrm{In/Cu}}$ by both PIXE and RBS. The $h_{\mathrm{In/Cu}}$ is 2.07 ± 0.02, the uncertainty was estimated as statistics. This means that accuracy of quantification is improved by using relative correction factor. By using $h_{\mathrm{In/Cu}}$ and $h_{\mathrm{Te/Cu}}$ values, we can estimate the composition of CuInTe samples more correctly. On the other hand, the h value must be 1 if the simulation is well modeled in the GUPIX. However, we found that just the elements of atomic number around 50 have h value bigger than 1.

Modified Rogowski Coil for Detecting Fast Plane Beams

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Due to the structure of planar beams or of the plane pulse forming lines, it comes the necessity to detect fast current pulses in planar configuration. Rogowski coil is a detector well known from more than a century[1] and it was studied considering a configuration next to a cylindrical coil. It is able to record variable current fluxing in a conductor which is responsible of the magnetic field around its axis. In principle, the voltage provided by the coil is derivative and in order to get information on original current, an integrating circuit is applied. For high frequency signals its response can be autointegrating providing a frequency independent attenuation factor. Moreover, the behaviour of the system is more complex owing to the fact that it is shielded by a metallic box to avoid stray signals and its behaviour is similar to a transmission line. The Rogowski coil can be developed also for planar currents like the current fluxing in a metallic sheet forming a transmission line, Fig. 1. This model is very useful for controlling of plane transmission line behaviour. Transmission lines of plane morphology are the best systems to provide a uniform area field and they are present in the accelerators for providing planar beams. A current i(t) in the conductor of width a determines a current density $j(t) = i(t)/a$. Assuming an input current like $i(t) = I_o u(t)$ the Rogowski coil response is:

$$i_c(t) = \frac{1}{n}\frac{d}{a} I_o, \tag{1}$$

with n being the ring number.

Generally, the response current exhibits an overlap of signals due to transmission line behaviour:

$$I_c(x,p) = \frac{I_{0p} R_c}{np(R_c + R_0)} \frac{d}{a} \frac{e^{-\tau_0 p x} + e^{-\tau_0 p(2d-x)}}{1 + \theta e^{-2\tau_0 p d}} + \frac{1}{np}\frac{d}{a} I_0 \approx \frac{1}{np}\frac{d}{a} I_0, \tag{2}$$

where $I_c(x,p)$ is the Laplace transforms of $i_c(x,t)$, R_0 is the characteristic resistance of the line, $\theta = (R_c - R_0)/(R_c + R_0)$ is the reflection coefficient, $\tau_0 = \sqrt{LC}$ is the propagation characteristic. Our detector have an inductor of 7 winders/mm and owing to the capacitance with the shield it presents a characteristic impedance of more than 1 k·. Closing it on a 50 Ω coaxial cable, it becomes autointegrating with an attenuation factor near 120. Experimental results are presented.

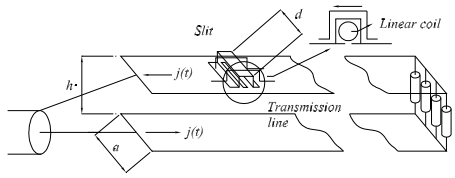

Figure 1: Sketch of the planar Rogowski coil.

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IBA analysis and mechanical characterization of TiAlPtN / TiAlN / TiAl multilayer films deposited over CoCrMo by means of Plasma Enhanced Magnetron Sputtering

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The elemental composition and the mechanical properties of multilayer coatings of TiAlPtN/ TiAlN/TiAl synthesized by PVD reactive magnetron sputtering over a CoCrMo alloy substrate, were analyzed and compared to those of the substrate alone. The objective of the present work was to create multilayers with different amounts of Pt in order to enhance the mechanical properties of a biomedical alloy of CoCrMo. The crystalline structure was determined by means of XRD experiments. The microhardness of the multilayers was evaluated by a Vickers test. The elemental composition and thickness of the coatings were evaluated by means Ion Beam Analysis Methods (IBA): RBS (Rutheford Backscattering Spectroscopy) and NRA (Nuclear Reaction Analysis) techniques, using an alpha and a deuteron and particle beams of 2 MeV each. In order to simulate the elemental profile of the samples, the SIMNRA simulation computer code was used. Adhesion experiments were performed on the coated samples with a tribometer in a pin on disk test. Also, to observe the structure of the films, SEM pictures of the cross sections of the coatings were taken. The IBA experiments showed, along with the SEM pictures, that the multilayer structure and the desired composition were achieved. It was observed that the microhardness of the films became diminished with the increment in the Pt concentration, up to a saturation point, in which no more changes could be appreciated.

Keywords: TiAlPtN; TiAlN; CoCrMo; IBA; SEM. *Work was financial supported by the DGAPA –IN102015 project

Studies on wear and corrosion resistance for a TiAlPtN / TiAlN / TiAL multilayer over a CoCrMo substrate prepared by plasma enhanced magnetron sputtering

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The RBS and NRA experiments showed, along with the SEM pictures, that the multilayer structure and the desired composition were achieved. It was observed that the microhardness of the films became diminished with the increment in the Pt concentration, up to a saturation point, in which no more changes could be appreciated.

Keywords: TiAlPtN; TiAlN; CoCrMo; IBA; SEM.

High Resolution Heavy Ion ERD at the Munich Q3D Spectrograph

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Also the Munich ERD group is celebrating the 40^{th} anniversary of elastic recoil detection.

Since about 25 years the high resolution elastic recoil detection experiment at the Munich tandem accelerator, using a Q3D magnetic spectrograph was optimized for ultra thin films analysis. This contribution will demonstrate the achievements in terms of depth resolution, sensitivity and accuracy. The potential of the method will be demonstrated on several applications.

Dye and electrolyte impregnation in templated TiO2 photoelectrodes monitored by combined alpha PIXE and Rutherford backscattering spectrometry

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During last decade, solid-state hole transporting materials have been investigated as alternative electrolyte materials to liquid-state dye-sensitized solar cells .

High surface area templated films have proved to provide improved pore accessibility promoting solid electrolyte penetration inside porous network, making possible efficient charge transfers.

In this on-going study, different templated TiO2 electrodes have been prepared before being dye-sensitized and impregnated with different combinations of dyes and electrolytes . We have used 2,4 MeV alpha beam with a new dedicated set up combining Rutherford backscattering spectrometry and PIXE detection to characterize the hole transporting materials infiltration and assess the impact of various formulations and combinations in terms of dye loading and solid electrolyte filling efficiencies.

In this paper the new set-up installed on the 30° beam line of the 2.5 MV Van de Graaff accelerator of the IPNAS laboratory will be described and first results of this study will be presented and discussed.

PIXE-PIGE analysis of Early Medieval Glass Artefacts at IPNAS cyclotron external beam line

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Knowledge of the elemental compositions of ancient glass artefacts provides clues as to production techniques and material chosen, either to shape a vessel or to produce decorative colored glass. Numerous archeometric studies, namely by means of Ion Beam Analysis techniques, have already demonstrated the suitability of these non invasive techniques to provide accurate chemical signatures and to assess the important changes occurring in glass manufacturing techniques, at that time. Together with the changes in commercial roads following the fall of the Roman Empire, the growing need for achitectural glass certainly contributed to innovations in glass crafts and, in Northern Europe, the transition from soda to potash glass may even be linked to it. At the end of VIIth century, churches had real stained glass windows and, walls as well as floors could be covered with mosaics. Combined with stone and painting, glass played a key role in the transmission and reflection of light and colors in buildings.

In this paper, to illustrate the current role played by PIXE-PIGE analysis in Cultural Heritage glass studies, we will present results obtained on the external beam line set up of the CEA-IPNAS facility of Liege and thus, on different kinds of glass artefacts within the framework of two distinct projects:

First, is an on-going project led on Merovingian glass vessels provided by different belgian museums. Analyzed objects presented in this paper, were excavated from three Merovingian period sites : Harmegnies, Viesville and Rebaix(Fig.1). Second corpus studied, is part of a project recently initiated on the territory of the Carolingian Empire and carried out in Belgium, France, Italy and Germany. It focuses on architectural glass artefacts and more specifically on mosaic's glass tesserae . The problematics, questions raised and results obtained on tesserae selected among the 755 items found during the excavation of Nevers baptistery in Burgundy region (France) will be presented (Fig.2).

Figure 1: Late Merovingian period glass artefacts from Viesville and Rebaix sites (Belgium)

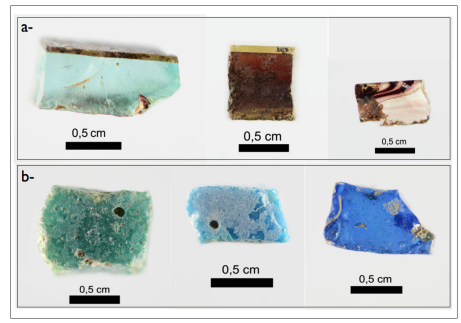

Figure 2: Tesserae from Nevers baptistery (France) : a- with cartellina & golden leaf b- shades of blue

Oxy-nitrides characterization with a new ERD-TOF system

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A new time-of flight (TOF) camera, developed and built by the Jyväskylä group, was installed on Elastic Recoil Detection (ERD) measurement setup on the Tandem Accelerator at Université de Montréal. The camera consists of two detectors that use a thin carbon membrane and microchannel plates (MCP) to produce the start and stop signals. The position of the first detector is fixed at 18 cm from the target, while the position of the second detector can be varied between 50 and 90 cm from the first detector. This allows to increase time resolution by increasing the distance between the time-of-flight detectors or to increase solid angle by decreasing the distance. Moving the detector also helps determining parameters such as the distance between detector foils and the delay time.

Compared to the original system, which had only one MCP detector and used the surface barrier energy detector for the stop signal, the energy is now measured from the timing signal with much better resolution, reaching ~2 nm near the surface. There is also no more need to keep track of the surface barrier detector calibration for each element, including the pulse height defect.

We show examples of quantitative depth profiles of oxy-nitride layers obtained with this new system. It allows quantitative measurements that would be difficult with other techniques, especially when light elements such as hydrogen, carbon, or nitrogen are mixed in various proportions in a heavy element matrix.

The Time-Resolved Ion Beam Induced Luminescence (TRIBIL) setup at LABEC and its preliminary results

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Luminescence techniques have a large range of applications, being employed in, e.g., ion implantation monitoring [1], discrimination between gemstones [2] and medical fields [3]. The use of ion beams as excitation source of the luminescence can be a powerful tool for material investigation because it can allow to detect subtle changes of imperfections and defect sites in insulators and semiconductors. Time-resolved measurements can provide an additional piece of information as they may allow to distinguish, in the time domain, features which can not be resolved in wavelength.

This work presents the new setup for Time-Resolved Ion Beam Induced Luminescence (TRIBIL) installed at the pulsed beam facility (DEFEL beam line) at the LABEC laboratory of the National Institute of Nuclear Physics (INFN) in Florence. DEFEL allows the creation of a pulsed beam from a continuous one by the use of two electrostatic deflectors that when working together can produce bunches with controlled number of ions per bunch (down to even one ion per bunch). Since it is known that luminescence decay often depends on dose and dose rate, in order to perform material characterization, for the first time the DEFEL beam line was used changing the pulsed beam features to a large extent: ion species; number of ions per bunch; and excitation duration. The detection of the luminescence decay is done by simply connecting the output of a photomultiplier tube to a sampling digitizer (CAEN/V1724), and using as an external trigger the signal given by the transition of the electrostatic plates (start signal). In this way, every time a bunch of particles hit the luminescence target, a waveform (luminescence decay) is acquired. The strong point of our system is that it allows us to characterize the whole luminescence signal generated by the bunch of particles that hit the target, i.e., the luminescence rise, the luminescence during excitation and the luminescence decay after the excitation is switched off. By monitoring the luminescence evolution in time during excitation it is possible to observe dynamic processes such as the creation and destruction of luminescence centers. For each irradiation, several waveforms are acquired and the average luminescence is calculated. The lifetimes of the luminescence decays are obtained by fitting the luminescence signal after the excitation is switched off.

TRIBIL measurements performed on CdWO4 crystals showed that our system is able to correctly reconstruct the expected luminescence decay of this well known scintillator. Moreover, we applied TRIBIL to lapis lazuli studies on the attempt to find new ways of discriminating stones from different origins [4]. TRIBIL measurements performed on stones from different mines show differences in their luminescence behavior related to the place of origin.

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Determination of sulfur density of particulate matter in exhaust gasses from a diesel engine by Rutherford backscattering spectroscopy

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Particulate matter (PM) in exhaust gasses from diesel engine has a harmful repercussion on environment. In particular, sulfur contained in PM not only hastens the corrosive wear of engine, but also brings heavy damage to human health. So it's important to assess sulfur content in PM. The PM has three components; dry soot (DS) produced as a result of imperfect combustion due to lack of oxygen, soluble organic fraction (SOF) consisting mainly of unburned fuel and lubricant, and sulfate (Sf) produced as a result of oxidation of sulfur in the fuel. The DS and the Sf are collectively called soluble organic fraction (ISF). The characteristics of the PM such as composition ratio of the components or the mass fraction are not fully understood yet, although they have critical effects on the performance of the engine.

We have studied the sulfur in the PM exhausted from a diesel engine using RBS and PIXE analyses [1]. The former RBS can analyze carbon and sulfur simultaneously. However, it cannot distinguish the carbon atoms in the DS and those in the SOF.

In the present work, by removing the SOF with dichloromethane, we have obtained the isolated ISF to analyze with RBS and evaluate the mass fractions for the first time. In the PM samples using the fuel with the sulfur content of 1.5%, the fractions are found to be 0.439, 0.027 and 0.534, respectively, for DS, Sf and SOF, which corresponds to 237 mg/m^3, 14.6 mg/m^3 and 288 mg/m^3, respectively. On the other hand, in the samples of the fuel sulfur content of 5.0%, these are 233 mg/m^3, 15.6 mg/m^3 and 50.7 mg/m^3, respectively. This means that the SOF emission from the fuel with sulfur content of 5.0% is five times smaller than that with sulfur content of 1.5%.

This is accounted for as follows. When the sulfur in the fuel increases, the time necessary for the ignition after the fuel injection (ignition delay) becomes larger by the ignition improvement effect of sulfur. The diesel engine employed in the present work is of small size. If the ignition delay is too large, the injected fuel molecules tend to accumulate on the combustion chamber walls, which results in increasing SOF emission. That is, if the fuel sulfur content is high, the SOF is reduced for burning prior to fuel depositing on the combustion chamber wall. In this way, evaluating 3 components contained in the PM leads to increasing knowledge on the characteristics of the engine.

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Elastic Recoil Detection Analysis of Thin Films

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Atomic layer deposition (ALD) has become one of the most important technologies for the growth of thin, nanometer scale conformal films. ALD is especially suited to produce thin films, when film quality, reproducibility and thickness are critical. Principles concerning the surface chemistry and growth rates have been studied for numerous systems, but very little attention has been paid to nucleation and initial stages of growth during ALD process.

Here, the elastic recoil detection analysis (ERDA) method is reviewed in the characterization of ALD grown films. Materials characterization by ERDA is applied in the analysis of the early steps of film nucleation and formation. It is found that ERDA analysis provides valuable information about film growth already from sub nanometer thickness. In a favorable experimental configuration, the nucleation of the film species can be detected at higher sensitivity in comparison to atomic force microscopy and energy-dispersive x-ray spectroscopy. In addition, ERDA provides elemental analysis over a wide film thickness range and enables accurate heavy to light mass impurity species detection, needed in film deposition process characterization.

The research is conducted within The Finnish Centre of Excellence in ALD.

Development of high-speed wavelength-dispersive IBIL analysis and imaging system using multi-channel photon-counting spectrometer

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Ion Beam Induced Luminescence (IBIL) analysis is one of ion beam analysis (IBA) techniques which have sensitivity to chemical composition of various targets [1,2]. Therefore, combined techniques of PIXE and IBIL are currently investigated using proton microbeam for the precise analysis and imaging of microscopic targets [3,4]. Moreover, IBIL from even organic target was performed under external microbeam irradiation condition [5]. However, most of analysis systems of IBIL use CCD based spectrometer with general response speed of several milliseconds, which is slower than general scanning speed of microbeam probe for micro-PIXE analysis.

In this study, we have developed high-speed wavelength-dispersive IBIL analysis system based on 32-channel photon-counting photomultiplier (PMT) (Hamamatasu H12211-20) combined with grating (Hamamatsu A10766-017-01). Signals obtained from 32 photon-counting PMT channels were processed in FPGA-based electrical circuit and multiplexed into single analog output. Pulses were reshaped with different amplitude correspond to the channel number of PMTs in range from 0 to 10 V to match the conventional signal processing system of micro-PIXE analysis [6]. The system was evaluated with external proton microbeam system at QST/Takasaki. The background level of the developed wavelength dispersive IBIL system was first evaluated as approximately 30 counts/sec/channel. Then particulate silicate mineral compounds on silicon substrate were placed at irradiation position for the evaluation. Multiple IBIL images of microscopic target were successfully obtained at the same time under general beam scan of proton microbeam. Differences in chemical composition of silicon and silicate compound were also visualized through the images.

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Elastic scattering cross section measurements on ^{19}F

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Particle Induced Gamma-ray Emission (PIGE) is regarded as the most suitable IBA technique for the quantitative determination of ^{19}F depth profile concentrations. However, it cannot be easily used for the simultaneous analysis of all the various light elements that can be present in a complex matrix, along with fluorine. In such cases Nuclear Reaction Analysis (NRA) is more suitable, along with Elastic Backscattering Spectroscopy (EBS), for the simultaneous determination of high-Z elements as well. For the above mentioned techniques the use of deuterons as probing beam presents the distinct advantage of causing the excitation of all the major light element/isotopes co-existing in a complex matrix. This, however, leads to the occurrence of complicated NRA/EBS charged-particle spectra, for the analysis of which, differential cross section data in literature is still not abundant or highly discrepant. More specifically, for the case of ^{19}F, no data for deuteron elastic scattering at low energies can be found in literature. The present work aims at filling this gap and providing accurate data for the application of the EBS technique in fluorine targets for several backscattering angles.

Differential cross sections measurements of the ^{19}F(d,d)^{19}F elastic scattering have been performed in the energy range between 0.9 and 2.0 MeV (in steps of 10 keV) and for five backward detection angles from 125^o to 170^o with respect to the beam axis. The deuteron beam was delivered by the 5.5 MV Tandem accelerator of the Institute of Nuclear and Particle Physics of the NCSR "Demokritos".

The target used for these measurements consisted of a thin ^{nat}LiF layer evaporated on top of a carbon foil. An ultra thin Au layer was evaporated on top of the target for wear protection and charge normalization purposes. Two additional thick targets were prepared, a ZnF_2 and a natural LiF highly pressurized tablet, in order to validate the measured cross sections at several deuteron beam energies.

Advanced mass discrimination in recoil spectrometry

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Elastic recoil detection analysis (ERDA) is recognized for its potential to probe the composition and the thickness of thin films made of light elements. Modern implementations of ERDA make use of a multi-dispersive detector telescope, for example a time of flight – energy (ToF-E) detector telescope [1,2]. By means of a mass transformation procedure [3] it is possible to extract the masses of recoils from their energies, to produce a time of flight – mass (ToF-M) histogram.

In the ToF-M histogram, the recorded masses of recoils are spread around the masses of the elements according to the resolution of the detector telescope [4]. Therefore, the signals from elements neighboring in the periodic table (e.g. magnesium, aluminum and silicon) can have overlapping masses in the ToF-M histogram. The overlap of recoils jeopardizes the identification of the detected ions of neighboring elements. Hence, when analyzing stacks of layers made of elements with 1 amu mass difference (e.g. aluminum and silicon) the determination of the thicknesses of the layers will be affected by the detector resolution.

In this contribution, we introduce an advanced mass discrimination procedure in elastic recoil detection analysis, based on the use of reference samples for the calibration of the detector resolution and an algorithm for spectral decomposition of the various isotopes. The procedure allows to discriminate light elements with mass difference down to 1 amu and it enables to calculate the thickness of thin films independently of their composition. We illustrate the effectiveness of the approach by comparing the thicknesses obtained from the procedure with the ones extracted with Rutherford backscattering spectrometry to validate the procedure on a demonstrative sample.

Finally, we correlate results of the procedure from data recorded with a silicon detector and a gas ionization chamber. We study the dependence of the energy resolution and the skewness on the detector type; we address the origins of the differences and we investigate the efficacy of the procedure to determine the amount of isotopes of minor abundance.

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Structural and optical properties of metal ion implanted GaN

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The field of advanced electronic and optical devices seeks for a new generation of transistors and lasers, which are going to be employed in ultra-low power high-speed memory and photonic devices. The practical developments of these novel spin-based devices depend on the availability of materials with the appropriate magnetic and optical properties, which is strongly connected to the internal morphology and structural properties of the prepared doped structures. In this contribution we present the growth and physical characterization of doped GaN epitaxial layers. GaN layers with (0001) crystallographic orientation grown by low-pressure metal-organic vapour phase epitaxy (MOVPE) on c-plane sapphire substrates were implanted with 200 keV and 400 keV V^+ ions at fluencies 5×10^{15} and 5×10^{16} cm^{-2}. Structural investigations are needed to understand the influence of defect distribution on the crystal-matrix recovery and the desired structural and optical properties. The structural properties of the ion-implanted layers were characterized by RBS-channeling and Raman spectroscopy to get the comprehensive insight into the structural modification of implanted GaN and to study the subsequent annealing influence on the crystalline matrix reconstruction. Photoluminescence measurement was provided to control the desired optical properties of the prepared structures. Changes in the surface morphology caused by the ion implantation were examined by AFM. The post-implantation annealing induced the structural recovery of the modified buried layer in GaN depending on the introduced disorder level e.g. depending on the used implantation fluence which was followed by the structural characterization and by the study of the surface morphology.

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RBS spectra simulation including 3D surface morphology implementation

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The Rutherford Backscattering Spectrometry (RBS) is well established technique for the elemental depth profiling in surface layers with a nanometer depth resolution. Unfortunately, the surface roughness of analysed samples can deteriorate the RBS spectrum and makes their interpretation more difficult and ambiguous. We developed a code for the RBS spectra simulation which takes into account 3D morphology of measured sample surface obtained by an AFM method. The simulated RBS spectrum is obtained as a sum of the many particular spectra from randomly chosen particle trajectories over the AFM picture. The main aim is to obtain more definite information on how the surface morphology affects the RBS spectra and shallow elemental depth profiles.

In this paper we present the RBS spectra simulation including the samples with periodical ripple patterns, which were prepared by the irradiation of polyethylene terephthalate (PET) foil with a KrF laser. The irradiated samples were subsequently covered by a 35-nm-thick vacuum-evaporated Au layer for better sensitivity of RBS. The simulated energy spectra were compared to the experimental ones measured using a beam of 2.0 MeV $^4He^+$ ions. An Ultra-Ortec PIPS detector recorded scattered He^+ ions at a scattering angle of 170° with the Cornell geometry. The angle between the incidence beam and the sample surface normal was step-changed from 0° to 75° to examine the roughness effects on the RBS spectrum measured in different geometries.

A reasonable agreement between the measured and simulated spectra was found and the present results indicate that the AFM data on the surface relief can be used for the simulation of RBS spectra.

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Electronic stopping powers of axial channelled He and Li ions in a Si crystal

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Motivation for experiments described in this paper was to get more original data of the energy losses of the ions in channelling direction in an energy range where is a data lack or the data are outdated [1, 2]. An accurate knowledge of the stopping powers in random and channelling directions is important for both theoretical physics and practical applications [2]. We have measured the electronic stopping powers of the He^{1+} and $Li^{1+,2+}$ ions in the random and channelling direction of the Si (100) crystal. The used energy range (2.0 – 7.6) MeV was changed by 200 and 400-keV steps. The ratio α between the channelling and random stopping powers was determined as a function of the angle for 2, 3 and 4 MeV He^{1+} ions and for 3 and 6 MeV $Li^{1+,2+}$ ions. The measurements were carried out using the Rutherford backscattering spectrometry in channelling mode (RBS-Ch). The difference between the Si/SiO_2 interface energy edges in the RBS random/channelling spectra provided information about the ratio between the stopping-powers in the channelling/random direction. For this purposes we have used Silicon on Insulator (SOI) sample, which consists of 200 nm thick Si (100) crystal on the top of a 380 nm buried layer of SiO_2 built into a Si wafer. The experimental stopping power values measured in random direction were than compared with results from SRIM-2013 and MSTAR codes. The experimental stopping powers measured in channelling direction were compared with data from literature.

The experimental stopping power values are a decreasing curve with the increasing energy. The stopping power difference between channelled and randomly going ions increases with the higher initial energy. The stopping powers in channeled direction were compared to the simulations using SRIM and MSTAR codes.

The research was realized at the CANAM (Center of Accelerators and Nuclear Analytical Methods) infrastructure LM 2011019 and has been supported by project GACR 15-01602S and SGS UJEP project.

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High Resolution Gas Ionization Chamber in Proportional Mode

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At energies below 1 MeV the performance of gas ionization chambers (GIC) for light ions like H, He, Li or Be is mainly determined by the level of the electronic noise [1]. With the ETH design of a GIC, which is equipped with Peltier cooled preamplifiers, an electronic noise level of 6-7 keV for protons was achieved, which corresponds to the lower limit for the energy resolution presently achievable with this detector.

Since the electronic noise level cannot be further reduced with state-of-the-art equipment the signal to noise ratio can only be improved by increasing the signal produced during the stopping process of the primary ion in the detector gas. This can be achieved by increasing the electric field strength up to the so-called proportional region, where drifting electrons gain enough energy between two collisions to ionize gas particles. The amplification is thereby determined by the ratio of the electric field strength E and the gas pressure p in the chamber, which defines the mean free drift path of the electrons between two collisions. The amplified detector signal remains thereby proportional to the energy deposited in the detector volume, if E/p is kept below the so-called Geiger-Müller region.

While the relative contribution of the preamplifier noise to the detector signal is reduced or becomes even negligible in the proportional mode, the energy resolution is more sensitive to variations in the electron multiplication process caused by electric field inhomogeneity or slight changes in gas pressure. Therefore, the energy resolution can only be improved if these variations are kept small enough.

Experiments with the ETH GIC in proportional mode have been performed at the 600 kV ETH AMS Tandy facility. The electron multiplication was initiated in isobutane gas by applying an electric field strength of up to 500 V/mm between the Frisch grid and the collecting anode. A Cremat CR-110 preamplifier module was used without cooling. First measurements with H, He and Be ions show a good linearity between the detector signal and the beam energy in the investigated energy range of 0.1 – 1 MeV. The obtained energy resolution at very low energies is very promising. For example between 100 – 300 keV a total energy resolution for protons of 5 to 7 keV was achieved, which is even lower than the electronic noise level of the cooled preamplifiers in the ionization mode. Further performance measurements as well as limitations of the proportional mode will be discussed in this presentation.

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ERDA at the 9 MV Tandem and at the 3 MV Tandetron of NIPNE-HH

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Recoil spectrometry with heavy ions has evolved into a rather universal IBA technique. The Elastic Recoil Detection technique has been proposed in 1976 by L'Écuyer et al. [1]. This method came out from heavy-ion nuclear physics following nuclear reaction studies in an inverse geometry, in which heavy projectiles are incident on lighter target nuclei which are detected and identified as recoil products of the interaction. The use of an absorber in order to discriminate between scattered projectiles and recoiling atoms limits the method. In 1984 an experimental setup for recoil spectroscopy including a compact ΔE(gas)–E(solid) telescope, was developed at the Tandem accelerator of NIPNE-HH [2].

The telescope consists of a ΔE pulse ionization chamber and a residual energy silicon detector, placed inside the ionization chamber. The telescope was placed inside the scattering chamber. In order to improve the resolution of the ionization chamber the preamplifier was coupled directly to the anode, in vacuum. The preamplifier consists of integrated circuits and very few external components. The essential part is a CSAM integrated circuit with large amplification factor (~ 5000) and a very low noise that proved to be stable; it could be operated in high vacuum without notable heating.

A prerequisite for the precise quantitative evaluation of the ERDA data is the correct energy calibration of the data. The calibration procedure for the telescope and the software used for the quantitative evaluation of the ERDA spectra are also presented.

Recently, a 3 MV Tandetron accelerator has been installed and commissioned at the NIPNE-HH. Among several ion-beam techniques for detection and depth profiling of hydrogen isotopes, Elastic Recoil Detection Analysis (ERDA) technique using a low energy 4He beam, proposed by Doyle and Peercy [3], is particularly advantageous; all hydrogen isotopes can be profiled simultaneously with a sensitivity as high as 0.1 at.%, the measurements can be performed using a relatively low energy accelerator and the samples undergoes less damage as compared with the use of high-Z analysis. The large recoil cross sections led to a rapid development of the technique.

The experimental setup allows simultaneous investigations by Rutherford Backscattering Spectrometry (RBS) and Elastic Recoil Detection Analysis (ERDA) of the samples. To filter out the scattered helium ions mylar foils (11 μm thick) were placed in front of the second detector. By measuring simultaneously both the H or D recoiling at a forward angle and backscattered ^{4}He ions, a rather complete characterization of the sample can be achieved. Selected results from our investigations obtained using these facilities will be presented.

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Analysis of light elements and results comparison between NRA, HI-ERDA, μ-Raman and SIMS

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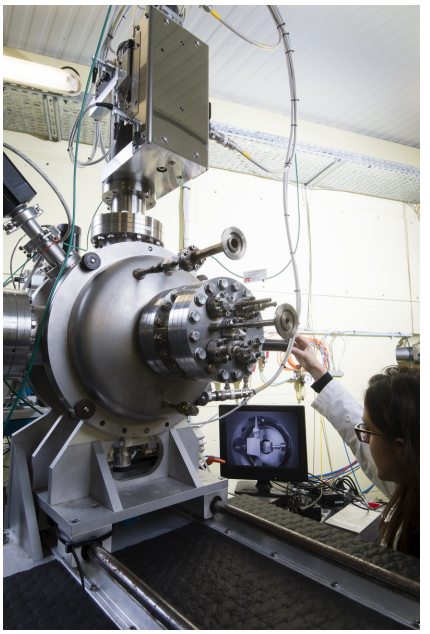
Implantation of hydrogen in materials is used for several applications: in electronics for doping or thin film production and for nuclear studies to simulate gas accumulation during reactor operation. Also helium and hydrogen are elements of interest due to their production by nuclear reactions in reactor structural materials or in nuclear waste. In the last case, interaction of hydrogen and helium with the host matrix can cause damage through embrittlement, hardening, and swelling.

During and after implantation, hydrogen and helium diffuse and can be trapped, resulting in possible changes to its chemical bonding or molecular structure. First, in order to characterize the behavior of hydrogen implanted in depth in materials, we have combined two techniques. SIMS (Secondary ion mass spectrometry) is used for profiling H from the surface to about 5 μm in depth without any preparation of the sample. μ-Raman is applied on cross-sections of the samples. Mappings of Raman spectra as a function of the depth are obtained along the ion path evidencing possible matrix-H bonds or H2 molecular structure.

Second, in order to characterize the behavior of helium with these materials we have implanted 3He+ or 4He+ and consecutive annealing [2]. After implantation, two routes are possible for the determination of helium profiles and concentrations. ^{3}He profiles are measured by the ^{3}He(d, p)^{4}He nuclear reaction and 4He profiles are determined by heavy-ion ERDA. In this contribution, the facility will be described focussing on instrumental developments for helium (NRA and HI-ERDA) and hydrogen (HI-ERDA, SIMS and μ-Raman) analysis. The recent system for HI-ERDA and the first measurements will be presented in details like He depth profiles and especially the optimisation of analysis characteristics for a better separation between H and He.



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Development of a simulation code for material analysis using the PIGE technique

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Particle Induced Gamma ray Emission (PIGE) is a well known and widely used Ion Beam Analysis (IBA) technique for non-destructive material analysis, usually in conjunction with Proton Induced X-ray Emission (PIXE). PIGE has certain advantages over charged particle Nuclear Reaction Analysis (NRA), with the enhanced detection sensitivity for many nuclides as well as its high isotopic selectivity being the most important ones. The main drawback in the applicability of PIGE regarding the quantification of light elements in various heavy element substrates is the need for many reference targets with similar matrices to the one under study, because of the importance of the energy loss in the calculations. In order to overcome this problem, there rises the need of an appropriate simulation code that uses as inputs the experimental spectrum and the respective differential cross sections, with the output being the quantification of the concentration depth profiles of the isotopes of interest.

A code like this is being developed in C++ and it is compatible with Windows, Linux and Mac. In the present version, the target has to be a homogeneous monolayer, the initial composition of which is given by the user. The code, taking into account the experimental conditions (accumulated charge, detector efficiency, etc.), calculates the expected yield for the reaction under study. Using successive iterations it fits the concentration of the sample isotopes until the experimental yield is reproduced within a certain accuracy. The energy loss in the target is calculated using the Ziegler, Biersack and Littmark (the so-called "ZBL") stopping for each element and then the Bragg's rule for the determination of the stopping power in compounds. The differential-cross-section files should be in R33 format and the user can give an initial yield for the lowest energy that the cross section is available.

More details regarding the main functions of the code and some examples with the results that were deduced by the spectra of standard (well known composition) targets will be presented.

Production of Thin Targets by Implantation and Measurement of the ^{16}O + ^{16}O Elastic Scarrering Cross Section Below the Coulomb Barrier

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In recent decades, the processes of fusion of ^{16}O were studied both theoretically [1,2] and experimentally [3,4,5,6,7,8], because the fusion reaction ^{16}O+^{16}O is essential for understanding the nuclear burning processes in advanced stages of stellar evolution, contributing significantly to the production of heavier elements. However, the lowest center-of-mass energy reached in these previous studies was around 6.5 MeV, but at this energy the discrepancies between the different experimental results at sub-barrier energies are around a factor of 3. Moreover, the theoretical calculations are not enable to fit both elastic scattering cross sections and fusion S-factors. In the aim of the study of the ^{16}O+^{16}O fusion reaction, we present the experimental elastic scattering cross section in the region of astrophysical interest.

Due to the extremely small cross sections involved, the production of targets for astrophysical purposes is a real challenge. Moreover, the use of thin transmission targets is sometimes relevant due to the measure of elastic scattering between identical particles, such as the ^{16}O+^{16}O reaction. The areal density of the target must be high to maximize the reaction products yields, but not so high as to allow a correct calculation of the effective beam energy. Besides this, the target must withstand high beam current densities without noticeable deterioration, and contaminants must be minimal.

The production of thin targets is performed with an innovative technique, in which a thin layer of ^{12}C (with few nm) is produced over a glass sheet by evaporation. The carbon layer on the top of the glass will be implanted with the wanted element. After that, the separation between the implanted carbon film and the glass sheet is achieved by submerging the glass sheet in water carefully as the glass slowly sinks the carbon film will stay floating on the water surface. The carbon film is finally picked up from the surface with a special tool. The targets were them analyzed with a 2.5 Van de Graaff Accelerator and a 3.0 MV Tandem Accelerator, at the Ion Beam Laboratory at CTN (Sacavém – Portugal).

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Study of the Matrix Effect on the PIXE Quantification of Active Pharmaceutical Ingredients in Different Formulations

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When it comes to perform a quality control on the amount of an active pharmaceutical ingredient (API) in its formulation the time of analysis and of calculation are two major factors in choosing the appropriate technique to be used. In fact, in our previous studies [1], we have demonstrated that Particle Induced X-ray Emission (PIXE) technique has a low cost for sample preparation and it is an accurate technique to quantify APIs via the analysis of their heteroatoms.

The commercial Fludinium® drug, which has two active ingredients Clidinium Bromide ($C_{22}H_{26}NO_3Br$) and dihydrochloride trifluoperazine ($C_{21}H_{24}N_3F_3S \cdot 2HCl$), has been taken as a case study in this work. Different amounts of its APIs and its placebo were mixed to provide various formulations.

In this work, we will study the matrix effect on the quantification of the three heteroatoms (Chlorine, sulfur and bromine) related to the above APIs in different formulations. In fact, we will demonstrate that the calculation of Br via its K alpha or its L alpha rays is independent from the matrix composition and can be done rapidly by simple comparison to an external standard; the so called "direct quantification" method. However, we will verify that the calculation of S, via its K alpha, is highly dependent on the matrix composition. Therefore a more sophisticated calculation method is needed to achieve an accurate quantification. In this case, the calculation will be achieved with different approaches by the mean of the simulation code GUPIX. On the other hand, we will show that when Cl is in its hydrochloride form in an API it can't be considered for calculation due to its instability under beam.

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Detection limit in boron analysis of thin films deposited on Si substrate by optimization of PIGE technique

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In order to assess a detection limit in the analysis of boron content in thin films deposited on Si substrate the non destructive proton-induced gamma-ray emission has been used, based on the ^{10}B(p,$\alpha\gamma$)^{7}Be nuclear reaction. From a systematic study involving variation of incident proton energy (from 1 to 3 MeV) and tilting angle of beam incidence (0°, 40°, 60° and 80°), it is demonstrated that the best sensitivity of B detection occurs at 1.5 MeV and 80°. Under these conditions and for a few tens minutes acquisition time, the lowest thickness of a boron layer deposited on Si substrate is estimated to be 1.1×10^{16} at/cm^2.

Consequences of such improvements will be evaluated as regards the amount of boron doped in thin layers of silicon as well as of boron inside a thin film of BGaInAs deposited onto GaAs substrate, responsible of changes in electronic and optical properties.

Emittance matching of a slow extracted beam for a rotating gantry

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A construction of a heavy-ion rotating-gantry is in progress at Heavy Ion Medical Accelerator in Chiba (HIMAC) to realize a higher precision cancer therapy with heavy ion. A scanning irradiation method will be applied to this gantry course with maximum beam energy of 430 MeV/u. In the rotating gantry, a horizontal and vertical emittance is coupled by its rotation. Therefore, beam spot at isocenter will vary in each gantry angle, because a slow extracted beam from the synchrotron have a different emittance size between a horizontal and a vertical. Furthermore, the shape of a horizontal emittance is not Gaussian distribution, because of the mechanism of the slow extraction method. In order to maintain the circular spot shape at isocenter without depending on the gantry angle, it is essential to achieve the symmetric phase-space distribution for the horizontal and vertical at the entrance of the rotating gantry. Thus, it is necessary to compensate the difference of the horizontal and vertical emittance with Gaussian distribution. In order to realize this emittance matching, we considered to use a thin scatterer method. The emittance matching can be realized to control the beta-function at the scatterer and a phase advance from the synchrotron to the scatterer. Firstly, we constructed the optimized optical design for the emittance matching. Secondly, we verified whether the emittance matching is feasible by a particle tracking calculation. Thirdly, we designed the thin scatterer device and equipped it in the high-energy beam transport line. After that we carried out the beam test in the existing course. As a result, we verified that the observed beam profile is in agreement with the tracking calculation as shown in figure 1.

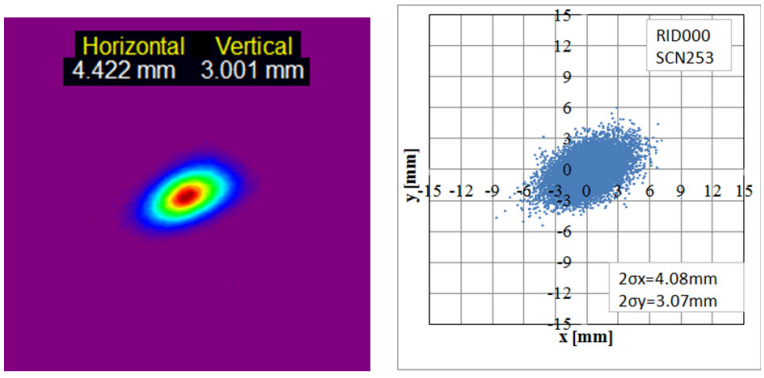

Figure 1: Comparison of the beam shape between the experimental result (left) and the tracking calculation (right). The projection profile of the horizontal direction is Gaussian distribution, although the phase advance from the synchrotron to this beam monitor is 2.5 π rad.

Modifications in Physico-chemical properties of Swift heavy ions irradiated Polyimide Kapton-H polymer

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Polyimide Kapton-H (Kp-H) polymer samples after being irradiated with 100 MeV O^{7+} ions were studied for modifications in optical, structural and chemical properties. These properties were studied by UV–visible (UV–Vis) spectroscopy, X-ray diffraction (XRD) and Fourier transform infrared (FTIR) spectroscopy respectively. The fluences of O^{7+} ions were taken in the range varying from 1×10^{11} to 5×10^{12} ions/cm^2. UV–vis studies showed a marginal shift in absorption edge towards the visible region and a decrease in band gap energy (E_g) from 2.64 to 2.58 eV for the irradiated samples. The corresponding number of carbon atoms per conjugation length increased from 169 to 176 for the irradiated samples. The XRD analyses showed a slight shift in the position of diffraction peaks indicated some structural changes in the irradiated polymer. An increase in the crystalline nature of the polymer at higher fluence as a result of decrease in the peak width (or FWHM) of XRD patterns was observed. The disappearance of some of the existed absorption bands and the developement of some new bands as studied by FTIR spectroscopy indicated some chemical modifications in the polymer upon irradiation.

Keywords: Kapton-H, X-ray diffraction, UV–visible, FTIR, Band gap

Thin film growth in the ion track structures by atomic layer deposition

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Fabrication of complex porous structures without a stiff substrate is possible from self-supporting polyimide foils using ion track technology. In this technology energetic heavy ions induce damage to a solid material along the ion track. After the ion irradiation the damaged areas are etched away.

Atomic layer deposition (ALD) is known to produce wide selection of thin films with high conformality and reproducibility also on high aspect ratio structures. The gaseous precursors fully penetrate inside the track and copy the surface topography perfectly.

Self-supporting 75 µm thick polyimide membranes (Kapton) were irradiated at JYFL in RADEF irradiation chamber with 600 MeV Xe^{25+} beam. The irradiated doses were 10^7 to 10^9 ions/cm^2, and single irradiations lasted from seconds to thirty minutes. During the irradiation the beam homogeneity and flux were monitored. Irradiation angle was continuously varied between ±15° and the foil was also rotated in order to get crossing ion tracks but still keeping the maximum pore diameter through the foil fixed. Irradiated foils were etched in sodium hypochlorite (NaOCl) and boric acid (BO_3) solution to reach pore diameter of 300 nm [1].

In this work we studied Al_2O_3 and TiO_2 growth on pristine and etched polyimide foils by RBS. The focus was on the first ALD growth cycles. Irradated, etched and thin film coated membranes were imaged using helium ion microscope (HIM) to verify the uniform pore size of the ion tracks and ALD thin film homogeneity through the pores.

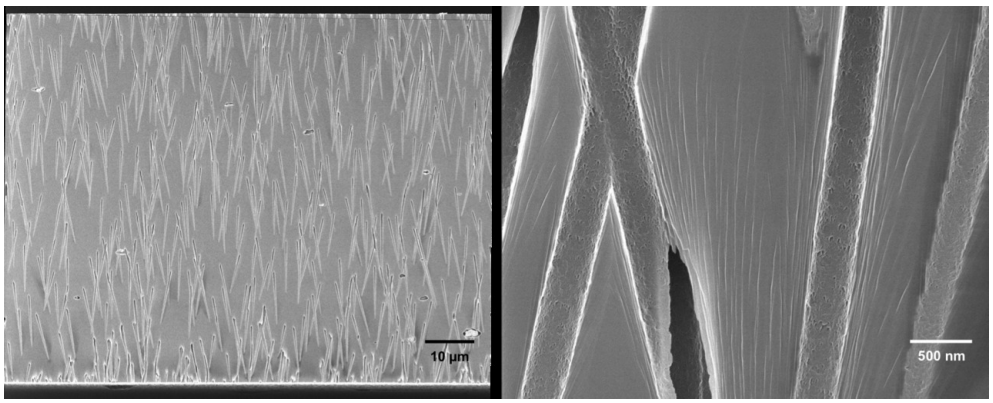

Figure 1: Etched ion tracks in the Kapton foil scanned with helium ion microscope. On the left cross-section of the 75 µm thick membrane and on the rights details of the 300 nm diameter tracks.

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Compositional, structural, and optical changes of polyimide implanted with 1 MeV Ni^+ ions using various ion currents

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The ion irradiation leads to deep structural and compositional changes in the irradiated polymers [1,2]. Using different the ion fluence and the ion current, it is possible to control the size and density of the nanoparticles and to form composites with specific optical or magnetic properties. Polyimide (PI, $(C_{22}H_{10}O_5N_2)_n$) foil, 50 μm thick, was implanted with 1 MeV Ni^+ ions at room temperature with fluencies of 1.0×10^{13} – 1.0×10^{15} cm^{-2} and different ion implantation currents used. Rutherford back-scattering (RBS) and elastic recoil detection analysis (ERDA) were used for determination of oxygen and hydrogen escape in pristine and implanted PI. Atomic force microscopy (AFM) was used for surface roughness changes in the implanted PI. The optical properties of the implanted PI were analysed using UV-Visible spectral study. The structural changes, for instance, polymeric functional group appearance, double bonds, carbon-cluster creation etc. were analysed using Fourier transform infrared spectroscopy (FTIR).

Ni-ion implantation causes a release of hydrogen and oxygen from the polymers penetrated by the ion beam especially at ion fluences above 1×10^{15} cm^{-2}. Hydrogen concentration in PI implanted by Ni to a fluence of 1×10^{15} cm^{-2} and a current density 7.6 nA/cm^{-2} is decreased from 26 % in pristine PI to 18 %. For lower ion implantation fluencies the hydrogen release was negligible (regardless the ion implantation currents). The oxygen release were more significant for the ion fluence of 1×10^{15} cm^{-2}, where was observed a decrease from 13 % in pristine PI to 7 %. For lower fluencies (1×10^{13} – 1.4×10^{14} cm^{-2}) the oxygen decrease were less pronounced. Comparing PI implanted using various ion implantation currents no significant changes in the release of hydrogen and oxygen concentration after implantation were observed.

The research has been implemented at the CANAM (Center of Accelerators and Nuclear Analytical Methods) infrastructure LM 2011019 and GACR project P108/12/G108 and SGS UJEP student project.

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Introduction of conductivity to the polymer with a heavy ion beam irradiation for production of a functional polymer substrate

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Recently, many products of functional polymers have been developed and these have been used in many fields. Radiation induced graft polymerization is one of the production method for a functional polymer, and the method is applied to an industrial production. The method can be conducted with ion beams, and we have studied the ion beam induced graft polymerization method [1,2]. If a polycarbonate substrate is irradiated by a heavy ion beam, a conductivity part is introduced in the substrate [3]. We apply these methods using ion beams to produce a functional polymer. In this study, an introduction of the conductivity to the polycarbonate substrate irradiated by a heavy ion beams is reported.

A tandem accelerator at Kobe University (NEC model 5SDH-2, 1.7 MV) was used for the ion beam irradiation in this study. Polycarbonate sample, the size was $30 \times 50 \times 1.0$ mm, was set on the target holder, and was irradiated by Cu^+ ion beam. The energy was from 300 keV to 1000 keV. The resistance of the sample was measured by an in-line four-point probe. For example, the conductivity was 2.7 S/m for 500 keV Cu^+ ion beam irradiation at the fluence of 5×10^{16} cm^{-2}. The dependence of the conductivity on the ion energy and the fluence was measured, and the dependence will be discussed in this presentation. In addition, the irradiation of polycarbonate with Au and Ag ion beam was conducted, and the conductivity was confirmed for each irradiation. Depth profile of the heavy metals in the sample after irradiation was measured by Rutherford back scattering spectroscopy analysis. The heavy metals did not exist at the surface, but exist near the ion range. The depth profile was compared with the calculated result by SRIM code.

Molecular orbital calculations with GAMESS, an ab initio quantum chemistry package, was conducted, and the relation between the conductivity and the structure of the polymer was discussed.

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Radiation hard technology and design of HfO2 based 1T1R cells and memory arrays

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Semiconductor memories, among rad hard integrated circuit scenario, are one of the most critical topics for space applications. Actually both volatile and nonvolatile memories, excluding few exceptions, are integrated using standard processes and standard architectures. This means that the final device is typically at least Rad tolerant and not Rad Hard and failure during mission is avoided using Error Correcting Code techniques including redundancy at the board level.

Since standard silicon memories, such as flash memories tend to fail under irradiation, a new approach is envisaged: the development of a specific memory technology, so called resistive random-access memory (RRAM). The switching effect of RRAM devices is caused by chemical Redox-reactions, therefore, radiation effects like total ionizing dose and single event effects don't affect the switching mechanism.

The intrinsic radiation tolerance of RRAM significantly reduces sensitivity to radiation-induced bit upsets. Nevertheless, the 1T1R structure of the memory array consists of NMOS access transistors, which are sensitive to radiation. In standard NMOS devices, ionizing radiation may generate holes trapped in the gate oxide, and the trapped holes could induce leakage paths from the drain to the source region. A suitable approach to eliminate the leakage path in NMOS transistors is to adopt a gate-enclosed layout. For the first time, we will present the electrical performance of a Rad Hard designed 1T1R device based on the combination of an Enclosed Layout Transistor (ELT) and an HfO2/Ti based resistor, as shown in fig. 1.

From the architectural point of view a 1Mbit test vehicle implementing RRAM array will be presented. In order to achieve an increased resistance against radiation the single bit is the result of the contribution of two RRAM cell located in different array locations; this guarantees an internal redundancy (no reference cells are required for read mode operations) and a wider margin window in a sensing module very similar to SRAMs.

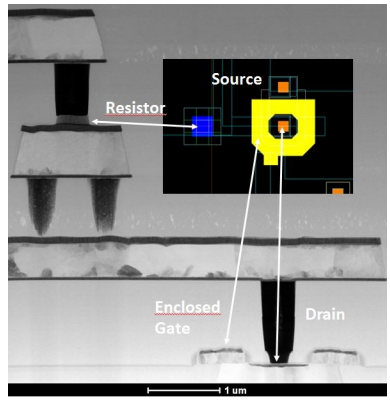

Figure 1: Fig. 1: TEM cross view of the Rad Hard designed 1T1R cell

Design of a 650 MHz proton RFQ linac

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A radio frequency quadrupole linear accelerator (RFQ linac) is suitable to accelerate protons and heavy ions in low energy region. It accepts DC beams extracted from an ion source and accelerates them up to design energy with bunching and focusing using the RFQ electric fields. Because of the difference of the quadrupole electrodes configuration, the RFQ linac is classified to the types of four-vane and four-rod. The four-vane RFQ linac, which accelerates beams with the electric field excited by the TE211 mode, has been used for proton acceleration driven by high operating frequency. We have studied a compact accelerator-driven neutron source system for industrial use, which consists of a proton source, a four-vane RFQ linac and a lithium target for neutrons production by the Li(p,n)Be reaction. The operating frequency of the proton RFQ linac is 650 MHz which is adopted for downsizing. We has been designed its specifications through beam trajectory and electromagnetic simulations. The details of the neutron source system and the simulation results will be presented.

Design of four-beam IH-RFQ linear accelerator

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The multi-beam acceleration method is an acceleration technique for low-energy high-intensity heavy ion beams, which involves accelerating multiple beams to decrease space charge effects, and then integrating these beams by a beam funneling system. At the Tokyo Institute of Technology a two beam IH-RFQ linear accelerator was developed using a two beam laser ion source with direct plasma injection scheme. This system accelerated a carbon ion beam with a current of 108 mA (54 mA/channel $\times$ 2) from 5 up to 60 keV/u [1].

In order to demonstrate that a four-beam IH-RFQ linear accelerator is suitable for high-intensity heavy ion beam acceleration, we have been developing a four-beam prototype. The four-beam IH-RFQ linear accelerator consists of sixteen RFQ electrodes (4×4 set) with stem electrodes installed alternately on upper and lower ridge electrodes.

As part of this development, we have designed a four-beam IH-RFQ linear accelerator using three dimensional electromagnetic simulation software and beam tracking simulation software. From these simulation results, we have designed the stem electrodes, the center plate and the side shells by evaluating the RF properties such as the resonance frequency, the power loss and the electric strength distribution between the RFQ electrodes. In the presentation we will discuss the design and simulation results.

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Development of a Laser ion source for high intensity heavy ion beams

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Laser ion sources (LISs) generate plasma from any solid material by irradiating a focused pulsed laser beam, and high intensity ion beams are produced. In TIARA accelerator facility, we are developing a laser ion source to provide high-intensity beams for single pulse acceleration in the AVF cyclotron and for the ion implanter. Highly charged heavy ion beams such as C^{5+} and C^{6+} and low-charged heavy ion beams such as C^{+} , Cu^{+}, Au^{+} etc. are required for single pulse acceleration in the cyclotron and for the ion implanter, respectively. A laser ion source test bench has been constructed to study the generation of various kinds of laser plasma.

The test bench consists of a LIS chamber, a plasma drift space, a Faraday cup and an electrostatic analyzer. A Nd:YAG Q-switched laser with the wavelength of 1064 nm, the pulse duration of 5-7 ns and the maximum energy per shot of 450 mJ is used. Plasma is generated by focusing the laser beam on a solid target in the chamber. The plasma freely expands in the plasma drift space. The ion current is measured by the Faraday cup and the charge state distribution is measured by the electrostatic analyzer.

As the laser-irradiated target surface is ablated, the focusing condition of the laser is changed. A new irradiating surface need to be supplied for each laser shot especially in producing highly charged ions. Therefore, the LIS chamber has a xyz motorized stage which mounts a plane target with the maximum size of 300 mm $\times$ 135 mm.

The details of the LIS test bench and the experimental results of carbon plasma generation will be presented.

Beam profilometer signal digitization for beam current integration and improved AMS diagnostics

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As part of a larger effort for accelerator automation for the benefit of AMS and IBA research, we have automated the operation of and digitized the output signal from the beam profilometers (BPM) in the 5-MV tandem accelerator system. As a result, beam diagnostics has become easier, more versatile and more quantitative. Several BPMs can be used at the same time and parameters such as centerpoints, widths, quartiles, and areas are computed from the X- and Y-profiles and stored to the accelerator database in real-time.

For AMS, the system provides quality-control information about beam emittance and current for each sample. For IBA, the system provides a method of beam current monitoring and irradiation fluence measurement, which is independent of sample conductivity and ionization issues. For in-air PIXE measurements, the BPM integrated charge is adequate for current normalization to one percent precision.

Use of a Gafchromic film HD-V2 for the Profile Measurement of Energetic Ion Beams

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A Gafchromic film (Ashland Inc.) [1], a type of radiochromic film, is widely used for dosimetry and quality assurance in radiation therapy using high-energy ion (~ 100 MeV/u) and photon beams because of its usability. In this paper, the coloration response of a Gafchromic film, HD-V2, to relatively lower-energy ion beams was investigated to measure and evaluate the transverse spatial profile of large-area ion beams that are often applied to materials sciences and biotechnology. Ion irradiation experiments were performed at an azimuthally-varying-field cyclotron in Takasaki Ion Accelerators for Advanced Radiation Application (TIARA). HD-V2 films were irradiated uniformly with proton and several heavy-ion beams (4.1 ~ 27 MeV/u) over a wide fluence range, and read with a flatbed scanner to analyze changes in the optical density (OD). The available fluence range and sensitivity of HD-V2 depended strongly on ion species, i.e., linear energy transfer. Moreover, we observed that the linear response OD range, where the increment of the OD is proportional to the fluence, is smaller than that of the previous model HD-810, but weakly dependent on ion species. However, the fluence distribution of an ion beam was determined using a response curve of HD-V2 including the nonlinear response range. We thus demonstrated experimentally that low-fluence irradiation with large-area uniform ion beams formed using multipole magnets was achieved and the irradiation area and uniformity were evaluated using HD-V2. The present results suggest that the Gafchromic film is useful for evaluating the characteristics of MeV/u-order ion beams.

[1] http://gafchromic.com/

Radiocarbon Measurements of Small Gaseous Samples at CologneAMS

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At the Center for Accelerator Mass Spectrometry of the University of Cologne (CologneAMS) a second HVE-SO110 ion source was installed recently which was tuned to measure gaseous ^{14}C samples with high efficiency. In order to allow for routine sample measurements a gas injection system from IONPLUS AG was connected to the sputter source and has been tested. In order to optimize the ion yield various settings of different source parameters were investigated. Based on simulations with SIMION computer code a modified immersion lens was designed and tested. Finally quite high efficiencies of up to 11% were reached. During standard measuring sequences efficiencies of about 2% were obtained for sample sizes in the range of 5–50 µg. In this presentation we will discuss details concerning our attempts to get an optimized source operation for gaseous radiocarbon samples and we will report on first results of blank values and reproducibility of isotopic ratios obtained for standard samples and potential memory effects.

The project is partially supported by Deutsches GeoForschunsZentrum GFZ, Helmholtz-Zentrum Potsdam.

AMS of ^{93}Zr: passive absorber versus gas-filled magnet.

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Probably the first positive detection of ^{93}Zr ($T_{1/2}$ = 1.5 Ma) has been reported by Steinberg and Glendenin (1). They irradiated uranium in a pile for about 10 month and extracted chemically the fission product ^{93}Zr. To determine ^{93}Zr in much less quantities is a challenging but desirable effort because of the great interest from different fields of science; as there are nuclear materials, fuel behavior and waste management, dosimetry, and also nuclear astrophysics, where ^{93}Zr represents a weak branching point in the s-process, and finally a challenging approach could be utilizing ^{93}Zr for dating of geological samples for time-scales comparable to the half-live of ^{93}Zr. However ^{93}Zr represents a very demanding background situation even for AMS. Its two stable neighboring isotopes ^{92}Zr and ^{94}Zr only differ in mass by about 1%, making them difficult to separate. Additionally, the stable isobar ^{93}Nb with only one unit difference in proton number, needs to be suppressed significantly to achieve high sensitivity. In recent studies at the Maier-Leibnitz-Laboratory in Garching, different experimental approaches have been explored: Firstly, by using stacked passive absorber (SiN) foils, exploiting the energy loss difference of ^{93}Zr and ^{93}Nb, in combination with a time of-flight measurement and isotopic suppression of the neighboring isotopes by a Wien-filter. And secondly, using the gas-filled magnet system GAMS providing isobaric suppression, in combination with an ionization chamber with a five-fold segmented anode. Both techniques have shown excellent preliminary results with sensitivities for the atom ratio of ^{93}Zr/Zr in the range of 10^{-10} and 10^{-11}. This opens the door towards first applications. In this presentation it will be discussed in detail both isobaric and isotopic suppression methods. First measurements on real samples will be shown.

[1] E.P. Steinberg, L.E. Glendelin, Phys.Rev.78 (1950) 624

Isobar separation performance of the Tsukuba 6 MV AMS system

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A new horizontal-type 6 MV Pelletron tandem accelerator was installed at the University of Tsukuba in September 2014. The tandem accelerator is used for various ion-beam research projects, such as AMS, microbeam applications, particle-induced X-ray emission (PIXE) analysis for geoscience and materials research, heavy ion RBS and ERDA, nuclear reaction analysis for hydrogen, high-energy ion irradiation for semiconductor and nuclear physics. The rare-particle detection system on the tandem accelerator (Tsukuba 6 MV AMS system) is designed and constructed for the high-sensitivity detection of ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca, and ^{129}I, and is expected also to measure other radioisotopes, for example, ^{32}Si and ^{90}Sr [1]. It has two Cs sputtering negative ion sources: a 40-sample MC-SNICS for the routine measurement of all nuclides and a hybrid source with a 39-sample MC-SNICS equipped with a CO_2 gas introduction system with either graphite or CO_2 samples for ^{14}C AMS. The main accelerator (model 18SDH-2 Pelletron accelerator developed by NEC, USA) has a long gas stripper tube assembly and a foil changer with 80 foil holders for equilibrium stripping ions. Carbon stripper foil is mainly used for ^{36}Cl AMS to obtain chlorine ions in a high charge state. The rare-particle detection system has a 22.5° ESA (3.81 m radius) with a resolution of $E/\Delta E = 200$. A five-electrode gas ionization detector [2] is installed on the end station of the system. First experiments of multi-nuclide AMS such as ^{14}C, ^{36}Cl and ^{129}I have been performed since Feb. 2016. The background of the system for ^{14}C measurements using the 4+ charge state at 5.0 MV is reached to $^{14}C/^{12}C = 2.4 \times 10^{-16}$. ^{36}Cl measurement is performed with carbon foil stripping into the 7+ charge state at 6.0 MV. $^{36}Cl^{7+}$ with an energy of 48.0 MeV is injected into the gas ionization detector. We use a 150-nm-thick Si_3N_4 foil for the entrance window of the gas ionization detector, and the optimal isobutane gas pressure is estimated to be 28 Torr for ^{36}Cl/Cl. The ^{36}Cl is clearly separated from the ^{36}S in the gas ionization detector. The background of ^{36}Cl can reach even below $^{36}Cl/Cl = 10^{-15}$. ^{129}I measurement is performed with the 5+ charge state at 5.0 MV. ^{129}I AMS background is measured at the level of 10^{-14}. In this presentation, first tests and isobar separation performance of the Tsukuba 6 MV AMS system will be reported.

[1] K. Sasa et al., Nucl. Instr. Meth. B, 361 (2015) 124–128.
[2] C. Maden al., Nucl. Instr. Meth. B, 259 (2007) 131–139.

Time series analysis of rare/stable isotopic concentration AMS-data.

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Data generated from AMS facilities to derive the concentration of any given "rare" isotope relative to the abundant stable has a structure that follows a "time series" [1]. Proper analysis or the data in this framework allows a significant reduction of the error bars without changing the main average values. In this work 14C concentration measurements performed at LEMA (Mexico) are reanalyzed as time series as an example. A comparison with results obtained performing a current correction will be presented.

[1] 1- Achelis, Steven B; Technicall analysis from A to Z, second printing, McGraw-Hill, 1995.

Actinides isotopic analysis using a 1 MV AMS system

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The VEGA 1 MV AMS system at ANSTO has been custom-designed to cover analysis of a wide range of long-lived radioisotopes, including routine radiocarbon analysis and multiple-isotope analysis of actinides. The system incorporates 1.0 m radius injection and analysing magnets with off-axis cups on high and low mass sides. Following the analysing magnet, rare isotope beams pass through a 1m radius spherical electrostatic analyser and a 120° 1 m radius magnet. The detector station consists of a two-anode gas detector, with off-axis options to direct isotopes to either a Faraday cup or an electron multiplier ion counter. All three analysing magnets are fitted with electrostatic bouncer systems. At the LE end, the bouncer works in the usual way for all isotope combinations of interest, including ^{12}C-^{13}C-^{14}C and actinides. The HE bouncers are used to transmit a range of masses of interest for actinides analysis, for example mass 239 to 244 Pu isotopes. For uranium analysis, the less rare isotopes can be directed to off axis cups or the ion counter. Software has been implemented to enable a high degree of flexibility in analysing up to 8 isotopes at a time. In this paper we present details of the system and its performance and applications.

X-ray sterilization of insects and micro organisms for cultural heritage applications

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The APAM* Laboratory of the ENEA Frascati Research Center is engaged in the preservation of cultural heritage as part of the COBRA** project addressed to the transfer of innovative technologies and methodologies from research to small and medium enterprises involved in the restorative measures. This work is aimed to demonstrate the effectiveness of the ionizing radiation on the disinfection of biodegraded art objects.

The conventional methods for the disinfestation of works of art, using chemicals toxic for humans and environment, however cause some damage to the treated material even if on micrometric scale (i. e. either cellulose degradation).

Ionizing radiations interact with the infesting biological material causing an irreversible DNA degradation. For this reason, they are certainly suitable for removal treatments of micro and macro organism colonies or bacteria. A 5 MeV electron linear accelerator, normally dedicated to the characterization of dose detectors and radiographies, has been employed to produce X-Rays Bremmstrahlung by a Tungsten converter with 200 mA of electrons. The spectral fluence of the radiation source has been calculated using the Monte Carlo MCNPX code.

The dosimetric characterization of the radiation field has been made using radiochromic films sensitive in the dose range of our interest (from 100 to 10,000 Gy) calibrated with a Farmer ionization chamber. The irradiation of the artifact prototypes are made within a lead shielding room at a variable distance from the X-Rays source. Samples subjected to irradiation consist in a bacterium, Agrobacterium rhizogenes strain A4, and an insect, Stegobium paniceum, that are found as wall paintings invasive coloniser and as a pest of wood works and paintings, respectively. Tests of insect disinfection have been performed on woods volumetric mock-ups at different wood depth.

The growing capacity of the treated bacterial cells re-cultured at the end of the treatment was evaluated on the bacterial sample and resulted to quite rapidly decrease during postirradiation incubation so that after one and two overnight incubation periods at 28°C no significant cell growth was observed. The fraction of surviving insect vs absorbed dose and operative conditions has been also evaluated: 40% and 100% of the individuals encountered death immediately after the low dose treatment and after four days respectively. The experiments prove the ability to efficaciously treat objects of cultural heritage with X-Rays in order to prevent the increase of the biodeterioration without damaging the materials: in fact, mechanical tests on both irradiated and not irradiated woods have demonstrated the absence of any induced degradation after the radiation exposition.

*Development of Particle Accelerators and Medical Applications

** Sviluppo e diffusione di metodi, tecnologie e strumenti avanzati per la COnservazione dei Beni culturali, basati sull'applicazione di Radiazioni e di tecnologie Abilitanti

Simultaneous use and self-consistent analyses of μ-PIXE and μ-EBS for the characterization of corrosion layers grown on ancient coins

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The quantification of major, minor and trace elements in coins can give valuable information about metal and monetary circulation, the smelting processes used, and eventual counterfeiting. Particle Induced X-ray Emission (PIXE) and Elastic Backscattering Spectrometry (EBS) are non-destructive techniques that can determine the coin chemical composition fingerprint down to the ppm range. Surface inhomogeneities created by corrosion growth may hinder a proper quantitative analysis unless a micro beam is used, which allows the selection of small regions with different degrees of corrosion. Using 1.0 and 2.0 MeV proton beams from the nuclear microprobe (resolution 3×4 μm^2) located at the Laboratory of Accelerators and Radiation Technologies at CTN (Sacavém – Portugal), μ-PIXE and μ-EBS spectra were taken simultaneously, for two copper and four silver XVI century Portuguese coins. 2D-PIXE maps were acquired for all coins, followed by point analyses in selected regions.

A self-consistent solution is hard to reach when the PIXE and EBS spectra studied separately, as for these coins a single PIXE or EBS spectrum is not enough to obtain a unique solution describing a concentration profile changing with depth. Thus, a simultaneous analysis of these spectra was performed using NDF code [1]. Grazing incidence XRD was also performed on these coins in order to identify the compounds present in the corrosion layer, namely oxides, carbides, etc, and that were used as input for NDF. The simultaneous fitting procedure allowed the differentiation of the superficial corrosion layer from the uncorroded volume underneath (as exemplified in Fig.1).

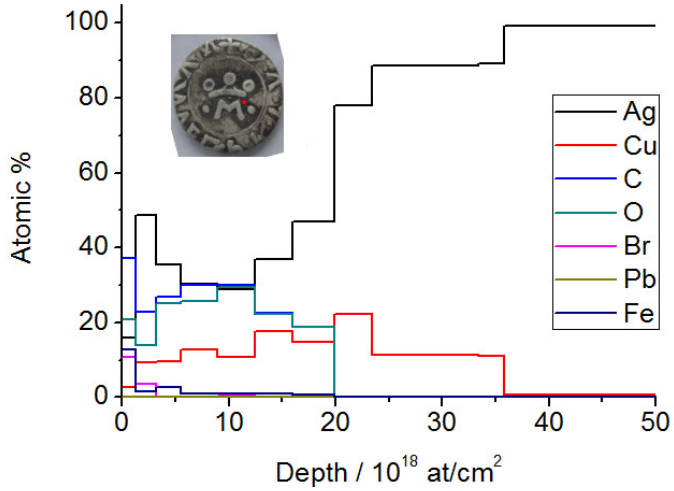

Figure 1: Elemental depth profile obtained by simultaneous μ-PIXE and μ-EBS spectra fitting with NDF (30×10^{18} at/cm^2 ≈ 1 μm). Coin: 5 Reais (Ag 916.6 - XVI century).

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Using AIFIRA external beam line to source obsidian artefacts in western Mediterranean contexts: new evidence on Middle Neolithic Sardinia

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Obsidian, together with flint, is quite certainly one of the best raw lithic materials capable of producing knapped objects. This volcanic glass is sometimes found in Neolithic sites at a far distance from the geological outcrops. Tracing back its origin has become a major issue in prehistoric archaeology. These provenance studies enable to identify exchanges, uncover ancient routes and contribute in some way to documenting the system and organisation of raw materials production [1].

As part of work led in Western Mediterranean contexts, PIXE measurements (Particle-Induced X-ray Emission) were carried out using the external beam line at the AIFIRA facility (Applications Interdisciplinaires des Faisceaux d'Ions en Région Aquitaine) of the CENBG (Centre Etudes Nucléaires de Bordeaux-Gradignan, France).

This method being strictly nondestructive, it is particularly well suited and efficient. The measurement of 15 elements (Na, Al, Si, K, Ca, Ti, Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr and Nb), obtained thanks to a Si(Li) detector coupled with a funny filter (and helium flux), allows for an easy discrimination between the four potential sources within the Tyrrhenian area (Lipari, Palmarola, Pantelleria and the volcanic massif of Monte Arci in Sardinia). Moreover, the method imposes few volumetric constraints, which is an important asset since it is possible to obtain accurate and precise results for artefacts presenting limited surface zones and thicknesses far below 3 mm.

In this presentation, we will focus especially on Middle Neolithic (5th millennium cal BC) sardinian obsidian assemblages in order to better comprehend the dynamics and the organisation of the exploitation of this raw material in a region directly connected to the source. These questions are of extreme importance mostly because sites situated in the direct acquisition area of the Monte Arci seem to have played a role in the building of exchange networks with overseas territories, driving therefore to the development of both cultural regionalisation and interaction between different groups in the Western Mediterranean.

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Micro-PIXE as an analytical method of choice in the search for the origins of ceramics shards found at the Grounds of the Royal Palace at Angkor.

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Angkor Thom, the former capital of the Khmer empire, was sacked by Thai armies and eventually abandoned in 1432. Its central Royal Palace district with its own walls provides a unique time capsule of a five hundred-year period between the time of the founding of the Phimeanakas temple around the 10th century and the sack of the city. Ancient artefacts, found at that site, must have been brought in before to 1432. The Royal Palace district has several pools that are occasionally dredged to remove the silt. The silt material excavated from the pool contained numerous shards of local ceramics and some porcelain fragments, which had the appearance of import ware from China. Some shards had a deep blue cobalt glaze typical of ware from the early Ming period. The presence of cobalt provided the opportunity to determine the origin of this element and thus help to determine whether the glaze used in the apparently Ming ware contained cobalt imported from the quarries of North Afghanistan.

The principal aim of the investigation was to examine the ability of elemental analysis performed with macro- and micro-PIXE method to identify the source of the cobalt used in the glazes of our samples. Furthermore, we made an attempt to localize the ancient kilns in China that may have produced the ceramics shards found in the Royal Palace district. The shards were first frontally irradiated with protons (Van de Graaff Generator), which provided the macro-PIXE element analysis. The shards were then transversally cut to ~2 mm slices and scanned with a proton micro beam (current ~100 pA) focused to a quadratic 1 micrometer spot. The proton beam energy ranged from 2 or 3 MeV according to the molecular weight of the elements desired for investigation. The X-ray emission from several rectangular scans with different magnifications at the shard surface was recorded with a 80-mm2 Si(Li) detector. The ratios of As/Co and Fe/Co determined from single cobalt grains, identified in the glaze, indicate that 'Su Ma Li Qing' (Samarra-blue), used as the cobalt pigment during the Yuan and early Ming Dynasty, is actually present in our samples. This type of blue pigment is characterized by high iron and arsenic but low manganese content. Finally, we calculated the ratios of Zr/Y and Rb/Y, for our two shards with the intention of finding similar pattern that may had been already reported in the literature. After some search, we were able to attribute the possible origins of the two shards to the kilns located in the provinces Hebei and Fuijan. This attribution was based on their close match to the composition of shard material found at these kiln sites. In conclusion, the porcelain shards found in the Royal Palace District were remnants of imported ware from two Chinese provinces, possibly during the early Ming Dynasty.

The experimental micro-PIXE analysis was done at the CANAM (Center of Accelerators and Nuclear Analytical Methods LM2011019) infra-structure at NPI ASCR v.v.i.

Multi-technique characterization of gold electroplating on silver substrates for cultural heritage applications

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Most of scientific studies of ancient gilded cultural heritage objects deal with the characterization of leaf gilding, fire gilding and other processes. Electroplating is the predominating technique for gilding cultural heritage metalworks since the 19th century when this technique substitutes the traditional fire gilding or amalgam gilding. However, the study and characterization of more modern electroplated gilded objects of the 19th and 20th century are scarce.

This work presents the detailed study of a series of silver plates gilded via electroplating techniques in which the characteristics of the coating gold layers and the interdiffusion profile across them are investigated as function of the electroplating variables (voltage, time, anode surface and temperature). Electroplating process was made on an electrolysis cell where high purity gold anodes (999.9 millesimal fineness) were dissolved in an electrolyte containing a gold-potassium cyanide plating solution (KAu[CN]). The rectangular silver plates (20x10x1 mm) to be gilded were disposed as the cathodes of the electrolysis cell. Their surfaces was pretreated with nitrate of mercury to amalgamate the surface by electrochemical replacement and were analyzed by means of atomic and nuclear techniques (SEM-EDX, EDXRF, PIXE and RBS) to obtain information about thickness, homogeneity, effective density, profile concentration of the gold layers and Au-Ag diffusion profiles.

Cross sections of the plates were taken and variable plating thickness was observed by SEM. On the other hand, the elemental composition of both the base metal and the plating was obtained by EDX microanalysis coupled to the scanning electron microscope. Portable EDXRF spectrometry and PIXE provided the elemental composition of the gold layers and substrates and these techniques were used as a tool to reconstruct the layered structure and determine the thickness and density of the plating. Diffusion profiles of the electrodeposited gold layers in the silver backings were obtained from RBS and related to the results using SEM-EDX, EDXRF and PIXE measurements. Electrodeposition times and voltage seriously influence the plating thickness, whereas that EDXRF, PIXE and RBS results were in agreement and indicated that the mass density of the electroplated gold layers are lower than nominal gold density values.

These analyses provide valuable information to historians and curators and can help the restoration processes of gold-plated silver objects.

Measurements of alpha particle induced reaction cross sections on ^{nat}Cd and ^{116}Cd for practical applications up to 50 MeV

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Compared to the proton and deuteron induced reactions alpha particle induced reactions are investigated only in special cases because of the less availability of particle accelerators able to produce intense alpha beams and the lower production yields. Because of the growing interest recently for the radioisotopes to be produced by alpha particle irradiation from cadmium (e.g. for medical applications [1]), it is worth to investigate the production possibilities both from natural and from enriched cadmium targets. The used natural targets were 15.6 μm commercial high purity foils, while the enriched ^{116}Cd was deposited on high purity 12 μm thick Cu backing. The average deposited thickness corresponds to 21.9 μm Cd thickness. The beam energy was adjusted and accurately measured by TOF (Time of Flight) methods [2,3] and turned to be higher than the nominal 50 MeV, i.e. 51.2 MeV. For cross section measurement the well-established stacked foil technique was used. Out of the Cd targets Ti foils were also inserted into the stacks for monitoring purposes. The Cu backing were also used for monitoring and recoil catcher in the case of enriched cadmium. The target foils were measured with gamma spectrometry and cross section values were determined for each measurable isotopes and energies.

In the case of the enriched ^{116}Cd irradiation the main goal was the measurement of the medically important unique radioisotope ^{117m}Sn [1]. Because the enrichment rate was not 100 %, some other contaminating radioisotopes were also measured, e.g. ^{117m}In. Our new cross section values were compared with the literature and with the results of theoretical model codes.

In the case of natural cadmium targets a series of radioisotopes could be measured, such as: ^{117m}Sn, ^{113}Sn, ^{110}Sn, ^{117g}In, ^{117m}In, ^{116m}In, ^{115m}In, ^{114m}In, ^{113m}In, ^{111}In, ^{110m}In, ^{109}In, ^{108m}In, ^{108g}In, ^{115}Cd and ^{111m}Cd. These results were also compared with the literature and with model codes. In both cases there were such isotopes where our new values were in good agreement with the previous measurements and/or with the results of model calculations in the overlapping energy range, but there are some isotopes where significant differences could be observed. In the case of some isotopes and energies our results have not been measured yet.

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[3] T. Watanabe et al., Proceedings of the 12th Annual Meeting of Particle Accelerator Society of Japan, p. 1198 (2015)

Commissioning of the full energy scanning irradiation with carbon-ion beams ranging from 55.6 to 430 MeV/u in NIRS-HIMAC

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To make the best use of the characteristics of a carbon-ion beam and provide flexible dose delivery, three-dimensional (3D) pencil-beam scanning is an ideal irradiation technique. As part of the efforts to achieve ion-scanning therapy, a new treatment facility equipped with a 3D scanning irradiation system was constructed as an extension to the existing HIMAC. The 3D scanning irradiation system has been utilized for treatment since 2011. At present, for depth direction, the hybrid depth scanning method has been employed, in which 11 beam energies ranging from 140 to 430 MeV/u are used in conjunction with the range shifter. To suppress the beam spread due the multiple scattering and the nuclear reaction, we have developed a full energy scanning method (FES). In FES, we prepared more than 200 energy steps with 1 or 2 mm intervals. To obtain the range of less than 1 mm without using an energy absorber such as a range shifter, the minimum energy is chosen as 55.6 MeV/u. Generally, a long time is required for accelerator tuning and beam commissioning tests for treatment by FES. In our presentation, we introduce the beam commissioning for FES in a short period of time and the performance of FES is evaluated.

PIXE and Zinc Histochemistry of Calcifying Aorta from Mice Overexpressing Alkaline Phosphatase in Vascular Smooth Muscle Cells

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The genetic overexpression of human tissue-nonspecific alkaline phosphatase (TNAP) in vascular smooth muscle cells ($Hprt^{ALP/Y}$; $Tagln\text{-}Cre^{+/-}$, here after referred to as TNAP-OE), triggers generalized aortic calcification (1). Aortic calcification localized in the medial vascular layer and appears early in life, in the absence of systemic changes in calcium, phosphate, or renal function. Then, TNAP-OE mice develops hypertension, cardiac hypertrophy and die prematurely (≃44 days) of heart failure. Two aortas from 14 days-post-natal (dpn) and three from 30 dpn male TNAP-OE mice were studied by PIXE and Zn-histochemistry. This study aimed to characterize calcium phosphate mineral, Zn content as well other biologically-relevant trace elements. Zn was studied with the aim to localize sites where TNAP is acting during initial mineralization, given that TNAP is a Zn-metalloenzyme and it is activated by Zn ions. Aortas were embedded in poly-methyl methacrylate, thin sections ($50-100$ µm thick) were prepared at 6-8 levels of the aorta. Broad beam PIXE analysis ($\varnothing = 1-2$ mm) were performed in selected sections from 14 dpn (1) and 30 dpn (1) aortas. Sections (100 µm thick) were glued with cyanoacrylate onto carbon (high-purity graphite) planchet and were analyzed twice, with and without Al filter, in order to detect P, Ca, S, Zn and other elements. The rest of the sections were stained for mineral (von Kossa, alizarin red), for organic matrix (toluidine blue, silver-methenamine), and for Zn-histochemistry after sodium sulfide treatment, with or without EDTA etching. In addition specificity for Zn staining was tested in synthetic bone mineral prepared with different Zn concentrations (17 ppm to 55,000 ppm). Mineral and Zn-content in aortic calcifications were compared with pelleted hydroxyapatite (bone ash) (NIST SRM-1400) and bovine bone (primary type). Comparing the aorta sections of 30 days vs 14 days, the PIXE data did not show a significant change of Ca or Zn but evidenced an increase of P and a change in the Ca/P ratio (from 3.63 to 2.42). Microscopy showed calcified deposits in the form of plaques and small stones localized in the media of the aorta at the level of and in between elastic fibers, Zn was located within and around elastic fibers as well as in the plasma membrane of vascular smooth muscle cells. The PIXE and Zn histochemistry data are compatible with the following mechanistic interpretation of events. In first instance, vascular smooth cells produce TNAP which diffuses impregnating elastic fibers as well as the calcified organic matrix, formed mainly by sulfated proteoglycans and glycoprotein, produced by the same cells. These sites are rich in Zn and contain S and, by concentrating first calcium and then phosphate, nucleate the initial mineral germ. Further mineral growth and maturation builds upon this initial seed of calcification. Thus, in this mouse model of generalized aortic calcification, TNAP seems to be implicated as a matrix protein acting to initiate calcification while embedded in the extracellular matrix.

[1] Sheen et al. J Bone Miner Res. 2015 May, 30(5):824-36. doi: 10.1002/jbmr.2420.

Proposal for facility design of carbon-ion radiotherapy

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In 1994, the National Institute of Radiological Sciences (NIRS) in Japan has been successfully conducted clinical application of carbon ions generated by Heavy Ion Medical Accelerator in Chiba (HIMAC), which is the world's first accelerator facility dedicated to medical application. Owing to good results and accumulated number of protocols, the carbon-ion RT with HIMAC was approved in 2003 as highly advanced medical technology by the Japanese government.

Then, NIRS proposed a downsized and cost reduced facility in order to boost application of carbon-ion RT. A pilot facility as the downsized carbon-ion RT facility was constructed in Gunma University, which has three treatment rooms with 4 beam-delivery systems based on the broad-beam method. The facility size was downsized to be one-third of the HIMAC (1). On the basis of the technology developed, a carbon-ion RT facility, which is called Saga-HIMAT, was constructed and successfully operated. On the other hand, NIRS has developed the fast 3D-scanning method as a new treatment research project, which makes a respiratory-gating irradiation also be possible. Further, a superconducting rotation gantry has been developed and is in a beam-commissioning stage. The NIRS 3D-scanning technology was transferred to the construction of the carbon-ion radiotherapy project (i-ROCK) in Kanagawa cancer center (2).

On the basis of the NIRS development experiences, the design considerations of carbon-ion RT facility will be presented to offer an optimum design for user's operation, which are with viewpoints such as number of rooms, irradiation methods and needs of a rotating gantry.

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[2] K. Noda et. al., NIM B, 331 (2014) 6-9

Development of a new ridge filter with honeycomb geometry for a pencil beam scanning system in particle radiotherapy

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Thanks to its characteristic depth-dose distribution with a Bragg peak, particle radiotherapy provides high dose localization to a tumor and is an effective tool for cancer therapy. The National Institute of Radiological Sciences (NIRS) in Japan has provided the particle radiotherapy with carbon-ion beam since 1994 using the Heavy-Ion Medical Accelerator in Chiba (HIMAC). To maximize characteristic advantage of the carbon-ion beams, the NIRS introduced a three-dimensional (3D) pencil beam scanning system in 2011[1]. The pencil beam scanning system achieves conformal dose distribution to the tumor by superposing a dose deposit of the individual pencil beam. Since the high irradiation accuracy of beam position is required due to the sharpness of the Bragg peak, a device called as ridge filter[2] is usually used to spread the Bragg peak size. The ridge filter has periodic stepped structure in one direction and a unit of the stepped structure called as a ridge bar. Since the energy loss of the scanned pencil beam depends on the thickness of the ridge bar the beam passed through, the energy distribution of the beam is spread.

When the lateral pencil beam size is constant, the ridge filter with densely packed ridge bars is preferred because the particles with different energy are more mixed and the Bragg peak spread as planned. Since the pencil beam with smaller lateral beam size provides higher dose conformation the tumor, the pencil beam size has been improved to be small approximately 1-2 mm. Recently, it is difficult to pack the sufficient number of ridge bar within the lateral pencil beam region due to manufacturing limitation and a new designed ridge filter is required to realize more accurate irradiation by using the pencil beam with smaller beam size.

We have designed the new ridge filter with honeycomb geometry. The new ridge bar has a structure stacked a hexagonal plate and the ridge bar is periodically arranged to be honeycomb geometry. Since the packed density of the new ridge bar is higher than that of the conventional ridge bar, it is expected that the new ridge filter with honeycomb geometry gives the spread Bragg peak as planned when the beam size is below 1 mm.

We have verified the advantages of the new ridge filter with honeycomb geometry by the calculation using particle tracking and the measurement of dose distribution. We will show the measurement and calculation results and that the new ridge filter is more useful for the pencil beam scanning with the smaller beam size.

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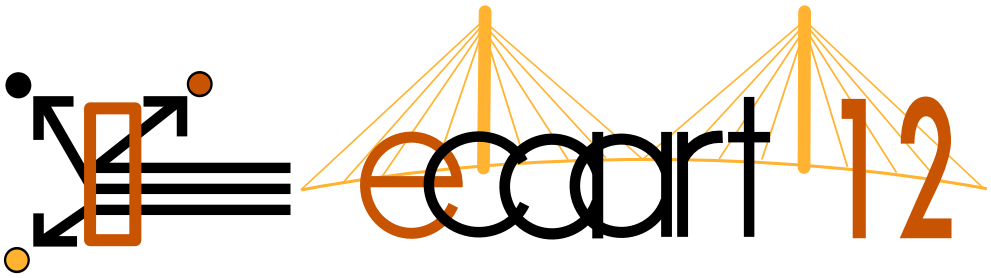

Abstracts

Posters

Session B, Thursday

Measurement of proton elastic and inelastic scattering cross section on Al from 2.5 to 4.1 MeV

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The knowledge of the cross sections for the inelastic scattering of MeV energy protons on nuclei with relatively low lying nuclear levels (up to several hundreds of keV) can be important when performing quantitative analysis of thick multielemental samples with the elastic backscattering spectrometry (EBS) technique. Indeed such a knowledge is necessary to efficiently disentangle possible overlapping shapes in the spectra due to both elastic and inelastic peaks from the different elements. Differential cross sections for the elastic and inelastic scattering of proton on aluminum, $^{27}Al(p,p_0)^{27}Al$, $^{27}Al(p,p_1)^{27}Al$ and $^{27}Al(p,p_2)^{27}Al$, from the first two excited levels of ^{27}Al at 843.8 and 1014.6 keV respectively, have been determined for proton energies between 2.5 and 4.1 MeV, using a variable energy step from 3 to 10 keV and for a scattering angle of 150°. The measurements were carried out at the HVEE 3 MV Tandetron accelerator at the INFN LABEC laboratory in Florence [1]. A 29 $\mu g/cm^2$ Al target evaporated on a self-supporting thin Ag film (102 $\mu g/cm^2$) was used. Absolute cross sections are calculated with a method not dependent on the absolute values of collected beam charge and detector solid angle, normalizing to the Rutherford cross section of protons on Ag; the overall accuracy is estimated to be around 5% at all the beam energies. To validate the obtained results, several benchmarking measurements were performed, using a thick pure Al foil. The experimental data are compared to data from the literature and similarities and discrepancies are presented and analysed.

[1] Chiari et al., NIM B 332 (2014) 355–358

X-ray production cross sections induced by 15–55 MeV ^{35}Cl, ^{79}Br and ^{127}I ions for selected elements

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The emission of x-rays as a result of the atomic excitation with protons and alpha-particles has been widely studied during past decades. When heavier ions are used as bombarding particles, the processes involved are more complex and their effects have not been fully described neither by theories nor experiments. However, there is an increasing interest in the application of heavy ions for analysis with particle induced x-ray emission (PIXE), as it can be used simultaneously with other heavy ion based techniques (ERDA, MeV-SIMS). In addition, the possibility of selective excitation and higher ionization cross sections with heavy ions could improve the sensitivity of PIXE.

As targets for x-ray production cross section measurements, ALD grown thin oxide, nitride and pure element films on silicon or carbon substrate were selected. Thicknesses of the films were from 30 nm to 150 nm. Thicknesses of the targets we selected so, that these can be considered as thin targets in the cross section measurements, but still thick enough to give satisfactory count rate for the x-ray and ERDA detectors. Elemental compositions and areal densities of targets used in the experiments were measured by TOF-ERDA.

X-ray production cross sections induced by Cl, Br and I ion beams within the energy range of 15–55 MeV for Ti, Cu, Zr, Nb, Ru, Ta and W have been measured at the 5 MV tandem accelerator of University of Helsinki. The x-ray spectra were measured simultaneously with TOF-ERDA spectra, which allows accurate beam fluence determination. For beam current monitoring, the direct current measurement from the target holder was improved by installing an electron suppression net, set at a potential of -300 V, surrounding the target. In this connection also a method based on the utilization of the beam profilometer signals was used. Determined ionization cross sections are compared with the predictions of the ECPSSR theory.

Approach for Realization of High Intensity Cyclotron Beam

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Demands of radionuclide for medical use are expected to increase rapidly from now on. Radionuclides will be used for nuclear medicine not only for diagnostic purposes such as positron emission tomography (PET) and Single-photon emission computed tomography (SPECT), but also for targeted radionuclide therapy (TRT). It would also be applied to a cancer treatment with the use of radioactive ^{11}C beam irradiation, which enables simultaneous imaging of irradiated field of the patient by the use of Open-PET during treatment. High intensity beam is inevitable for radionuclide production to realize such applications. At NIRS of QST (National Institutes for Quantum and Radiological Science and Technology), there exist a cyclotron NIRS-930 [1] (Thomson-CSF, Kb=110 MeV, Kf=90 MeV) and two small cyclotrons used exclusively for short-lived radionuclide production. We are aiming to improve intensity of NIRS-930. For the purpose of increasing the beam intensity, it is important to understand the beam behavior and the cause of beam loss. As we can measure beam loss at the limited points where the prove electrodes exist, we need a simulation of beam in the cyclotron using computers in order to get more precise information related to beam losses. There exist some simulation codes for ion beam in cyclotron considering space charge effects. We utilized SNOP code [2], which was developed at JINR, because it is superior in simulating the beam of whole cyclotron from injection to extraction. The electric or magnetic fields of each element were calculated with TOSCA [3]. Simulation study at NIRS-930 using SNOP code reproduced the beam parameters in case of harmonic 1 [4]. Then we performed the simulation of 18 MeV protons with harmonic 2, which is one of the most commonly used beams for radionuclide production now. In the present paper, simulation studies for finding better operating parameters and upgrading scheme will be presented.

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Charge Collection Efficiency in Segmented Semiconductor Detector interstrip region

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Charged particle semiconductor detectors have been used in Ion Beam Analysis (IBA) for over four decades without great changes in either design or fabrication. However one area where improvement is desirable would be to increase the detector solid angle so as to improve spectrum statistics for a given incident beam fluence. This would allow use of very low fluences opening the way for example to increased time resolution in real-time RBS or analysis of materials that are highly sensitive to beam damage. In order to achieve this goal without incurring the costs of degraded resolution due to kinematic broadening or large detector capacitance, a single-chip segmented detector (SEGDET) was designed and built within the SPIRIT EU infrastructure project. In this work we present the Charge Collection Efficiency (CCE) in the vicinity between two adjacent segments focusing on the interstrip zone. Microbeam Ion Beam Induced Charge (IBIC) was used to perform X-Y mapping of CCE with different ion masses and energies, as a function of detector operating conditions (bias voltage changes, detector housing possibilities and guard ring configuration). We show the CCE in the active area edge region and have also mapped the charge from the interstrip region, shared between adjacent segments. The results indicate that the electrical extent of the interstrip region is very close to the physical extent of the interstrip and guard ring structure with interstrip impacts contributing less than 8% to the complete spectrum. The interstrip contributions to the spectra can be substantially reduced by an offline anti-coincidence criterion through the list mode data analysis, which should also be easy to implement directly in the data acquisition software.

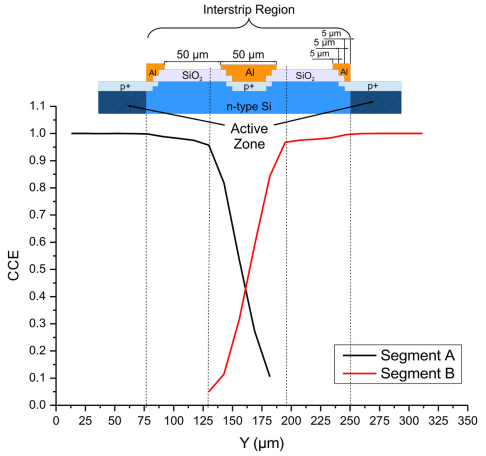

Figure 1: Interstrip region schema (top) and Charge Collection Efficiency of 4.5 MeV protons for 30 V detector bias and floating guard ring, between two adjacent segments (A and B) including the interstrip region (bottom).

Calibration of an analysing magnet using the $^{12}C(d,p)^{13}C$ nuclear reaction with a carbon thick target*

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It is known that the absolute energy of an ion beam produced by an accelerator is usually determined by a magnetic analyzer, which must be calibrated. Various methods for accelerator energy calibration are extensively reported in the literature, like nuclear nuclear reaction resonances, neutron threshold, time of flight, etc.

This work reports a simple method to calibrate the magnet associated to a vertical 5.5 MV Van de Graaff accelerator. The method is based in bombarding with deuterons beam, at different bombarding energies, a thick carbon target and measuring with a surface barrier detector the particle energies spectra produced. The analyzer magnetic field "H" is measured for each spectrum and the beam energy is deduced by the best fit to de the spectrum using the $^{12}C(d,p)^{13}C$ nuclear cross sections available in the IBANDL (Ion Beam Nuclear Data Library).

Keywords: C; NR; 12C(d,p)13C; analyzing magnet calibration;
Work was financial supported by the DGAPA –IN102015 project

Study of sputtering yield amplification of Al, Si and C by ion beam analysis and CO-SS*

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Magnetron sputtering is widely used to produce thin films. An important application is to make multicomponent thin films where two or more elements are included in the cathode. The thickness and chemical composition of the films depend on the experimental parameters used, the system geometry and the spatial distribution of the elements in the target. If the target is made of two, or more, spatially separate pieces of different materials then the composition of the deposit will depend on a combination of the relative areas and the sputtering yield of each material.

CO-SS: Co-Sputtering Simulation is a freeware developed by the authors to simulate the spatial variation and composition of the deposition by magnetron sputtering and co-sputtering technique. In this study thin films of AlTi, CW and SiW were produced to study the modification of the sputtering yield both experimentally and by modelling using CO-SS. The 4" x ¼" sputtering targets were of high purity Al, C and Si and the sputtering conditions was maintained at 20 sccm of argon, a gas pressure of 30 mTorr and a plasma power of 40 watts. A series of thin films was prepared of the pure metal or with 1, 2 or 3 small pieces (0.7×2.5 cm) of the second material (Ti or W) placed on the racetrack directly above the 2.5×7.5 cm glass substrates. The substrates were placed such that they received material from both the uncovered and covered parts of the racetrack.

The spatial variation of the thickness and composition of the films was determined by profilometer and the ^{4}He RBS technique, respectively. The results showed the existence of sputtering yield amplification of Al, C and Si.

Keywords: AlTi; CW; SiW; CO-SS: Co-Sputtering Simulation; RBS; sputtering yield amplification. *Work was financial supported by the DGAPA –IN102015 project

Composition and source apportionment of fine particulate matter during extended calm periods in the city of Rijeka, Croatia

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In the city of Rijeka, Croatia, an extended, two-year aerosol pollution monitoring campaign was recently completed. During that period, 345 samples of fine fraction of aerosols were collected on stretched Teflon filters. All samples were analyzed by Ion Beam Analysis techniques (PIXE and PIGE) and concentrations of 22 elements were determined. Concentrations of black carbon were determined by Laser Integrated Plate Method.

For the Bay of Kvarner, where city of Rijeka is located, common are long periods of calm weather. As a consequence, during these periods, air pollution is steadily increasing. To pin point and characterize local, mostly industrial, air pollution sources, we used only samples collected during the extended calm periods. Speed of 1.5 m/s was used as a cut-off wind speed. In this way, 188 samples were isolated and statistically evaluated by means of Positive Matrix Factorization. The results show that the major, local pollution sources are the following: secondary sulfates, heavy oil combustion, auto, smoke, road dust, industry iron and port activities. As expected, natural components of aerosol pollution such as soil and sea salt are dramatically reduced.

Keywords: Fine particles, PM2.5, Ion beam analysis, LIPM, Positive Matrix Factorization, Air pollution sources

Studies on Pd and Mg thin films coated PMMA foils by magnetron sputtering

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Polymethylmethacrylate thin foils were prepared by physicochemical processes. By changing their density the clear and opaque foils were obtained. DC magnetron sputtering method was used for covering the foils with Pd and Mg metal layers. The high absorbent foils were obtained producing PMMA microbeads and metallic coatings.

Rutherford Backscattering Spectroscopy, optical and morphological studies were performed to characterize the prepared foils useful in the field of laser-matter interaction.

Analysis of trace elements in lake sediment samples by PIXE spectrometry

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Abstract This work aims to determine the elemental composition of lake sediments, in order to contribute to the characterization of their origin and evolution, in complementary mode by Particle Induced X-Ray Emission (PIXE) technique using the 3 MV TandetronTM particle accelerator from the National Institute for R&D in Physics and Nuclear Engineering "Horia Hulubei" (IFIN-HH), Magurele-Bucharest, together with Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) technique at Multidisciplinary Research Institute for Science and Technology from Valahia University of Targoviste (ICSTM-UVT). Sediment cores were collected from three lakes (i.e. Amara Lake, Câineni Lake and Movila Miresii Lake) in August 2015. The sediments were collected from shallow depths of water, 1 to 3 m by means of a floating platform, using the piston corer, and then the samples were transported on ice and stored in a freezer at -18 °C. The sediment column was cut longitudinally, analyzed by microscopy and digital photographed. Volumetric sampling was continuously performed for the composite profiles with 2 cm resolution. The qualitatively and quantitatively determining of chemical composition and distribution of elements on the surface of samples, as well as the surface morphology of sediments was performed by using scanning electron microscope (SEM) SU-70 Hitachi, coupled with an energy dispersive spectrometer (EDS). Analysis for a suite of metals rather than just target anthropogenic metals (e.g. Pb, Cu, Zn, Mn, Cd, Fe) was performed by using PIXE method and ICP-MS technique in order to a well interpretations about the sources of different chemicals. The obtained high content of several elements including Cu, Fe and Zn in sediment samples is correlated with their sources.

Keywords: PIXE spectrometry, ICP-MS, sediment, elemental composition.

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Characteristics of metal nanometric layers deposited on n-GaSb (100)

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Among III-V semiconductor compounds, gallium antimonide (GaSb) is of special interest as a substrate material for device applications, as laser diodes with low threshold voltage, photodetectors with high efficiency, high frequency devices or to high efficiency thermophotovoltaic (TPV) cells [1]. GaSb is a III-V compound with zinc blende crystal structure and with an energy gap of 0.726 eV and is worth to mention that the PV structure GaAs/GaSb had set a record solar efficiency of 35%, in this view opening a new era for photovoltaic applications.

The problems related to the formation of ohmic contacts on n and p-GaSb represent a technological skill considered in general a real state-of-art in obtaining semiconductor devices [2].

In this work we have systematically investigated the characteristics of Au/Ge/Ni contact layers deposited in vacuum (8×10^{-2} Torr) on n-GaSb and annealed at relatively low temperature (3000°C).

The deposited layers were investigated by Rutherford Backscattering Spectrometry using a 3 MeV $^4He^{++}$ beam extracted from the Alphatross ion source of the 3 MV Tandetron accelerator of IFIN-HH. The RBS experimental spectrum was fitted using the code RUMP [3,4].

The deposited layer is 1500×10^{15} at/cm^2 thick. Au and Ge are found with a 2:1 Au to Ge ratio. Ni is present only in the first 500×10^{15} at/cm^2 of the layer with a slightly decreasing concentration from 55% down to 15%.

The RBS measurements were complemented by XPS measurements on native n-GaSb(100) of Ga 3d line and Sb 4d line, and also with the depth profiling measurements of AuGeNi contact using Multiple Surface Analysis SPECS based on Phoibos 150 electron analyser. The characteristics of the annealing process were investigated by a HRTEM system.

The information extracted from different experiments is used in the effort of understanding material preparation in order to develop a competitive photosensitive Schottky device for terrestrial application.

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The study of H and D depth profiles in tungsten and steel samples by ERDA and complementary IBA techniques

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Different kinds of steel and tungsten samples after exposure in hydrogen and deuterium environment and after low energy hydrogen implantation were studied by ERDA, RBS and PIXE analysis at multipurpose target chamber on 3 MV TANDETRON accelerator at NPI in Rez. The methods limitation, detection limits and influence of sample composition, surface roughness and experimental arrangement on final results are of great importance especially in these kind of samples where the balk concentration of H a D are very low and the surface of samples is not perfect. The search for optimal experimental conditions with respect to stopping foil composition, thickness and homogeneity, primary beam energy and ion type (He, Li, O), beam and detection geometry will be discussed in our contribution.

This work has been supported by the GACR project 14-12837S and it was done at the CANAM (Center of Accelerators and Nuclear Analytical Methods LM2011019) infrastructure at NPI ASCR v.v.i.

Simulations of time-of-flight ERDA spectrometer performance

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The performance of a time-of-flight spectrometer consisting of two timing detectors and an ionization chamber energy detector has been studied using a Monte Carlo simulation for the recoil creation and ion transport through the sample and detectors. For the purposes of this study the code MCERD [1] was used, with modifications to calculate recoil cascades in the gas ionization chamber.

The ionization chamber pulses have been calculated using Shockley-Ramo theorem in 2D and the pulse processing of a digitizing data acquisition setup [2] has been modeled. These simulations model the Frisch grid inefficiency, pile-up and range related variations in gas ionization chamber anode and cathode pulse shapes.

Complete time-of-flight–energy histograms were simulated under realistic experimental conditions. The simulations were used to study instrumentation related effects in coincidence timing and position sensitivity, such as background in time-of-flight – energy histograms. Corresponding measurements were made and simulated results are compared with data collected using the digitizing setup.

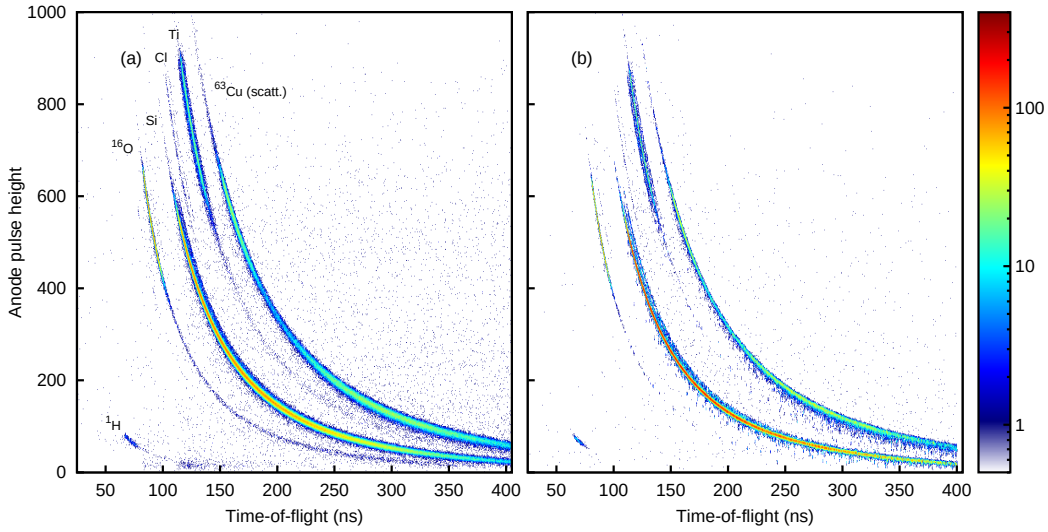

Figure 1: TiO_2 sample measured (a) and simulated (b) with a 13.3 MeV ^{63}Cu beam. The number of coincidence counts per second was approximately 1300 in both cases.

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Micro-PIXE analysis and imaging of Radio-photoluminescence glass beads dosimeter designed for micro-dosimetry

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There has been increasing interest of micrometer-scale radiation dosimetry for medical applications of high-energy particles where the radiation effects to organs must be carefully handled [1,2]. Several researches have been proposed accurate dose monitoring with solid materials including semiconductors and scintillators [3,4]. However, convenient and accurate dosimetry is not still fully accomplished with ideal sensitivity to primary ionized radiation independent of secondary-generated and background radiations. On the other hand, interesting properties of radio-photoluminescence (RPL) from phosphate glass dosimeters with copper activators were reported under exposure to different types of ionized radiation [5]. The effect of high and low linear energy transfer (LET) radiation was separately appeared in the spectrum of RPL. These RPL glass dosimeter could be an alternative candidate of micro-dosimetry device if its structure could be modified in the scale of micrometer. In this study, we have developed sub-millimeter size radio-photoluminescence glass beads dosimeter with silver and copper-activators. To evaluate elemental composition of these RPL glass beads dosimeters, a focused 3 MeV proton microbeam was employed for micro-PIXE analysis and imaging in scale upto 800 um x 800 um. The results suggested that the fabricated RPL glass beads dosimeter had uniform elemental distribution of both luminescence centers of silver and copper. RPL response of RPL glass dosimeter was also evaluated by ion beam induced luminescence analysis. Results suggested that fabricated RPL glass beads dosimeters had basic properties for particle dosimetry.

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Minimum detection limit and applications of proton and helium induced x-ray emission using transition-edge sensor array

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Superconducting transition-edge sensor (TES) can be used as a x-ray microcalorimeter, when the temperature change of the absorber material is detected using superconductor between its superconducting and normal state. This allows the detector to reach an energy resolution as low as 1.8 eV [1] at 5.9 keV. These detectors have seen many applications and one of them is particle-induced x-ray emission, PIXE. The energy dispersive detection, great energy resolution, and good detection efficiency have all been demonstrated before making TES an appealing choice for x-ray detection in PIXE [2, 3].

The TES-array at the University of Jyväskylä consists of 160 pixels each with a unique energy calibration, energy resolution, and efficiency. The detector array is cooled down to 65 mK using an adiabatic demagnetization refrigerator, ADR. The system stays in operation temperature for circa 12 hours, after which a regeneration cycle of 2–3 hours is needed. The energy resolution of the best pixel has been shown to be 3.1 eV [2] at 5.9 keV. The detection system is in high vacuum, and a 125 µm thick Be filter is used to stop backscattered ions and three IR filters stages at various temperatures are used to minimize the heat transfer via thermal radiation.

In this paper, we will determine the minimum detection limits (MDLs) of elements heavier than silicon for both bulk samples (in mg/kg) and thin film samples (in at./cm^2). MDLs are determined by measuring standard reference materials and detection limits for both proton and helium beams are measured. MDLs of the TES-array and a silicon drift detector (SDD) are compared. The potential of TES-PIXE in the analysis of biofuel ashes and paint pigments will be discussed.

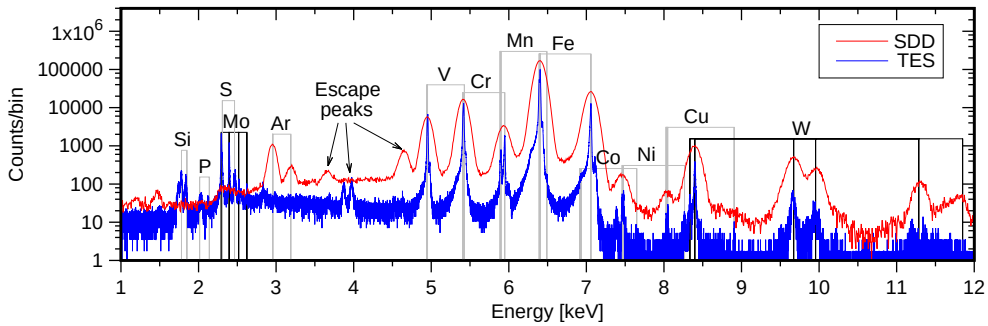

Figure 1: NIST reference sample, SRM 1157 – tool steel, measured with proton beam using transition-edge sensor, TES, array and silicon drift detector, SDD.

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Atomic Layer Deposition of $TiAl_xN_y$ and $TiAl_xC_y$ Thin Films

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MAX-phases are a group of nitrides and carbides which combine properties of metals and ceramics. Atomic layer deposition (ALD) can provide conformal thin films even on high-aspect-ratio structures. MAX-phase thin films have not been deposited using ALD.

Roughly 100 nm thick $TiAl_xN_y$ thin films were deposited on silicon substrate using common precursors $TiCl_4$, $(CH_3)_3Al$ and NH_3. Deposition temperature was varied bet-ween 325–450 °C. Deposited films were annealed at 600–1000 °C in vacuum and N_2-atmosphere. Films were investigated using broad range of charecterization methods including time-of-flight elastic recoil detection analysis (ToF-ERDA), X-ray diffractometry, X-ray reflectometry, Raman spectroscopy, ellipsometry, helium ion microscopy, atomic force microscopy and 4-point probe measurement for resistivity.

The Ti:Al ratio in asdeposited films was found to linearly depend on $TiCl_4$:$(CH_3)_3Al$ pulse ratio. Higher deposition temperature yielded more Al-rich films. Nitrogen content was independent of deposition temperature and Ti:Al ratio. Films contained hydrogen and carbon as main impurities but also a few atomic percent of chlorine was detected. The oxygen content in films was below 0.2 at.%. Impurity content decreased with increasing deposition temperature. Films were mostly amorphous containing small scattered TiN and AlN crystals a few nanometers in size.

During post-deposition annealing impurity oxygen was incorporated in films while other impurities decreased. Films deposited at higher temperature were found to be more oxidation resistant than films deposited at lower temperature. Crystallinity was only slightly increased after annealing.

In addition $TiAl_xC_y$ films were deposited at 500 °C using $TiCl_4$ and $(CH_3)_3Al$. Films were carbon rich containing only few atomic percents of aluminum. Similar to nitride films, $TiAl_xC_y$ films were mostly amorphous and contained only small TiC crystals.

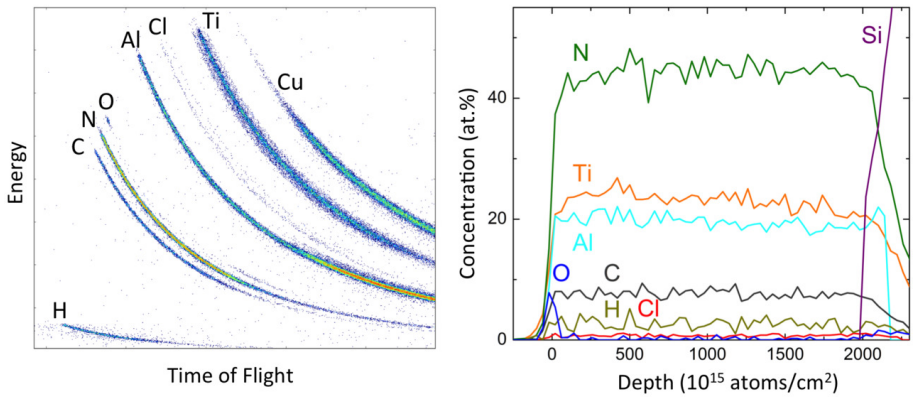

Figure 1: A raw ToF-ERDA histogram (left) of $TiAl_xN_y$ film deposited on silicon at 450 °C and corresponding depth profile (right). Measurement was done using 13.615 MeV $^{63}Cu^{7+}$ beam.

Tang dynasty (618–907) bowl measured with PIXE

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Brownish bowl (Fig. 1) originating from an underwater shipwreck located near Belitung island in the Java Sea, some 600 km south-east from Singapore, has been measured with particle induced X-ray emission. The Belitung shipwreck [1] is the wreck of an Arab dhow which sailed from Africa to China around 830 AD, but never returned from the journey. The wreck holds some 60 000 items, including Ghangsha ware like the one we measured. Our task was to determine the possible origin of the bowl in question, and the composition of glazing, ceramic body and bluish pigments.

The bowl was measured using 3 MeV proton beam from the 1.7 MV Pelletron accelerator at the Accelerator Laboratory of the University of Jyväskylä. Sample and references (NIST SRM 611, 1157) were measured in atmosphere where the beam was brought through the 200 nm thick Si_3N_4 window. Silicon drift detector with an effective area of 17 mm^2 from Amptek was used to collect the characteristic X-ray photons from the 2.5 mm diameter measurement spot. Measurement spots included thinner glazing with pigments, thick glazing and the ceramic body of the bowl.

The cobalt content of the blue pigments was very small, the bluish color originates from a copper oxide. A matching composition of elements for similar measurement spots from the shards found from the Changsha kiln site heas been measured earlier [2,3]. If compared to other references from other kiln sites (Fig. 1), the measured bowl has the closest match to the claimed origin at the Changsha kiln site, dated to the Tang dynasty period of 618–907.

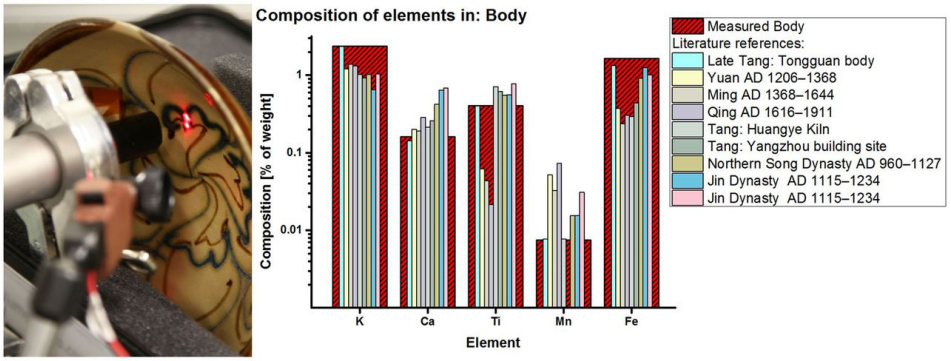

Figure 1: Tang Bowl from the Belitung shipwreck with measured body clay composition compared to reference studies.

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The stopping power and energy straggling of H and He ions in a graphene oxide

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The understanding of deceleration processes in graphene-based materials is of high interests as data are scarce [1]. Graphene is an interesting material with excellent electronic [2], mechanical [3], and thermal properties [4].

In this work, we performed measurements of the energy loss and straggling of the 2 – 9 MeV H^+ and He^+ ions in graphene oxide foils. The experiments were based on a transmission technique, where the ions scattered from a very thin gold layer are penetrating the graphene oxide foil and are registered by Ultra Ortec detector. Parameters in the experiments were chosen according the ion projected range (to avoid any problems caused by ion implantation), so that Bragg peak was out of the material. Thicknesses of the graphene-oxide foils were determined using detail image analysis of a grapheme oxide cut, which was used for refining the density of the graphene oxide foils. The density of the graphene oxide foils were verified by a standard technique of the microbalance weighing. The stoichiometry of the graphene oxide foils before the irradiation were determined by Rutherford backscattering spectrometry (RBS) and elastic recoil detection analysis (ERDA) using 2 MeV He^+ beam. The measured energy stopping powers H^+ and He^+ ions in graphene oxide are compared with the predictions obtained from SRIM-2013 and MSTAR codes. The energy straggling is compared with those calculated using Bohrs, Bethe-Livingston and Yang predictions. The measured energy straggling values of the graphene oxide foils irradiated by H^+ and He^+ ions were corrected for the foil roughness and thickness inhomogeneity using Besenbacher's approach, where parameters were taken from AFM measurement.

The results show that the stopping power of the H^+ and He^+ ions irradiated graphene oxide foils decreases with increasing energies, the differences between measured and calculated values being below 3.8%. The energy straggling determined in our experiment was obtained higher than Bohr's was and Bethe-Livingston predicted value; the predictions by Yang are in better agreement with our experiment. The Yang formula systematically underestimates the measured values with an average deviation of about 8–25% and 15–34% for thin and thick graphene oxide foils.

The research was realized at the CANAM (Center of Accelerators and Nuclear Analytical Methods) infrastructure LM 2011019 and has been supported by project GACR 16-05167S.

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Accurate accelerator energy calibration using selected resonances in proton elastic scattering and in (p,γ) and (p,pγ) reactions

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The sufficiently accurate and simple energy calibration of accelerators needed in many ion beam applications, faces a series of important practical problems for proton beam energies above about 2–3 MeV. Several commonly applied resonance reactions are available at low proton energies, typically up to energies of about 2 MeV.

The present work aims at contributing in this field by providing a set of standard, high-accuracy nuclear resonance reaction data points to be used for accelerator energy calibration up to 3.8 MeV, more specifically with the use of the ^{27}Al(p,γ), ^{13}C(p,γ), ^{12}C(p,p) and ^{32}S(p,pγ) resonant reactions, as a result of a comprehensive investigation in two different laboratories. The use of resonances at higher energies, namely up to 6 MeV, is also investigated and discussed. The measurements have been performed in two different electrostatic accelerators, namely at the 5.5 MV HV TN-11 one at the NCSR "Demokritos", Greece, and at the 5 MV 15SDH-2 Pelletron tandem accelerator in Uppsala, Sweden. Common points are used to normalize and validate the data.

The use of the ^{16}O(p,p) resonance at 3.47 MeV is also discussed and the overall accuracy of the technique is thoroughly analyzed.

The Design and Fabrication of a Time of Flight -Energy Spectrometer at Korea Institute of Science and Technolog

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The design and fabrication of a time of flight-energy (TOF-E) spectrometer for elastic recoil spectra analysis by heavy ion bombardment at Korea Institute of Science and Technology (KIST) is reported. The aim was to improve the elemental resolution and to lower the detection limit relatively poorer in standard backscattering spectrometry. The spectrometer is composed of two time detectors and an energy detector. A commercial solid-state silicon detector (ORTEC BF-018-100-60) is used for energy measurement, the time-detector is electrostatic mirror type which are popular in the TOF business of the MeV ion or recoils[1][2]. Each time detector is composed of a diamond like carbon (DLC) film that emits electrons when an ion passes through, an electrostatic mirror mesh that reflects the secondary electrons while maintaining large ion beam transmission, and an off-axis micro-channel plate (MCP) for electron detection. The electrostatic mirror is composed of gold coated tungsten wires that are electrically welded on a stainless steel rectangular window. SIMION 8.1 was used to model the DLC to MCP electron reflection components to test the design and determine voltage requirements. The spectrometer was incorporated with the 2 MV Pelletron accelerator at KIST to test the performance characteristics-efficiency and resolution. Later, this spectrometer will be incorporated into an ion beam analysis line on the 6 MV Tandetron accelerator system at KIST in order to inspect thicker film analysis using the gas ionization chamber (GIC) as the energy detector.

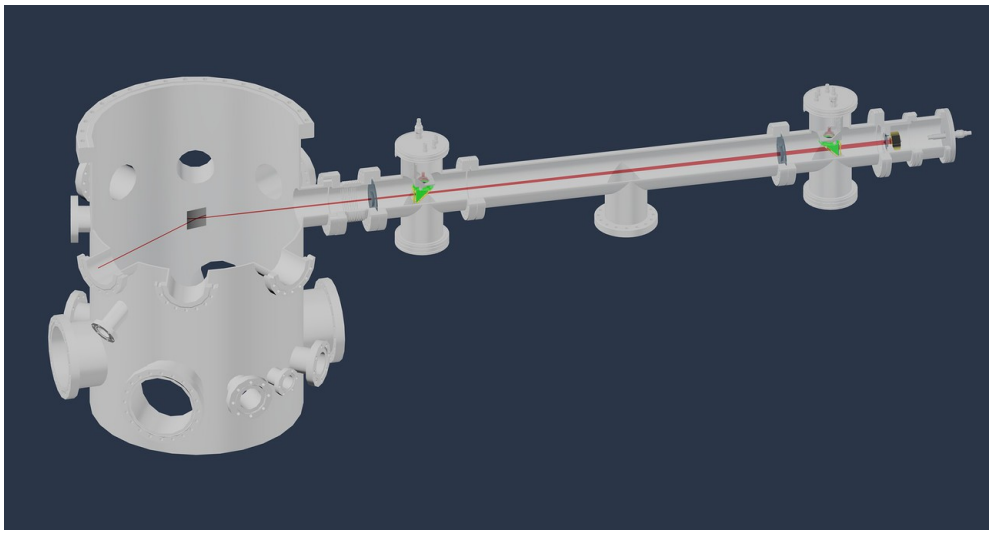

Figure 1: TOF-ERDA system of KIST

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Characterization of Al doped p-type SiC thin films using PIXE Technique

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The non-destructive quantitative characterization of an impurity or a thin film has application in various fields of science. However, it is usually not an easy task. Taking the case of aluminum, this element can be used as a p-type dopant for Si-Based semiconductors. From the analytical point of view, the non-destructive detection of Al inside a Si containing crystalline matrix is rendered difficult by both the rather low solubility of this element in such materials and the signal interferences between Al and Si due to their vicinity in the periodic table of elements. This is done in this work using the Proton Induced X-ray Emission (PIXE) technique.

First, a reference sample was used to optimize the Aluminum detection for PIXE technique. It consists of a 2.5 nm of high purity Aluminum thin films thermally evaporated on silicon carbide substrates. From a systematic study involving variation of incident proton energy (from 0.2 to 3 MeV) and tilting angle of beam incidence (0°, 40°, 60° and 80°),it is demonstrated that the best sensitivity of Al detection occurs at 0.3 MeV and 80°. For the given tilt angle of 0°, the LOD of Al decreases by one order of magnitude when the proton energy decreases from 3 to 0.3 MeV. Moreover the LOD decreases when the tilt angle increases for a given proton energy.

Then these optimized conditions were applied for Al detection inside SiC matrix. The sample consists of a highly Al doped homoepitaxial 4H-SiC layer grown on n type 4H-SiC(0001) 8°off substrate using Vapor-Liquid-Solid mechanism. Namely, Al70Si30 melt was fed by 3 sccm of propane at 1100°C to grow the Al-doped epitaxial layer. At 80° tilt angle under 0.3 MeV protons, it shows that the sensitivity of aluminum is very high and the determination of Al concentration in the SiC layer is thus possible. Knowing the layer thickness (1 µm), the Al concentration was determined to be 3.9×10^{20} at/cm^3 and the LOD of aluminum in this case is equal to 6×10^{18} at/cm^3. On the other hand, beside Al and Si signals, other elements such, as Na, S, Cl, K and Ca, were also detected by PIXE and attributed to surface contamination.

Characterization of archeological pottery from Tyre historical site using PIXE technique and cluster analysis

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It is proposed to study the excavated ceramics from Tyre, the prestigious city of antiquity (locally named Sour and located at 85 km south of Beirut, Lebanon). The originality of Tyre in this context is its long permanence of prosperity as a great center of pottery production and maritime trade through the centuries without interruptions, which were experienced by neighboring cities and rivals. In this work, several series of excavated pottery are analyzed in order to characterize the Tyre production, based on the elemental composition, and thus to be distinguished from those of other neighboring workshops (Serapta, Sidon or Acre), possible sites of ceramic production at this period. Particle induced X-ray emission technique PIXE is used to determine the elemental composition of about 107 excavated shards. The elemental composition provided by PIXE and based on 12 most abundant elements, ranging from Mg to Zr, was used in a multivariate statistical program, were two well defined groups were identified.

High energy combined PIXE/PIGE analysis on geological samples

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PIXE (Particle Induced X-ray Emission) and PIGE (Particle Induced Gamma-ray Emission) are two complementary multi-elemental and non-destructive analysis techniques widely used with protons around few MeV of incident energy. In the past, several attempts have been made to apply PIXE with high energy protons (HEPIXE) [1]. Indeed, high energy PIXE analysis allows to increase the analysis depth so that thick samples (mm range) can be studied. It allows exciting the K-shell electrons leading to the emission of high energy X-rays. Additionally, the production cross sections for X-rays and gamma vary barely, making easier the experimental analysis.

To our knowledge, high energy PIGE combined with HEPIXE [2] has not been reported and we are developing, at the ARRONAX facility [3], the possibility to use these two techniques with different particles as projectile to be able to study geological samples. The main difficulty when coupling the two techniques at high energy is the increase of the gamma background. We overcome this disadvantage by shielding our gamma detector (HPGe) and by irradiating at low intensities (50–100 pA).

Experiments were performed using 68 MeV protons and 17 MeV deuterons on sand samples (5 mm thick) as their mass fractions and density can be easily modified by adding water. Two different kinds of sand have been used: Fontainebleau and volcanic sand.

Results show that using proton beams, PIGE allows to get information on the density, ρSi, (number of atoms per volume) whereas using deuterons beams, PIGE is sensitive to the Si mass fractions, aSi. With the help of a standard, in our case the Fontainebleau sand, it is possible to get information on the matrix elements (density and mass fractions of silicium and oxygen) [4] and therefore we can access to the irradiated area density (g/cm^3) for every sample. With the help of PIXE technique, it is then possible to get the volcanic sand composition.

In conclusion, by properly setting experimental conditions and by using different probes at different energies, it is possible to get all the required information to determine the full composition and the density of a sample using combined PIGE and PIXE techniques at high energies.

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Depth profiling of ions implanted silicon wafer using resonant elastic backscattering He +^{28}Si

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We have measured energy spectra of He-ions backscattered from a silicon wafer implanted with ions. In the He +^{28}Si scattering, there is a very sharp nuclear resonance at the He energy of 5.374-MeV. Varying incident He energy and using the energy loss in Si wafer, we can control He ions to match the resonance energy around the location of ion implantation. Thus, scanning over the implantation layers with the sharp resonance, we can obtain the depth profile of implanted ions as the profile of resonance peaks.

The resonance peaks have been measured by the incident He energy from 5.1 to 5.6 MeV with 3 to 15 keV steps at a scattering angle of 160°. We have prepared the Si wafers implanted with some ions: hydrogen (5x10^{17} ions/cm^2) at 32 keV, carbon (6.8 × 10^{17} ions/cm^2) at 100 keV, nitrogen (6 × 10^{17} ions/cm^2) at 100 keV, and argon (3 × 10^{17} ions/cm^2) at 190 keV. These implanted energies are corresponding to a mean depth of about 0.25 micrometer in Si. To avoid axial channeling, the wafers were tilted by 7° from normal incidence.

The envelope which is made by observed resonance peaks indicates a Gaussian shape. Thus, fitting the shape, we can evaluate the depth profile by parameters such as a center position, a width and a height (yield). The center position indicates a mean depth of implanted ions which means the projected range in Si wafer. The width is a result of the convolution between the width of resonance peak and the spread of implanted ions, that means the range straggling. The height of the peak depends on a cross section, i.e., an amount of Si atoms per a path length of the resonant He-ions which pass through the implantation layer or not.

At this conference, we present the method of nuclear resonance to evaluate the depth profiling for ion implantation in Si wafer. We will show the depth and width of implantation and also compare the results with the range and range straggling that are corresponding values of SRIM predictions.

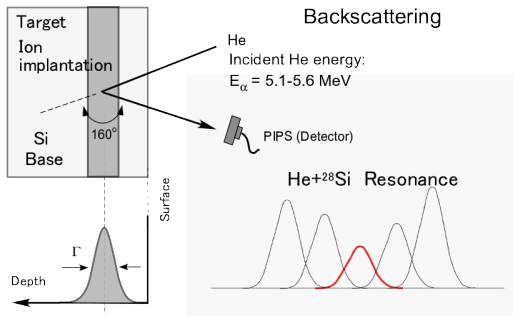

Figure 1: Resonant He backscattering measurements from the ion-implanted silicon.

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Quantification of elements with characteristic K X-ray energies for nuclear microprobe detector setup at Jozef Stefan Institute

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When analyzing PIXE spectra with various programs for elemental analysis, accurate physical detector description is mandatory. The detector efficiency transfer function is of essential importance for correct detector description and thus quantification of detected elements.

The objective presented in this work was to determine the efficiency of Si(Li), SDD (silicon drift detector) and iGe (intrinsic germanium) semiconductor x-ray detectors for nuclear microprobe detector setup at Jozef Stefan Institute (JSI). For x-ray energies under the silicon K absorption edge special attention was implied to most accurately describe SDD and Si(Li) detector efficiency in order to achieve better quantification of chemical elements with characteristic K x-ray lines with energy under the silicon absorption edge (1.84 keV). The same applies for iGe detector and chemical elements with characteristic K x-ray lines with energy under the germanium absorption edge (11.115 keV). Measurements were conducted on various standardized monoelemental and multielemental samples with known thickness and composition. Samples were exposed to focused proton beam with distinct energy, beam current and diameter. Measured spectra were analyzed with spectra deconvolution programs (GUPIXWIN [1] and GEOPIXE [2]) and description of all parameters of detection system with accurate physical model to be used in both programs is attempted. Physical causes for matching the physical model with individual parameters based on resemblances and differences between them were studied. The method to achieve accurate physical detector transfer function is described.

The determined physical model for each x-ray detector is the same for both programs and gives matching quantification results for any target analyzed, regardless of its thickness and composition, within statistical error (not more than 5%) throughout the entire energy range of each detector. The entire detector setup covers the energy range between 0.7 to 54 keV which is used for most applications on nuclear microprobe setup at JSI [3].

Keywords: PIXE, focused ion beam, element quantification, GUPIXWIN, GEOPIXE, semiconductor detector, detector transfer function

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ERD and helium ion microscopy study of beam induced damage in non-homogeneous materials

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Ion beam analysis (IBA) methods are always destructive to some extent. Beam ions can generate heat, create damage in the crystal lattice, decompose molecules and sputter atoms from the sample material, among other effects. Often materials containing volatile species of light elements, such as hydrogen, oxygen and nitrogen are the most sensitive to beam induced damage.

Ideally, all IBA measurements should be performed in a way that possible composition changes can be followed during the measurements. Best way to do this is to collect data in list mode and perform analysis so that results can be studied as a function of ion fluence incident in the sample. If changes are observed the analysis result can be obtained from the beginning of the measurement, or if the changes are small and monotonous, the sample condition in the beginning of the experiment can be extrapolated. Analysis becomes more complicated if the sample contains different layers with different damage behavior, and even more so if the sample is laterally inhomogeneous.

In this work we study beam induced damage in thin films of two different types of materials: porous low-k materials, and atomic layer deposited (ALD) metal-organic hybrid material. Both materials contain large amounts of light volatile species; hydrogen, nitrogen and oxygen. In both cases samples are also inhomogeneous: low-k materials have pores of 1-3 nm diameter, and hybrid material features a continuous thin film with granular structure of 1 µm size on top.

We study the materials by performing ToF-ERD measurements, helium ion microscopy (HIM) imaging and AFM topography measurements. Different beam ions and fluences are used in ToF-ERD measurements and HIM imaging and AFM measurements are used to observe the beam induced effects. The results are compared to Monte Carlo simulations of ToF-ERD energy spectra.

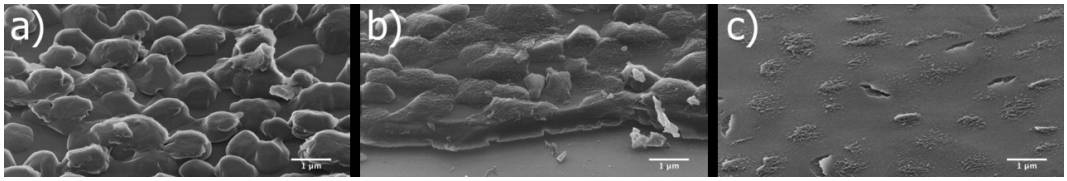

Figure 1: Helium ion microscopy images of thin films of metal-organic hybrid material. Image a) shows the sample before a ToF-ERD measurement, image b) shows the sample with a low fluence of the incident beam, and image c) after a full measurement. Note the cross section of the film in image b) illustrating the complex film structure.

Study of Structural, Optical and Electrical properties of SHI induced modified oxide based nanocomposite thin films

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Nanocomposite thin films of SnO_2–TiO_2 were grown on Si (100) and ITO substrates at room temperature by RF Sputtering deposition technique followed by annealing at 600°C for 4 hours. Dense electronic excitation induced modification in these samples were done by irradiating Swift Heavy Ion (SHI) beams of 100 MeV Au using 15 UD Pelletron Accelerator at Inter University Accelerator Centre, New Delhi, India with varying ion fluencies of 5×10^{11} ions/cm^2 to 5×10^{13} ions/cm^2. Phase transformation, particle size variation, stability of different planes of pristine and irradiated thin films were studied by Glancing Angle X-ray Diffraction (GAXRD) technique. Rutherford Backscattering (RBS) results confirms the absence of any impurity and the density of the sample decreases after irradiation due to amorphization. Depth profiling was done from RBS results. The grain size distribution and uniformity of the surface were studied from Atomic Force Microscopy (AFM) results. This shows grain size dependence on irradiation fluence. Change in band gap due to variation in SHI irradiation ion fluence were observed from optical studies of these films by UV/Visible Spectroscopy using Tauc's relationship. Electrical properties were studied by I-V characteristics at room temperature and low temperature R-T curve. The defects produced (oxygen vacancies and distortion in unit cell of the material) due to transient thermal process are assumed to be key factors in modifying the material properties. Detailed results will be discussed during presentation.

Keywords: GAXRD, RBS, AFM, UV/Visible, R-T.

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New experimental methods for light ion track etched pores in polymer films

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Membranes with precisely controlled pore sizes, morphologies and densities are commonly achieved by chemical etching of ion tracks in thin polymer films. They attract much interest due to their high selectivity in separation and sensing processes. The lower LET thresholds for creating continuous etchable latent ion tracks in such materials, e.g. PC, PET and PI, are reported as 720–900 eV nm^{-1} [1,2]. Such dense radiolytic damage necessitates irradiation with medium to heavy ions. We have investigated new experimental strategies to test whether ion track etching thresholds can be extended down to lower LET irradiation with light ions.

8 µm thick polyarylate films were irradiated with 1.4 MeV D^+ ions from an IBA Cyclone 10/5 cyclotron. SRIM simulations indicated that LET values were approximately 40 eV nm^{-1}. Screening conventional post-irradiation treatment and etching methods confirmed that such low radiolytic damage was insufficient for the etching of individual tracks. When the ion fluence was increased to $5{\cdot}10^{12}$ cm^{-2} and irradiated films were etched in a NaOH-ethanol solution under UV light, continuous non-cylindrical pores were achieved (Figure 1). The physical and chemical mechanisms that permit etching of these multiply-overlapped ion tracks is under investigation. Of particular interest are the degree of ion track overlap, inter-track reactions and the influence of UV on etching.

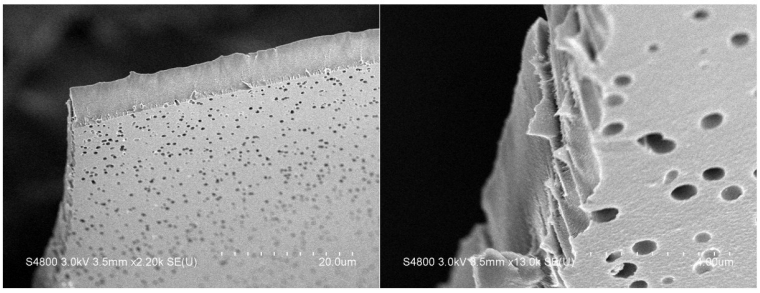

Figure 1: SEM images of pores achieved by etching low LET 1.4 MeV D^+ ion tracks in polyarylate.

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Erbium ion implantation into different crystallographic cuts of zinc oxide

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Erbium (Er) enrichment of photonic materials can be used to amplify optical emission at wavelengths 1.5 μm or to facilitate emission of visible light. Er ion implantation is a well-established method to enrich photonic crystals. The influence of surface orientation of photonic single-crystals (e.g. $LiNbO_3$ or Al_2O_3) on the Er depth distribution after ion implantation as well as crystal recovery during subsequent annealing has been studied by our group in the past extensively.

Zinc oxide (ZnO – $P6_3mc$) is an optical crystal with increasing importance due to its wide band gap of 3.3 eV, its low phonon energy (compared to e.g. silica glasses), and its physical and chemical stability. In this contribution we investigate Er-doped ZnO, which has been prepared by 190 keV Er ion implantation at fluences of 1 and 5×10^{16} cm^{-2} into three different crystallographic ZnO cuts: Z<0001>, X<11$\bar{2}$0> and Y<10$\bar{1}$0>. In particular, we study the Er concentration depth profiles, the Er coordination and irradiation-induced structural changes as well as the luminescent properties of as-implanted and subsequently high-temperature annealed (1000 °C) ZnO crystals.

We find that the luminescence intensity of as-implanted crystals depends on ion implantation fluence and the irradiated crystal surface orientation. Highest luminescence is observed when implanted Er atoms substitute Zn in the crystal. High-temperature annealing results in increased luminescence for Z-cut implantation and higher fluences. It was found that despite the same hexagonal structural motive of ZnO, $LiNbO_3$ and Al_2O_3, ZnO has different behaviour of crystallographic cuts – both structural and luminescence.

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Hydrophilicity Rendering of Polydimethylsiloxane using Oxygen Ion Beam Implantation

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Polydimethylsiloxane (PDMS) has been widely used in microfluidic applications due to most of its well-suited physical and chemical properties. However, hydrophobic property of PDMS makes it very difficult when used as a device for water based applications. One of the most popular PDMS hydrophobicity modification methods due to its comparatively quick and easy technique is oxygen plasma PDMS surface treatment, in which silica-like layer is induced at the PDMS surface. The hydrophilic PDMS surface generated from this technique, however, returns to its original hydrophobicity within hours of surface treatment. This study explored low energy oxygen ion implantation into PDMS structure so the embeded oxygen species in PDMS structure would lengthen its hydrophilic property longevity. The 15–25 keV oxygen ions with various doses were implanted into a 5 mm thick PDMS sheet. X-ray photoelectron spectroscopy (XPS) was used to investigate the change in PDMS compositions and bonding energies after oxygen ion implantation. The hydrophilicity of PDMS was observed to last for over a month after the implantation.

Comparison of copper and silver ion implantation in silicate glasses

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Glasses containing silver and copper are perspective photonic materials for lasing devices and all-optics components. It has been already shown that the oxidation state of the implants depends on many factors. Here we are going to report on one of them, i.e. on influence of composition of silicate glass matrix on resulting oxidation states of into them implanted Cu and Ag ions after subsequent implantation of oxygen ions. Three types of silicate glasses having a different extent of cross-linking were implanted with Cu+ or Ag+ ions with an energy of 330 keV and a fluence 1×10^{16} ions/cm^2. Subsequently, the glasses were implanted with O+ ions into the same depth as the already implanted Cu and Ag ions. Concentration profiles of Cu and Ag in the glasses were studied by Rutherford Backscattering Spectroscopy. After metal and oxygen implantation, the samples were also characterized by optical absorption and photoluminescence spectroscopy. The samples were annealed around transformation temperature of the glass (600 °C) in ambient atmosphere for various times ranging from 1 to 5 hours. The effect of annealing on distribution of the implants and absorption and emission spectra of the as-implanted glasses will be discussed as well.

Acknowledgement: The research has been realised at the CANAM (Center of Accelerators and Nuclear Analytical Methods LM 2011019) infrastructure and has been supported by project No. GA 15-01602S.

New dedicated set-ups for the testing of materials under space radiation environment at IPNAS

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Since few years, IPNAS laboratory has started several collaborations with different departments of the Centre Spatial de Liège to develop set-ups suitable to test space-dedicated materials and components behavior and thus, under space environment specific conditions. During long flights in space, expected interactions and damages in exposed materials, are mostly due to energetic electrons and protons.

As IPNAS irradiation facility hosts several accelerators therefore, covering a broad range of particle/energy conjunctions (0.3–20 MeV for protons), it represents an ideal set of irradiation tools for materials testing campaigns.

This paper reports the development and recent uses of two new irradiation set-ups especially installed on two dedicated beam lines: first one on a 30° beam line of the 2.5 MV VanDeGraaff (0.1–2.5 MeV) and second one on a 40° beam line of our variable energy CGRMEV 520 cyclotron (2.5–20 MeV) .

Goals, radiation test plans applied, and typical results obtained, in the framework of two different projects will be exposed to highlight both specific needs and features developed on these vacuum chambers, to perform adequate tests:

As space electronic systems employ enclosures to shield sensitive components from space radiation, the first example will present the set-up used for the tests and few results obtained within the SIDER project aiming at the improvement of the radiation shielding behaviour of composite materials investigated and developed as an an alternative to state-of-the-art aluminum exhibiting low strength-to-weight ratios.

The second example is an optical coating qualification radiation test campaign led on both chambers in the framework of the Sentinel-4 program of the COPERNICUS Initiative. The Sentinel-4 payload is a high resolution spectrometer system operating with 3 designated bands in the solar reflectance spectrum, covering the ultraviolet (305–400 nm), visible (400–500 nm) and near infrared (750–775 nm) bands. The optical coating deposited on NiP coated Be mirrors has been tested under various beam conditions and the radiation test plan applied will be detailed to emphasize specific care taken for the design of a suitable and safe set-up .

Modelling of the Irradiation of a Nanoporous Iron Target

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Nanoporous materials have emerged very recently as a class of candidate structural materials for advanced nuclear reactors. Computer modelling can be used to explore and explain the response of nanoporous materials to irradiation. The modelling will provide fundamental understanding of the atomistic processes responsible for the experimental observations. In the work presented here we use the Molecular Dynamics simulation program LAMMPS to simulate a primary knock-on atom (PKA) initiated cascade in a set of Fe spherical crystalline nanoparticles of 20 nm diameter which have random orientation with respect to each other. The space between the nanoparticles is filled with Fe atoms to represent the grain boundaries. A 10 keV PKA is then initiated from various positions in one of the nanoparticles and the ensuing cascade is followed and the number of vacancies observed as a function of time. Some cascades are completely contained within a single nanoparticle and others cross the grain boundary and interact with multiple spheres. The survival and recovery of the vacancies in this material are analysed and compared. The aim is to investigate the behaviour of the effects of the irradiation as the size of the nanoparticles is varied.

Particle Accelerator Focus Automation

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The Laboratory of Accelerators and Radiation Technologies (LATR) at the Nuclear and Technological Campus of Instituto Superior Técnico (IST) has an horizontal electrostatic particle accelerator based on the Van de Graaff machine which is used for research in the area of material characterization. This machine produces alfa (He+) and proton (H+) beams of some μA up to 3 MeV energies and has a cylindrical Lens of the Einzel type, which focus the beam using static electrical fields.

In this work is described the developed system to automatically focus the ion beam on the LATR-IST particle accelerator with an electrostatic lens, using a personal computer running LabVIEW, a multifunction input/output board and signal conditioning circuits.

The focusing procedure consists on a scanning method approach to find the lens control voltage which maximizes the beam current measured on a tantalum beam stopper target, which is used as feedback for the scanning cycle. Thus, this system is able to automatically determine the proper voltage to apply to the Einzel Lens to achieve perfect beam focus.

Important to mention that this system is part of a broader system of complete automation of the accelerator which is able to set the terminal voltage to the desired value, light up the ion source and focus the beam. All these procedures were automated bringing great advantages to the operation of the particle accelerator by allowing it to be easily operated, less human presence required and the possibility of total remote control in safe conditions.

Design of an electron-accelerator-driven compact neutron source for non-destructive assay

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The threat of nuclear and radiological terrorism remains one of the greatest challenges to international security, and the threat is constantly evolving. In order to prevent nuclear terrorism, it is important to avoid unlawful import of nuclear materials, such as uranium and plutonium. Development of technologies for non-destructive measurement, detection and recognition of nuclear materials is essential for control at national borders.

At Tokyo Institute of Technology, an ultra-compact neutron source system driven by an electron-accelerator has been developed for non-destructive assay (NDA). In the system, a beryllium target and a moderator are used to generate thermal/epithermal neutrons.Beryllium is suitable for use in generating neutrons because of the low threshold energy of photonuclear reactions. The system is composed of a combination of an S-band (2856 MHz) electron linear accelerator (linac) and a thermionic source chosen to minimize the size of instrument per acceleration energy. The advantage of this system compared to neutron tubes is that it operates reliably at high-frequencies.

In the presentation, we will present an optimized design of the beryllium target and neutron moderator as determined by Monte-Carlo simulation code PHITS. Detailed specifications of ultra-compact neutron source system and the estimated neutron flux as a function of beam energy and beam power will be reported.

Beam position alignment and its verification for therapeutic ion beams from synchrotron

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Control of the beam position for three-dimensional pencil-beam scanning is important because the position accuracy of the beam has a serious matter on the alignment of the irradiation field. To suppress this matter, we have developed a simple procedure for beamline tuning.

At first, the beam transport line is adjusted by steering the beam position to the central orbit using magnets and fluorescent screen monitors. In particular, the reference axis is defined with an acrylic phantom in which a steel sphere is embedded. Misalignment between beam position and reference axis is checked by the verification system, which consists of the screen monitor. If the beam position is deviated from the reference axis, two pairs of steering magnets which are placed on downstream of the beam transport line will be corrected. These adjustments are iterated until the deviations for eleven energies of the beam are within 0.5 mm of the reference axis. To demonstrate the success of our procedure, we performed beam commissioning at the Kanagawa Cancer Center using our procedure.

Fig. 1 shows the measurement results of the beam misalignment after tuning. Horizontal and vertical misalignments are shown before correction and after correction. The reduction of the beam misalignment are confirmed due to our adjustment. Moreover, misalignments are within 0.5 mm for all energies. In this conference, we will report on the result of these measurements.

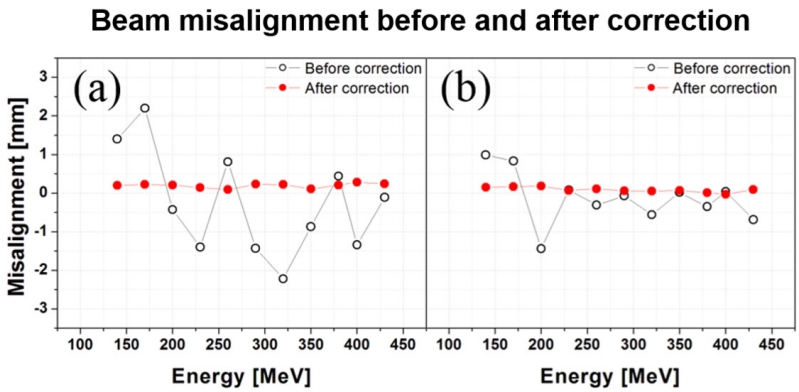

Figure 1: Fig. 1. Measurement results of the beam misalignment. Horizontal (a) and vertical (b) misalignments at horizontal course are shown before correction (open circles) and after correction (dotted circles)

Beam Emittance Measurements on Negative Sputter Ion Sources: Construction and Test of an Allison Scanner

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To investigate the beam emittance of ion sources, especially with respect to space charge, an Allison scanner was designed and built. Commonly used slit-grid or slit-slit scanners have a limited resolution or require a long measurement time. To overcome these limitations an Allison scanner combines high (variable) resolution with a fast response time. This scanner type consists of an electrical sweep plate between two plane-parallel slits which allows the simultaneous measurement of divergence and position of the beam.

With our custom-made Allison scanner phase space measurements at the Erlangen AMS facility and at the Jena 14C-AMS lab were performed. The results are compared with ion optic simulations based on different mathematical methods such as Finite Element Method (FEM), the Finite Difference Method (FDM), and the Boundary Element Method (BEM).

Experimental study of planar gamma-sources with controlled spectrum

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Planar γ-sources with the manipulated number and positioning of the spectral bands have been fabricated and examined. Every device comprises a stack of foils from inactive elementary substances and a planar single-photon γ-source. The spectrum of a combined source is formed by mixing γ-radiation of its hot element and X-ray induced in the cold elements due to the effect of γ-fluorescence. As hot elements, the planar sources on the basis of the ^{57}Co and ^{179}Ta isotopes are used. Both types of sources are produced at an electron accelerator by activating the foils from nickel and tantalum with high-energy bremsstrahlung. By changing the material of the cold elements (indium, tantalum, tungsten, lead), their thicknesses and sequence, the possibility is demonstrated to control the energy and intensity of the spectral bands of the combined source within the span 24…122 keV being of special interest for medical introscopy. The measured band intensity of the sources under study is in the satisfactory agreement with the data obtained using a developed analytical model.

A method of manufacturing planar gamma-sources with controlled spectrum

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Single- and multi-photon γ-sources are widely used in medical and industrial introscopy, elemental analysis, inspection check-up, etc. In this report we describe a technique of production planar γ-sources with the specified spectral bands in the photon energy range up to ~ 100 keV. The approach is based on obtaining mixed γ,X-radiation by inducing the K-lines of characteristic X-ray in the thin layers of elementary substances by an external planar single-photon γ-source with higher photon energy. Such sources on the basis of the ^{57}Co and ^{179}Ta isotopes can be manufactured at an electron accelerator by irradiation of nickel and tantalum foils of natural isotopic composition with high-energy bremsstrahlung. An analytic model of a combined planar γ,X-source in the form of a stack of cold and γ-active foils is developed. The model enables the analysis and optimisation of the source with respect to its intensity and spectral composition. A variant of the accelerator exit device for joint manufacturing the planar ^{57}Co and ^{179}Ta sources is proposed and studied by a computer simulation. It is shown that from the viewpoint of target isotope yield the photonuclear method is competitive as compared to the reactor and cyclotron techniques.

Developments for 230 MeV Superconducting Cyclotrons for Proton Therapy and Proton Irradiation

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There are very strong demand for mid-energy of proton machine recent years due to the surging cancer patients and fast progress of the space science in China. For the applications of proton therapy and proton irradiation, the energy range of proton beam usually is from 200 MeV to 250 MeV, or even higher for astronavigation. Based on the R&D starting from 2009, a construction projects of 230 MeV superconducting cyclotron, which have been implemented recently at China Institute of Atomic Energy(CIAE). It was started in Jan 2015, for the program of proton therapy and space science launched by China National Nuclear Corporation (CNNC). In this paper, the designs for the SC cyclotron and its key components, including the main magnet, SC coils, internal ion source and central region, extraction system, etc, and the construction progress of the machine CYCIAE-230 will be presented.

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Optimization of $\Delta E - E$ detector for ^{41}Ca AMS measurement using PHITS code simulation

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Until upgrade of tandem accelerator at University of Tsukuba Tandem Accelerator Complex (UTTAC), our group had measured ^{14}C, ^{26}Al and ^{36}Cl using 12UD Pelletron tandem accelerator. According to upgrade, terminal voltage changed from 12 MV to 6 MV and detector structure was changed. Therefore we should investigate Accelerator Mass Spectrometry (AMS) measurement condition (terminal voltage, detected ion valence, the condition of detector). Hard-to-measure nuclides of AMS, for example ^{41}Ca, needs trial and error until getting optimum condition. So we will reproduce AMS measurements using Particle and Heavy Ion Transport code System (PHITS)[1] and decide best condition of most separate interference spectrums from purpose spectrum. For this method, efficient development of hard to measure nuclides of AMS is expected.

As a first step, we compared actual measurement results of ^{41}Ca AMS with simulation results of same measurement condition. Computational scheme is the same size as the real detector (5 anode type gas counter). This detector anode separate 5 plate (dE1, dE2, dE3, dE4, dE5 plate). Energy loss can be measured each plate region. Measurement date is output as two-dimensional plot that dE1+dE2 vs. dE4+dE5 energy loss. We compared actual measurement with simulation result about energy loss in detector. And it was confirmed that both value match and positional relationship of each spectrums can be reproduced. From these results, specifying nuclide spectrum other than the target nuclide has become possible. However actual measurement plot more spread than simulation result. The PHITS code simulation for two-dimensional plot can be calculated taking into account for beam straggling, but can't take into account for energy resolution of detector. So we expected that this spread is due to it. And actual amount of energy loss matched simulation result in dE1 + dE2 plate, but it slightly differenced in dE4 +dE5 plate. This is because the PHITS code can't calculate in very low energy region or there is a possibility that computational scheme is deficiency.

Although there is no ^{41}K in this first measurement, it is important that we should know measurement condition for good separation of ^{41}K and ^{41}Ca because ^{41}K most interfere with ^{41}Ca. So, using PHITS code, we simulated that how change this separation when changed detector gas pressure. And it was found that isobutane 26-30 Torr is best. Also, it was optimized combination of detector electrodes and insert gas type using PHITS code. we intend to hold presentation about it.

[1] T. Sato, K. Niita, N. Matsuda, S. Hashimoto, Y. Iwamoto, S. Noda, T. Ogawa, H. Iwase, H. Nakashima, T. Fukahori, K. Okumura, T. Kai, S. Chiba, T. Furuta and L. Sihver, Particle and Heavy Ion Transport Code System PHITS, Version 2.52, J. Nucl. Sci. Technol. 50:9, 913-923 (2013)

^{26}Al measurements using AlO^- ions and a Gas-filled Magnet

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AMS measurements of ^{26}Al are often limited by a low overall efficiency because of the low negative ion yield of Al^- ions. To improve the performance of ^{26}Al both high transmission through the accelerator and high negative ion yields in the source are desirable.

At the compact ETH 500 kV AMS facility TANDY the high transmission for the 2+ charge state of up to 50% in combination with the recently introduced absorber-detector setup used to suppress the m/q interference of $^{13}C^{1+}$ [1] provides an improvement in efficiency of about a factor of 3 compared to the previous setup at the ETH 6 MV TANDEM AMS facility.

However, compared to Al^- ions the yield of AlO^- ions in the ion source is at least one order of magnitude higher. This promises a significant improvement of measurement efficiency at large AMS facilities operating at terminal voltages of several MV, where the occurring intense interference of ^{26}Mg can be sufficiently suppressed.

To enable the use of AlO^- ions for AMS measurements at the ETH 6 MV TANDEM AMS facility, a 180° gas-filled magnet (GFM) setup with an optimized detector design was developed to separate the two isobars ^{26}Mg and ^{26}Al. The use of a gas-filled magnet provides a spatial separation due to the different mean charge state and stopping power of both isobars in gas. In contrast to the degrader foil method charge-state losses are avoided since in gas the ions effectively form only one mean charge state. Based on calculations of the ion trajectories in the gas-filled magnet and straggling simulations, a suppression of ^{26}Mg by about three orders of magnitude is expected, which was confirmed by first measurements. A new detector with large silicon nitride entrance window was designed to maximize the acceptance of the broadened ^{26}Al ion beam at the exit of the gas-filled magnet. The optimized segmented anode configuration provides an additional suppression of ^{26}Mg by five orders of magnitude.

The new GFM setup and first measurements demonstrating the improvements of AMS measurements of ^{26}Al will be presented.

[1] A. M. Müller, M. Christl, J. Lachner, H.-A. Synal, C. Vockenhuber, and C. Zanella. Nucl. Instr. and Meth. B 361 (2015) 257

A comparison between two preparation techniques prior to radiocarbon analysis of modern teeth

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AMS-Radiocarbon analysis of modern teeth has become important for forensic studies. The radiocarbon concentration in teeth reflects the 14C atmospheric concentration during teeth formation and allows the calculation of the actual year of birth. Through AMS, it is possible to measure the radiocarbon concentrations in a tissue with high precision. However, there is a debate about which should be the best fraction used for dating: the collagen carbon or the carbon from enamel. This work focusses on the results obtained from enamel and collagen in order to compare them.

Micro-PIXE mapping for the identification of prehistoric pigment provenance

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Natural ochers and iron oxide based pigments are common in numerous archaeological contexts since the Paleolithic period. Elemental composition can provide information on the mineralogical composition and it has been demonstrated that trace element analysis of the iron-oxide phase is relevant for provenance identification [1]. However, theses rocks are very heterogeneous at macro- and microscopic scales and can present variable proportions of accessory minerals. Moreover, when natural ochers and iron oxide are used as pigment or paint for decorating walls or objects, their presence in very thin layers on the surface of stones or biomaterials such as bones and ivory can limit accurate fingerprinting.

Micro-PIXE combined with micro-RBS can help taking into account the heterogeneity of the samples. The development of elemental PIXE-RBS imaging system (Figure 1) such as recently implemented on the AGLAE accelerator (C2RMF, Paris [2]) has been used to select the areas of interest. In this work, PIXE imaging data sets obtained at various scales were used to identify heterogeneities of iron oxide based pigments. In rocks, iron oxide phase and non-ferrous minerals such as quartzand clays are differentiated. For archaeological artifacts, the most preserved layer of pigment is selected. As a result, only the iron phase is selected and analyzed for multivariate data analysis and hierarchical cluttering. Pixel displaying low contents of iron is discarded from further data processing. The results obtained show a better classification that enhances samples grouping in the framework of provenance identification. This procedure has been applied on two archaeological sites: the shelter of Pataud in France (28 000-26 000 years BP) (Figure 1) and the El Mnasra (100 000-75 000 years BP) cave in Marocco.

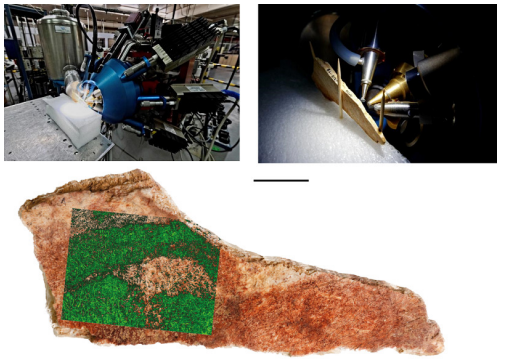

Figure 1: AGLAE PIXE-RBS imaging system and PIXE Fe map (green) of pigment covering a paleolithic decorated bone artefact from Abri Pataud.

[1] Beck L., Nucl. Instr. and Meth. B 332 (2014) 439
[2] Pichon L. et al., Nucl. Instr. and Meth 318 (2014) 27

A new small-footprint external-beam PIXE facility for cultural heritage applications using pulsed proton beams

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In the framework of the COBRA (i) project elemental analysis of cultural heritage objects based on the particle induced X-ray emission (PIXE) are foreseen in a collaboration between the APAM (ii) laboratory of ENEA-Frascati and the LABEC (iii) laboratory of INFN in Florence.

With this aim a 3-7 MeV pulsed proton beam driven by the injector of the protontherapy accelerator under construction for the TOP-IMPLART (iv) Project [1] will be used to demonstrate the feasibility of the technique with a small-footprint pulsed accelerator to Italian small and medium enterprises interested in the conservation of ancient artifacts.

The experimental set-up for PIXE analysis on the TOP-IMPLART machine consists of a modified assembly of the vertical beam line usually dedicated to radiobiology experiments [2,3]: the beam produced by the injector (RFQ+DTL, a PL7 ACCSYS-HITACHI model) is bent to 90 degree by a magnet, is collimated by a 300 μm aperture inserted in the end nozzle and it is extracted into ambient pressure by an exit window consisting of a Upilex foil 7.5 μm thick. The beam is pulsed with a variable pulse duration of 20-100 μs and a repetition rate variable from 10 to 100 Hz.

The X-ray detection system is based on a Ketek silicon drift detector (SDD) with 10 mm^2 active area and 450 μm thickness, with a thin Beryllium entrance window (8 μm); the energy resolution of the detector is 129 eV FWHM at Mn Ka line.

The results of the preliminary calibration of this new set-up for PIXE measurements using thin elemental and thick target standards are presented.

i COBRA: Sviluppo e diffusione di metodi, tecnologie e strumenti avanzati per la COnservazione dei Beni culturali, basati sull'applicazione di Radiazioni e di tecnologie Abilitanti

ii APAM: Development of Particle Accelerators and Medical Applications

iii LABEC: LAboratorio BEni Culturali

iv TOP-IMPLART: Oncological Therapy with Protons – Intensity Modulated Proton Linear Accelerator for RadioTherapy

[1] C. Ronsivalle, et al., "The TOP-IMPLART project", Eur. Phys. J. Plus 2011, 126, 7
[2] M. Vadrucci, et al., "Experimental activity in the ENEA-Frascati irradiation facility with 3-7 MeV protons" IPAC 2014: Proceedings of the 5th International Particle Accelerator Conference, 2014, 2156 – 2158
[3] M. Vadrucci, et al., "Radiobiology Experiments for Characterization of the low-energy TOP-IMPLART Proton Beam" accepted by Biophysics and Bioengineering Letters, 2015

Portable XRF scanner for Cultural Heritage applications

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As it is well know, X-Ray Fluorescence (XRF) analyses are an essential issue in the field of Cultural Heritage diagnostics since they allow for multi-elemental, non-invasive, non-destructive in-situ characterisations. The LABEC laboratory of the National Institute of Nuclear Physics (INFN) in Florence has a long-lasting experience in this field, and in 2011 an XRF spectrometer with high sensitivity for low-Z elements was developed [1]. This instrument has been successfully used for many applications on works of art (see for example [2, 3, 4] and references therein).

To improve the analytical possibilities we recently developed, in collaboration with the INFN network of laboratories for Cultural Heritage studies (CHNet), a second generation instrument capable of elemental imaging. Indeed, most of the samples in Cultural Heritage field have to be considered non-homogeneous, even when they show apparently uniform structures. For this reason, "traditional" spot XRF analyses can result in misleading information on the composition of the material, while reconstructing elemental maps over an area lead to achieving much more significant and reliable results. This is why there is a growing demand of these instruments.

The entire system basically consists of a measuring head (X-ray tube, detector, laser pointing system and a camera) placed on motorized micrometric linear stages that can be moved on the three directions. The linear stages are installed on a box that contains power supplies and an analog-to-digital converter. The system is remotely controlled by a laptop computer. Our scanning XRF system allows the user to personalize its functions. This is possible because we developed the software that controls the scanning movement and the data acquisition, synchronizing both in order to reconstruct elemental maps from the area of interest.

Thanks to collaboration with the Opificio delle Pietre Dure, one of the most important restoration laboratories in Europe, we had the occasion to test our prototype on many paintings by the Old Masters [5], the main results of which will be briefly reported in order to show capabilities and advantages of this kind of technique.

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[2] L. Castelli, L. Giuntini, F. Taccetti et al., X.Ray Spectrom. 42 (6), 2013, 537-540
[3] A. Mazzinghi, NCC 3 (37), 2014, 253-262
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XRF and micro-PIXE studies of inhomogeneity of ancient bronze and silver alloys

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We analyzed 180 Scythian-like arrowheads and pre-monetary signs using X-Ray Fluorescence (XRF) and 60 small samples (~100 µm diameter), taken from previously corrosion-cleaned areas on such items, using µPIXE. The objects were found in Dobrudja, nearby the Greek colony Histria, and at Floriile, by the Danube.

The most relevant result for numismatists is that the same type of alloy was used both for the fighting arrowheads and for the pre-monetary signs.

Our analyses suggest three types of alloys: Cu-Sn-Pb (*regular* bronze), Cu-Sn-Mn-Pb and Cu-Sn-Sb-Pb.

The question to be answered is how antimony and manganese can be components of the copper alloy. Antimony is found in poly-metallic geological deposits. Its presence in the alloy is an indicator for the use of secondary enriched sulfide ores in bronze metallurgy, containing Cu, As, Sb and little Ag, Ni and Bi.

Analysis performed on bronze items fron the collections of the British Museum suggests that antimonal bronze was found mainly in the Kuban area (NE of the Black Sea), known for a strong Scythian presence. Unless a relatively pure Cu-Sb mineral was widely available, the most likely explanation for this compositional pattern is either the co-smelting of copper minerals with a relatively pure antimony mineral (*eg.* stibnite, Sb_2S_3) or the deliberate addition of metallic antimony to copper.

The most credible hypothesis concerning the use of antimonal bronze for some *arrowhead*-like pre-monetary signs found both in Olbia (a Greek colony in Southern Ucraine) and Histria is their Scythian provenance.

The problem of ancient bronze containing manganese is even more complicated. An explanation could be the use of manganese oxides as flux necessary to smelt oxidized ores. Such ores, occurring in a highly siliceous gangue, must be fluxed with an iron mineral as hematite or limonite; thus, our guess is the use of copper ores from the Nikolaev region (Ukraine), very rich in manganese minerals, an area also known for a significant Scythian presence. This idea needs more investigation.

The presence of Sb and Mn in Scythian bronze is facilitated by the use of primitive metallurgical procedures.

An interesting aspect of Geto-Dacian coinage is the presence of tin, starting with the 3^{rd} century BC silver imitation tetradrachms. The average fineness and weight of the coin issues corroborate the hypothesis that Sn was added deliberately and gradually. There is a reduction of the fineness with time, and an increase of the Sn concentration: at the beginning of the 2^{nd} century BC, it was more or less proportional to the copper concentration. It is possible that bronze was used instead of copper in alloying silver. Adding tin in Ag/Cu alloys was possibly preferred, as tin attenuated the red tint of copper, resulting a silvery aspect.

Elemental maps of Cu, Mn, Pb, Ag and Sn are presented to illustrate these aspects.

Development of NIRS Pencil Beam Scanning System for Carbon Ion Radiotherapy

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At Heavy Ion Medical Accelerator in Chiba (HIMAC), more than 10000 patients have been successfully treated by carbon ion beams since 1994. The successful results of treatments have led us to construct a new treatment facility equipped with a three-dimensional pencil beam scanning (PBS) irradiation system, which is one of sophisticated techniques for cancer therapy with high energetic ion beam. This new facility comprises two treatment rooms having fixed beam lines and one treatment room having rotating gantry line. The challenge of this project is to realize treatment of a moving target by scanning irradiation. Thus, to realize this, the development of the fast scanning system is one of the most important issues in this project. After intense commissioning and quality assurance tests, the treatment with scanned ion beam was started in May 2011, and treatment of moving target was started in March 2015. After the construction of fixed beam lines, we start design and construction of a superconducting rotating gantry. The construction of rotating gantry is completed in September 2015. In this paper, the developments of the PBS irradiation system are described.

Recent progress of a superconducting rotating-gantry for carbon radiotherapy

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A superconducting rotating-gantry for carbon radiotherapy was developed. This isocentric rotating gantry can transport carbon ions with the maximum energy of 430 MeV/u to an isocenter with irradiation angles of over ±180 degrees, and is further capable of performing three-dimensional raster-scanning irradiation. The combined-function superconducting magnets were employed for the rotating gantry. The superconducting magnets with optimized beam optics allowed a compact gantry design with a large scan size at the isocenter; the length and the radius of the gantry are approximately 13 and 5.5 m, respectively, which are comparable to those for the existing proton gantries. The total weight of the gantry was estimated to be approximately 300 tons, which is roughly half of the existing gantry for carbon radiotherapy. A construction of the gantry structure begun by 2014, and the installation of the entire gantry system to the Heavy Ion Medical Accelerator in Chiba (HIMAC) complex at National Institute of Radiological Sciences (NIRS) completed by the end of September, 2015. Beam turning begun by October, 2015, and carbon beams, as accelerated by the HIMAC synchrotron, having maximum energy of 430 MeV/u are transported with the rotating gantry to the isocenter. The size and shape of the beam spots at the isocenter were finely tuned over various combinations of the beam energies and the gantry angle. We will present the recent progress as well as the current status of the superconducting rotating-gantry.

Computer Simulation and Experimental Investigation of Mo-99 yield in thick targets as a Tc-99m generator

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One of the basic requirements for the production technology of radionuclides is to provide a high specific activity of the target nuclide as well as its full activity in target. Traditionally this problem is solved by using a large volume of photonuclear targets with subsequent processing by radiochemical separation target nuclide [1]. Modelling and experimental study of the spatial distribution of the activity is carried out in this work for the Mo-99 target. The computer simulation of the Tc-99m production at the electron accelerator in energy range from 20 MeV to 90 MeV has been done using the GEANT4 toolkit [2] to estimate the isotope yields from the finite size targets.

Experimental investigation of Mo-99 yield from thick targets has been done on the electron accelerator with subsequent spectrometric analysis of induced activity. In order to measure the activities of the samples and identify the produced radionuclides we used the gamma-spectrometer InSpector-2000 (made by Canberra) based on the HPGe detector.

Dependency of Mo-99 activity on target depth at fixed energies of primary electrons has been investigated by both calculations and experiment. The converter and targets were placed inside the neutron moderator, represented by paraffin layer. The physical processes for electrons, positrons and gamma-rays were described with using the "Livermore" low-energy model in GEANT4 toolkit. It has been shown that the main feature of the Mo-99 isotope production in the thick targets is the significant depth inhomogeneity of activity. The simulation results (solid curves) as well as experimental data (points) for the Mo-99 production with and without neutron moderator for 60 MeV incident energy of electrons are shown on the Figure 1. There is a good agreement between the calculated and experimental data.

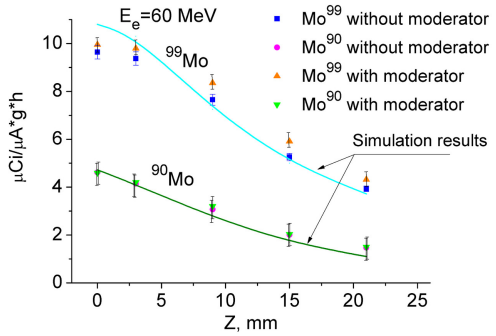

Figure 1: Modeled Mo-99 yield at an electron energy 60 MeV

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Performance of the HIMAC Beam Control System Using Multiple-Energy Synchrotron Operation

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The National Institute of Radiological Sciences (NIRS) has performed carbon-ion radiotherapy on more than 9000 patients since 1994 and began the treatment with pencil beam scanning from 2011. Multiple-energy synchrotron operation [1] was developed to realize fast 3D scanning irradiation at the Heavy Ion Medical Accelerator in Chia (HIMAC) in NIRS. It can provide carbon-ion beams with various energies ranging from 48 to 430 MeV/n in a single synchrotron cycle. To make use of its advantage, a fast beam chopper system has been installed in the high-energy beam transport (HEBT). This system is used to prevent uncontrollable spilled beams, which is caused by varying the beam energy, being delivered to the irradiation port. The changes of the beam energy can be performed quickly and reliably by using the HEBT chopper system. In addition, the intensity control system of the extracted beam has been equipped to save the irradiation time. It can lead a fast scanning sequence by keeping the beam intensity high within the limits determined by the performance of the magnet power supplies and so on. The irradiation tests were carried out to verify the performance of the beam control system using multiple-energy operation. The system could output the beams of more than 140 different energies in 60 seconds. The output beam intensity could be controlled for their energies without large ripple and overshoot. Experimental irradiation for prostate cancer treatment was also successfully performed, and its result proved that our system can greatly reduce the irradiation time.

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Design and performance of daily QA system for carbon ion therapy at NIRS

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Since carbon ion deposits most of their energy in the last final millimeters of their trajectory, the accuracy of the beam energy/range is required for carbon ion treatment especially for using scanning method. Physical advantages of carbon ion are not only for the beam direction, but also for the lateral direction compare with conventional photon or proton beam. Although QA procedures are necessary for establishing safe and accurate dose delivery of any radiation therapy treatment modality, much high level of QA procedures are required for carbon-ion therapy. At the National Institute of Radiological Sciences (NIRS), we have been commissioning the rotating-gantry system for the carbon-ion radiotherapy. This rotating-gantry can transport heavy ions having 430 MeV/u to an isocenter with irradiation angles of over ±180° that is able to rotate around the patient so that the tumor can be irradiated from many directions. A three-dimensional pencil beam scanning irradiation system which is equipped with the rotating-gantry, provide the optimal use of physical characteristics of carbon-ion and to achieve accurate treatment. This irradiation system can provide the treatment of a moving target by fast scanning irradiation. A maximum scanning velocity is 100 mm/ms at isocenter. To ensure the treatment quality using such a complex system, calibration of the primary dose monitor, range check, dose rate check, machine safety check, and some mechanical tests should be performed efficiently. For this purpose, we have developed a measurement system dedicated for quality assurance (QA) of this gantry system. The system consists of an ionization chamber system and a scintillator system. For the ionization chamber system, a Farmer type ionization chamber is inserted into the center of a plastic water phantom. The thickness of the phantom could be changed so that employ both calibration of the output at entrance and output checking at center of the irradiation field. For the scintillator system, the ranges of beams are verified using a CCD camera and a scintillator. From the taken images, maximum gradient points are determined by some image processing and compared with reference data. In this paper, we describe consideration of the daily QA system for the rotating-gantry.

Measurement of gamma-ray production X-sections in Li and F induced by protons from 810 keV to 3200 keV

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The analytical potential of Particle Induced Gamma-ray Emission (PIGE) has been greatly improved since the increase by a factor of 3 of X-section data, regarding Li, F, Na, Mg, Al, Si, recently produced as a result of a IAEA coordinated research project. For Li and F four reaction channels have normally been considered for analytic purposes: ^{7}Li(p,nγ_{1-0})^{7}Be (E_γ=429 keV), ^{7}Li(p,pγ_{1-0})^{7}Li (E_γ=478 keV), ^{19}F(p,pγ_{1-0})^{19}F (E_γ=110 keV), ^{19}F(p,pγ_{2-0})^{19}F (E_γ=197 keV). The 110 keV data, recently produced within the IAEA CRP, are all included in a band that has a maximum spread of about 8% (around 3200 keV), still within the evaluated cumulative errors. Below 3 MeV the reported data are practically overlapping. The situation is different for the 197 keV data. Here the maximum spread reaches about 25% (around 3400 keV), outside the quoted cumulative errors. To verify coherence of data PIGE from natural LiF targets has been studied at the Centro de Micro Análisis de Materiales (CMAM) of the Universidad Autónoma de Madrid, in 10 keV steps (or lower over sharp resonances), from 810 to 3200 keV. Contrary to most of the other cases, our X-sections have been directly extracted from measured quantities: yields, target thickness, collected charge, detector absolute efficiency and not relative to the RBS X-section on a heavy nucleus (Ag or Au). The reaction chamber has been equipped with a tantalum Faraday cup with secondary electron suppression and a reverse electrode germanium detector (REGe), having a peculiar polymer entrance window, that makes the efficiency grow up to 56 keV. The high absolute efficiency allowed us to operate with low currents (max 30 nA, max dead-time 0.6% in all measurements), while reaching rapidly a high statistics in each of the four gamma-ray peaks.

X-section results are presented and discussed in comparison to CMAM previous results [1] and to other recent results. This work was performed within the IAEA coordinated research project "Development of a Reference Database for Particle-Induced Gamma-ray Emission (PIGE) Spectroscopy".

[1] A. Caciolli et al. Nucl. Instr. and Meth. B 249 (2006) 98-100

X-ray production cross sections from C and Si up to 1 MeV/amu on Ti, Fe, Zn, Nb, Ru and Ta

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The development of SIMS at MeV energies promises to offer the community a new analytical methodology and is the object of coordinated research. Due to IBA multi-technique character, the development opens also the way to the combination of the MeV-SIMS with other IBA techniques, in particular heavy ion PIXE. Several data exist already for ionization and production X-sections. However one has to observe that lesser direct results are found for X-ray production and that a list of X-section values, measured with a concerted protocol and a cross check procedure in different laboratories and at energies convenient also for heavy-ions SIMS, would be convenient both as a reliable operative tool and as an experimental base on which test theoretical models. Cross sections have been measured at CMAM in the Time-of-Flight experimental station, equipped with an intercepting and transmission Faraday cup, both provided with a secondary electrons suppressor. X-rays were detected by a Ketek Axas-A 10 mm^2 SDD detector, protected by a convenient absorber from the impact of backscattered ions. Its absolute efficiency has been measured using known proton production X-sections and a set of targets the thickness of which was measured in a concerted round robin. The transmission of the Faraday cup has been repeatedly determined and the charge collected by it transformed to charge on sample. We have investigated the production induced by C and Si ions from 1 MeV/amu down to 0.25 MeV/amu on the following thin targets: TiO_2, Fe_3O_4, ZnO, NbO, RuO_2 and Ta_2O_3 on different supports. We review here the experimental procedure; we report on obtained X-sections and compare our results with previous ones and with theoretical models.

This work was performed within the IAEA coordinated research project (CRP) #F11019: ”Development of molecular concentration mapping techniques using MeV focused ion beams”.

TANGO control system for electrostatic accelerators

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A modern tandem accelerator (like the 5 MV one installed at the Universidad Autonoma de Madrid by HVEE) is tipically a growing facility. In order to perform the planned expansion projects, in terms of beamline upgrades and instrumentation, we have felt, in our facility, the need of an extension and upgrade of the original control system. The proposed new control system takes advantage of the existing devices and incorporates the control required in the new beamlines and the auxiliary equipment related to the accelerator operation. The control software from HVEE (TOS- Tandem Operating System), has been modified to act as a device server in TANGO control system. The TANGO database server runs in a different computer. Our choice of TANGO is due to the fast learning curve, stability and the existence of a large community developing "device servers" for the most general devices. The TANGO control system can absorb data from the auxiliary telemetry system, giving the possibility to integrate in a same unique control system both parts. Readouts, writings, logging and trendings are basic parts of TANGO, giving the developer a simple yet powerful tool to directly develop programs which otherwise, would consist in independent pieces of software that are almost impossible to interconnect. Most values from the actual telemetry are nowadays exported to TANGO, plus few other auxiliary telemetry values. We are at a stage where we have probed the readouts-writes-trending. The part that is daily used, is a GUI (Graphical User Interface) that display several telemetry values used during fine tuning of the beam, at the low energy part of the accelerator. For the following stages, trendings and control of other telemetry values is to be implemented, replacing separate pieces of software. In a final stage, a general GUI for the operator, plus particular GUIs for the users is to be implemented.

Investigation of the accelerating electric fields in laser-induced ion beams

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The Front Surface Acceleration (FSA) obtained in Laser Ion Source (LIS) systems is one of the most interesting methods to produce accelerated protons and ions. We implemented a LIS to study the ion acceleration mechanisms. In this device, the plasma is generated by a KrF excimer laser operating at 248 nm, focused on an aluminum target mounted inside a vacuum chamber. The laser energy was varied from 28 to 56 mJ/pulse and focused onto the target by a 15 cm focal lens forming a 0.05 cm diameter spot. A high impedance resistive probe was used to map the electric potential inside the chamber, near the target. In order to avoid the effect of plasma particles investing the probe, a PVC shield was realized. Particles inevitably streaked the shield but their influence on the probe was negligible. We detected the time resolved profiles of the electric potential moving the probe from 4.7 cm to 6.2 cm with respect to the main target axis, while the height of the shield from the surface normal on the target symmetry center was about 3 cm. The corresponding electric field can be very important to elucidate the phenomenon responsible of the accelerating field formation. The behavior of the field depends on the distance x as $1/x^{1.85}$ with 28 mJ laser energy, $1/x^{1.77}$ with 49 mJ and $1/x^{1.74}$ with 56 mJ. The dependence of the field changes slightly for our three cases, the power degree decreases at increasing laser energy. It is possible to hypothesize that the electric field strength stems from the contribution of an electrostatic and an induced field. Considering exclusively the induced field at the center of the created plasma, a strength of some kV/m could be reached, which could deliver ions up to 1 keV of energy. These values were justified by measurement performed with an electrostatic barrier.

Plasma production in carbon – based materials

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High intensity lasers can induce in solid targets a charge resulting in a time-dependent target polarization. In this work, the characterization of plastic targets subjected to a laser irradiation has been studied. They were PMMA and UHMWPE. A focus is particularly devoted to the interaction of the target charge with the grounded chamber,which is tried to be understood through the ratio of the charged plastic target area to the area of the target – holder contact area. A possible correlation between the target current and the main features ofthe produced plasma is analyzed, in order to acquire a deeper knowledge on laser – matter interactions. The experimental setup is shown in Fig.1.

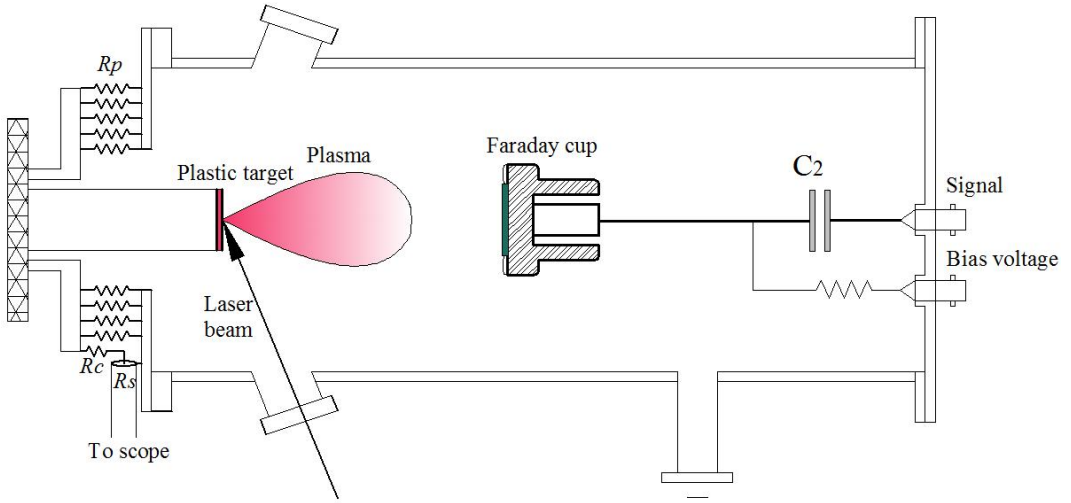

Figure 1: Experimental setup

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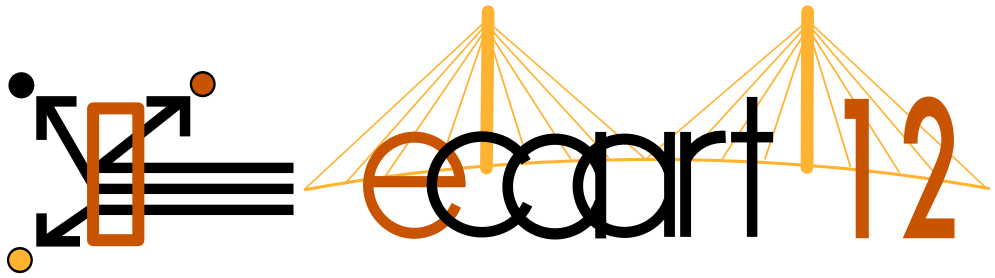

List of Authors

	Monday	Tuesday	Wednesday	Thursday	Friday
	Opening				
9:00 - 10:00	M.Q. Ren	J. L'Écuyer	J.M.C. Brown	S. Huotari	M. Strobl
	K. Noda	S. Eschbaumer	M. Mayer	C-O. Bacri	A. Bosser
	C. Santos		M. Kokkoris	M. Fonseca	T. Zhang
10:00 - 11:00	R.P. Webb	T. Sajavaara	G. Terwagne	V. Alarcon-Diez	Coffee
	Coffee	Coffee	Coffee	Coffee	C. Jeynes
11:00 - 12:00	A. Javanainen	C. Pacheco	J. Meersschaut	Z. Siketić	Concluding remarks
	L.C. Feldman	L. Beck	IBT roadmap	T. Seki	Closing
	S. Akhmadaliev	I. Bogdanović Radović		K. Morita	Lunch
12:00 - 13:00	J. Cajzl	A. Subercaze		F. Moisy	
	Lunch	Lunch	Lunch	Lunch	
13:00 - 14:00			Conference outing 13:30 - 22:00		
14:00 - 15:00	C. Welte	V. Malka		Poster session B	
	P. Steier	M. Klein			
	K. Wilcken	M.V. Mores			
15:00 - 16:00	M. Schiffer	T. Kalvas			
	V. Palonen	K. Mizohata			
	Coffee	Coffee			
16:00 - 17:00	Lab visit	Poster session A			
17:00 - 18:00				Cruise and conference dinner 16:45 - 24:00	