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Recent experiments on photo-assisted negative ion production in caesium sputter ion source at the JYFL Pelletron facility

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Abstract. We have measured the effect of a 15 W, 445 nm laser on Br^- beam current produced by a SNICS ion source by systematically varying the ion source parameters, most importantly the target holder material, and temperatures of the ioniser and Cs oven. The target holder material has no significant effect on the observed photoenhancement of the beam current. The evidence shows that the laser allows reaching higher beam currents at low ioniser temperatures compared to running the source without the laser but at higher ioniser temperature. We have observed a priming effect, i.e. applying a number of laser pulses at certain ion source settings causes the beam current measured without the laser to increase significantly and remain high after ceasing the laser pulsing. These observations suggest that the photo-assisted effect is related to changes of the cathode caesium coverage. Finally, we report the results of our first attempts to sustain a stable beam current at the elevated level over several hours, achieved through active control of the laser power.

1. Introduction

The negative ion generation in Caesium Sputter Ion Sources (SNICS) is a pivotal process for Ion Beam Analysis (IBA) and Accelerator Mass Spectrometry (AMS) applications. In SNICS the negative ion formation takes place on the cathode surface upon exposure to caesium ion (Cs^+) bombardment. Recent investigations have explored the potential of laser-induced enhancement of the negative ion production and the underlying mechanisms. The initial hypothesis explaining the increase of negative ion currents, observed when the cathode of the SNICS is exposed to a laser beam, was based on resonant ion pair production [1, 2, 3, 4] through resonant excitation of neutral caesium atoms to 7p electronic states [5] from the ground state with 455.6508 nm and 459.4295 nm photons. Subsequent studies questioned this hypothesis by demonstrating the laser-assisted negative ion production effect with non-resonant lasers, incapable of promoting Cs atoms to 7p states [6, 7]. In those experiments beam current enhancement factors up to two were observed. It was later concluded with a tunable wavelength laser (in 450-461 nm wavelength range) that the resonant ion pair production does not contribute to the observed beam current enhancement [8]. It was recently reported in [9] that the extracted beam currents of negative ions of halide elements can be increased by a factor of up to 9 by exposing the cathode to 605 mW of laser power at 445 nm. The observed enhancement depends on the applied laser power, wavelength, pulse length, and the ion source conditions such as temperatures of the ioniser and Cs oven. A qualitative model, based on photoelectron emission and changing work function of the cathode surface due to variation of its Cs coverage, explaining the enhancement was proposed in [9].

Here we report photo-enhanced Br^- beam currents, obtained by systematically varying the ion source parameters, most importantly the ioniser and Cs oven temperatures, and measuring the effect of a 15 W, 445 nm laser on the Br^- current. Furthermore, we report the results of our first attempts to sustain a stable beam current at the elevated level, achieved through active control of the laser power.

2. Experimental setup and procedure

The experiments were conducted at the University of Jyväskylä Accelerator Laboratory (JYFL-ACCLAB) with a multi-cathode source of negative ions through caesium sputtering (MC-SNICS) [10] manufactured by the National Electrostatics Corporation. Details of the MC-SNICS setup have been elucidated in prior literature [10, 11]. The negative ion production is achieved through sputtering process, where the cathode (housing the "target" of ionised material) is bombarded by energetic Cs^+ ions [12, 13]. The Cs is sourced from an external oven and surface ionised on the hot ioniser. Cesium not only ejects atoms or molecules from the cathode surface (some of them as negative ions), but also significantly reduces the cathode work function as the evaporated caesium condenses on the cathode surface, which increases the negative ion yield [11, 14, 15, 16]. In our experiments the Cs^+ ions were accelerated towards the cathode by applying $-4\,\mathrm{kV}$ potential, and focused by the caesium focus lens, which is an electrode biased to $1.2\,\mathrm{kV}$ with respect to the ionisation chamber potential. An additional $-8\,\mathrm{kV}$ potential is applied between the ion source and the beamline to form the negative ion beam. The ion source is liquid-cooled but has no thermocouples to monitor e.g. the cathode temperature.

Here we used four target holders, made of Al, Cu, Ti, and Ni, to observe whether the material affects the photoelectron effect and negative ion current. This could be anticipated as the laser beam spot at the cathode is larger than the 1 mm diameter CsBr target (pressed into the target holder) and the work functions of caesiated metals are different.[1] We used a nominally 15 W, 445 nm (Opt Lasers PLH3D-15W) laser and measured the Br^- beam current with 60-150 W ioniser heating power (affecting the ioniser temperature and Cs^+ flux) and 145-170 °C Cs oven temperature. A Digilent Analog Discovery 2 module was used to manually control the laser power and to stabilise the beam current. The transported, mass-analyzed Br^- beam current was measured from a Faraday cup downstream from a dipole magnet.

3. Experimental results

3.1. Experiments with different target holder materials

The experiments were started by measuring the photoenhancement of Br^- beam current, produced from CsBr target, with Ni, Cu, Ti, and Al target holders. Figure 1 shows the extracted Br^- beam from these cathodes with 605 mW laser power. In all cases there is a prompt effect when the laser pulses are turned on or off, as well as a slow increase of the Br^- current during the laser exposure. We note that the baseline beam current is different in each case due to the inherent variation of the SNICS beam current. We associate the prompt effect to photoelectron emission followed by increased Cs^+ sputtering rate of the target (see Ref. [9] for details), and the gradual increase to a thermal transient, i.e. heating of the cathode and subsequent modification of its Cs coverage. In this experiment, the prompt effect on the beam current varies within 0.1-0.26 µA. This variation is observed from one laser pulse to another regardless of the target holder material. Thus, we conclude that there is no significant difference of prompt beam current enhancement, presumably caused by photoelectron emission, between the caesiated target holder materials.

3.2. Effect of the ioniser temperature

The ioniser heating power affects the Cs^+ flux to the cathode by increasing the surface ionisation probability and minimising the residence time of Cs on the ioniser. In order to establish whether the

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[1] All laser powers quoted in the text are those incident on the 1 mm target

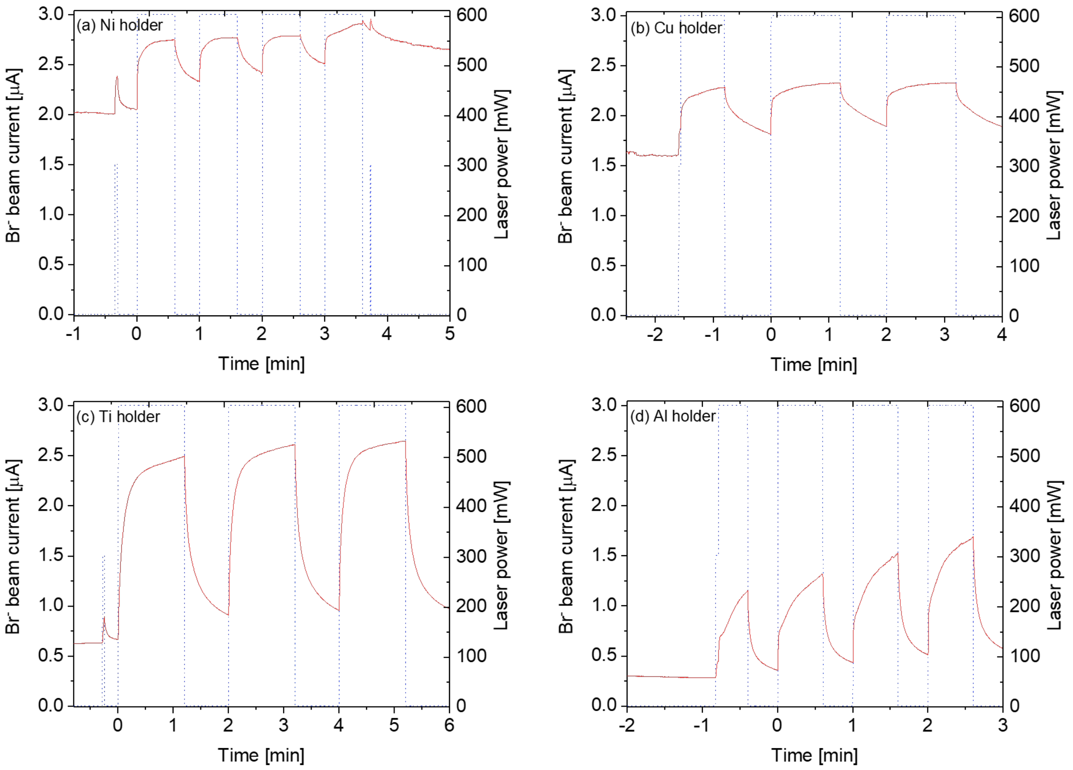

Figure 1. The effect of the 445 nm, 605 mW laser on the Br$^-$ beam current from (a) Ni, (b) Cu, (c) Ti, and (d) Al target holders. The laser pulses are highlighted with blue dotted lines and the beam current corresponds to solid red line.

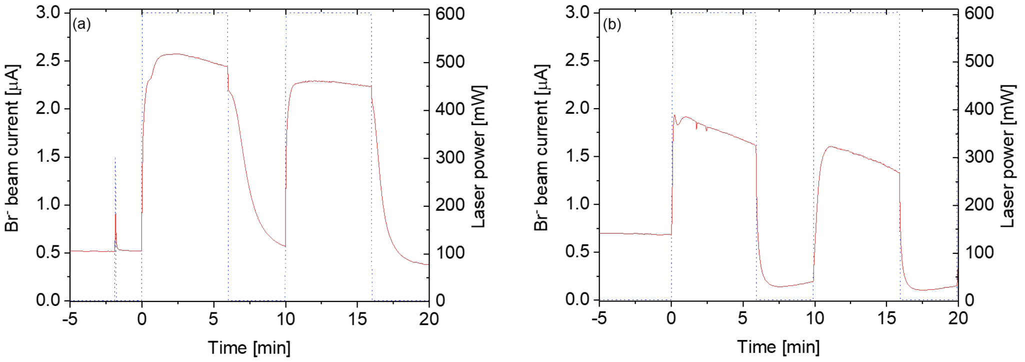

Figure 2. The effect of different ioniser heating power on the Br$^-$ beam current with 605 mW laser power and Cu target holder. In (a) the ioniser heating power is 77 W and in (b) 124 W, respectively. The laser pulses are highlighted with blue dotted lines and the beam current with solid red line.

laser-assisted beam current production depends on the ioniser temperature, we measured the Br$^-$ beam current at different ioniser powers keeping other ion source parameters constant. Figure 2 shows the response of the Br$^-$ beam current to the ioniser heating power: (a) 77 W and (b) 124 W. Applying the laser beam allows reaching higher Br$^-$ beam current at 77 W ioniser power compared to running the source with 124 W ioniser power (note that the "baseline" current is approximately 0.5 μA in each case). This observation has been made repeatedly over 2 years of experiments [9]. We conclude that at lower ioniser power (temperature) the laser can affect the Cs coverage of the sputtering target more than at high ioniser power where the Cs$^+$ sputtering rate is higher, which presumably affects the Cs coverage of the cathode. Thus, higher negative ion yield can be achieved at low ioniser power when the laser pulse is applied.

3.3. Priming effect

Figure 3(a) shows the Br$^-$ beam current which increases up to 2.8 μA by applying a number of 3.6 minute laser pulses with 2.4 minutes in between them. After 8 laser pulses the maximum extracted beam current remains almost same, and the effect of the laser becomes small. Furthermore, after the laser pulsing is stopped, the extracted beam current remains at the elevated level, i.e. approximately at 2.6 μA. Figure 3(b) shows the corresponding cathode current, which reacts promptly to the laser beam with the photoelectron contribution remaining approximately constant throughout the pulsing. On the other hand, the total cathode current first decreases, which indicates reducing Cs$^+$ flux and/or secondary electron yield. These observations can be explained by the laser changing the cathode surface conditions towards more favourable Cs coverage for negative ion production. Notably the effect persists for few hours, which highlights the potential of the laser to control the temperature and Cs coverage of the cathode.

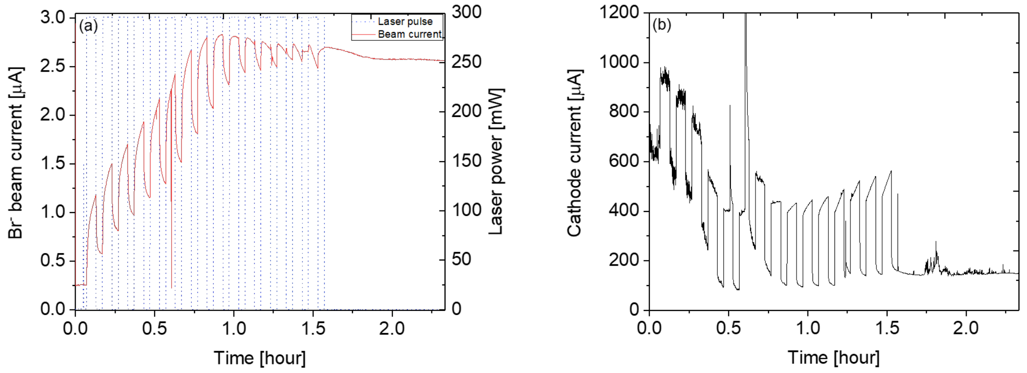

Figure 3. The effect of the 445 nm, 295 mW laser on the (a) Br$^-$ beam current and corresponding (b) cathode current. The laser pulse length is 3.6 min with 60% duty factor. In this case Ti target holder, ioniser heating power 81 W, and Cs oven temperature 145 °C were used.

3.4. Stabilisation of the Br$^-$ beam current

All previous experiments [6, 7, 8, 9] were conducted with laser pulse lengths in the order of seconds to minutes. Typically the beam current of a SNICS ion source varies significantly over time, which motivated us to attempt stabilising the beam current for several hours by active control of the laser power. Figure 4(a) shows our first attempt to sustain a stable Br$^-$ beam current at the higher level achieved with the laser. The corresponding cathode current is shown in Figure 4(b). In this experiment, we used continuous laser beam and controlled the laser power manually to compensate for the beam current fluctuation. Figure 4(a) shows that when laser was turned on we first observe a prompt effect allegedly due to the photoelectron emission, and then a gradual increase of the beam current presumably due to changing cathode surface caesium coverage. After this initial phase we gradually increased the laser power when the beam current started to decrease. Figure 4(a) shows that we were able to sustain the elevated beam current for few hours (typical operation time of the SNICS ion source) by active control of the laser power. Figure 4(b) shows that also the cathode current increases with increasing laser power.

4. Conclusion

The comparison of photo-assisted Br$^-$ beam current production with different target holders has shown no significant difference between the materials. We have also observed that the beam current

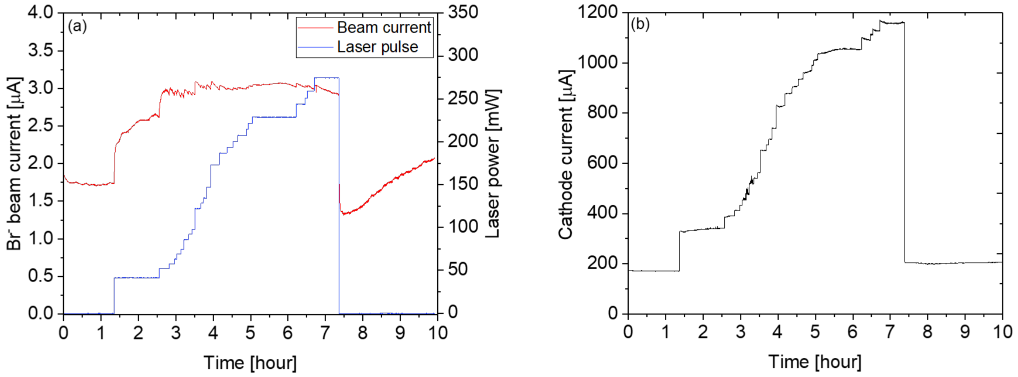

Figure 4. The effect of the 445 nm laser with different laser power on the (a) Br$^-$ beam current and corresponding (b) cathode current. In this case Ti target holder, ioniser heating power 90 W and Cs oven temperature 165 °C were used.

enhancement achieved with the laser depends on ioniser temperature. In certain ion source condition applying a number of laser pulses introduces a priming effect of the extracted beam current, which indicates that the laser beam changes the cathode surface condition. We have successfully demonstrated that the laser can be applied for stabilising the beam current up to seversal hours, which motivates implementing an active feedback system to make finer adjustments to the laser power to compensate for beam current trends. Furthermore, we plan to study the Cs coverage effects with different targets and negative ion beams (other than CsBr and Br$^-$). Finally, we will compare the effect of pulsed laser to the effect of pulsed cathode voltage reported in [17].

Acknowledgements

Patent application (number 20225597, “Method for photo-assisted enhancement of the intensity and stability of negative ion beams produced with alkali metal-based surface ionisation ion sources”) has been filed to the Finnish Patent and Registration Office.

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