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Title: First experiments with gasdynamic ion source in CW mode

Year: 2016

Version:

Please cite the original version:

Skalyga, V., Izotov, I., Golubev, S., Vodopyanov, A., & Tarvainen, O. (2016). First experiments with gasdynamic ion source in CW mode. *Review of Scientific Instruments*, 87(2), Article 02A715. <https://doi.org/10.1063/1.4934208>

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Citation: *Review of Scientific Instruments* **87**, 02A715 (2016); doi: 10.1063/1.4934208

View online: <http://dx.doi.org/10.1063/1.4934208>

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First experiments with gasdynamic ion source in CW mode

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(Presented 24 August 2015; received 5 September 2015; accepted 7 October 2015; published online 26 October 2015)

A new type of ECR ion source—a gasdynamic ECR ion source—has been recently developed at the Institute of Applied Physics. The main advantages of such device are extremely high ion beam current with a current density up to 600–700 emA/cm² in combination with low emittance, i.e., normalized RMS emittance below 0.1 π mm mrad. Previous investigations were carried out in pulsed operation with 37.5 or 75 GHz gyrotron radiation with power up to 100 kW at SMIS 37 experimental facility. The present work demonstrates the first experience of operating the gasdynamic ECR ion source in CW mode. A test bench of SMIS 24 facility has been developed at IAP RAS. 24 GHz radiation of CW gyrotron was used for plasma heating in a magnetic trap with simple mirror configuration. Initial studies of plasma parameters were performed. Ion beams with pulsed and CW high voltage were successfully extracted from the CW discharge. Obtained experimental results demonstrate that all advantages of the gasdynamic source can be realized also in CW operation. © 2015 AIP Publishing LLC. [<http://dx.doi.org/10.1063/1.4934208>]

I. INTRODUCTION

Investigations in the field of gasdynamic ECR plasma confinement in recent years resulted in development of pulsed high current ion sources capable to deliver ion beams with 100–500 mA current and normalized RMS emittance below 0.1 π mm mrad.^{1–6} Such results became possible, thanks to key features of quasi-gasdynamic plasma confinement in the case of heating with mm-waveband gyrotron radiation, namely, high plasma density and low plasma lifetime.^{7,8} While the pulsed operation of gasdynamic ion sources was studied in details,^{1–8} such devices have not been tested in CW mode before. In recent years, a new SMIS 24 experimental facility was installed at the Institute of Applied Physics of Russian Academy of Sciences (Nizhny Novgorod, Russia). At SMIS 24, the plasma is heated by 24 GHz radiation of CW gyrotron and confined in a simple mirror trap similarly to SMIS 37 facility which was used for pulsed operation experiments. In this paper, the first results on CW ECR discharge ignition, study of plasma parameters, and ion beam extraction are presented.

II. SMIS 24 EXPERIMENTAL FACILITY

The photograph and scheme of SMIS 24 is shown in Fig. 1. The microwave radiation is produced by CW 24 GHz 5 kW gyrotron (manufactured by GYCOM⁹). Radiation goes through microwave transmission line to a water-cooled DC-

break which is designed up to 100 kV. Following the DC-break, the radiation passes through a specially developed microwave coupling system optimized to maximize the electric field distribution on trap axis and minimize microwave reflection.

Plasma is created in the plasma chamber with 380 mm length and 38 mm diameter. The magnetic field is produced by a pair of water-cooled Bitter solenoids. The maximum magnetic field on trap axis reaches the value of 1.1 T. The ratio between magnetic field at the magnetic mirror and the trap center is 5 and the distance between magnetic mirrors (trap length) is 180 mm. The magnetic field distribution inside the plasma chamber is shown in Figure 2.

A two-electrode extraction system was used in the beam extraction experiments. In the first experiments, the plasma electrode and puller had 4 mm and 10 mm apertures, respectively. The available extraction voltage was in the range of 20–60 kV. Due to low power of the power supply, the extraction system was placed far behind the magnetic mirror to reduce the ion current density so that the total extracted current could meet the power supply maximum output. The plasma electrode (extractor) position together with the magnetic field distribution on axis and calculated expected ion current density is shown in Figure 3. The calculations are made by assuming 10¹³ cm⁻³ plasma density and electron average energy on the order of 100 eV. According to the estimation, we expected approximately 5.6 mA of total extracted ion current.

A Langmuir probe and a Faraday cup were used as diagnostic tools. The probe was used for the measurement of plasma flux parameters (electron temperature and spatial distribution). The Faraday cup was used to measure the total beam current. Argon was used in the experiments as a feeding gas in the pressure range of 10⁻⁶–10⁻⁴ Torr.

Note: Contributed paper, published as part of the Proceedings of the 16th International Conference on Ion Sources, New York, New York, USA, August 2015.

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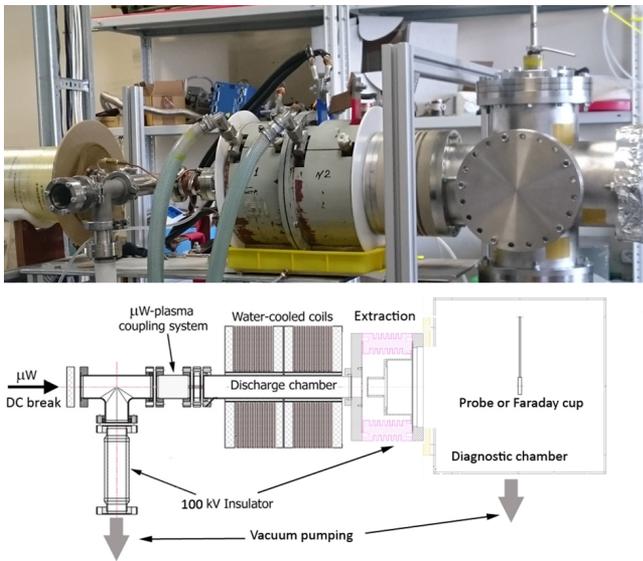


FIG. 1. SMIS 24 experimental facility. Gyrotron is on the left side (not shown).

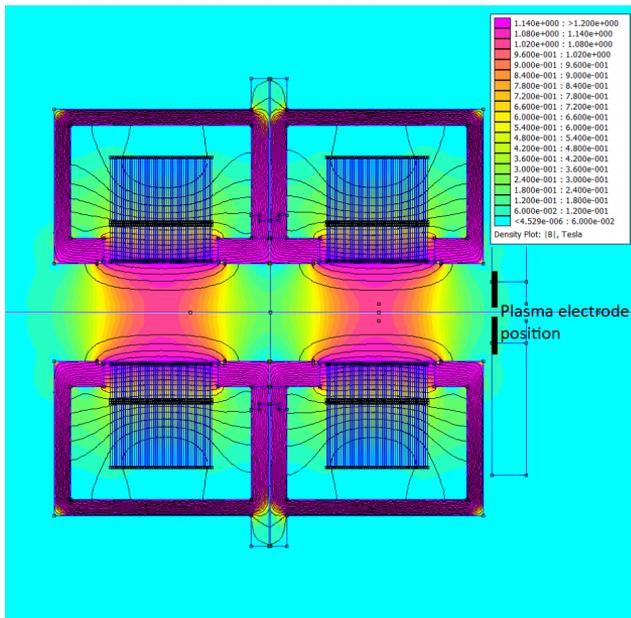


FIG. 2. Magnetic field structure of SMIS 24. Plasma electrode of the extraction system is schematically shown.

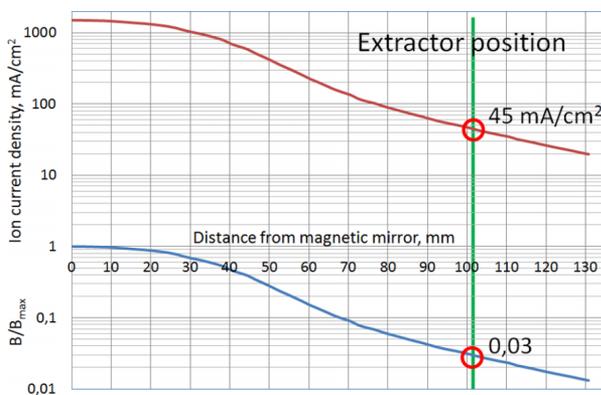


FIG. 3. Magnetic field distribution behind the magnetic mirror (blue). Calculated ion current density (red). Plasma electrode position (green).

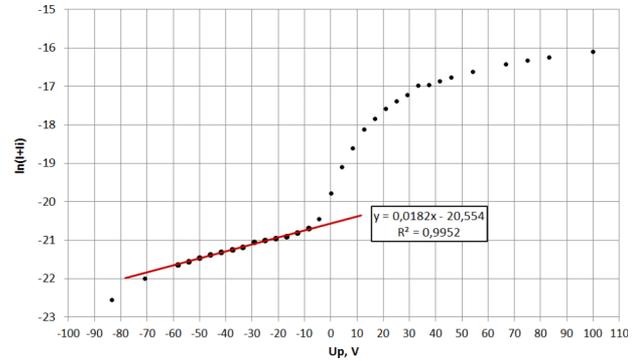


FIG. 4. Probe I-V curve. Microwave power = 200 W. Argon pressure = 6×10^{-6} Torr.

III. FIRST EXPERIMENTAL RESULTS

As the first experimental step, Langmuir probe I-V curves were collected from the plasma flux escaping the trap in order to determine the electron temperature and spatial distribution of the flux density. An example of typical I-V curve is shown in Figure 4 in the case of 200 W microwave power and 6×10^{-6} Torr neutral gas pressure. The measured electron temperature is 55 eV.

By moving the probe along the axis and measuring the ion saturation current, we measured the plasma flux density distribution, which is shown in Figure 5 together with the magnetic field distribution. It could be concluded from the figure that the plasma flux density approximately follows the magnetic field strength. This means that the plasma flux density at the magnetic mirror of the trap could be obtained by scaling the magnetic field. The corresponding maximum plasma flux density in our experiments reached 1 eA/cm^2 at the magnetic mirror. This value fits our initial calculations on probable plasma parameters. Measured plasma flux density in the case of 55 eV electron temperature under quasi-gasdynamic confinement corresponds to $1 \times 10^{13} \text{ cm}^{-3}$ plasma density inside the trap.

The first ion beam was extracted with the configuration described above. All results shown in this paper were collected with 25 kV extraction voltage. The total ion current dependence on neutral gas pressure is shown in Figure 6 for two microwave power levels. The flat part of the dependence probably corresponds to discharge conditions

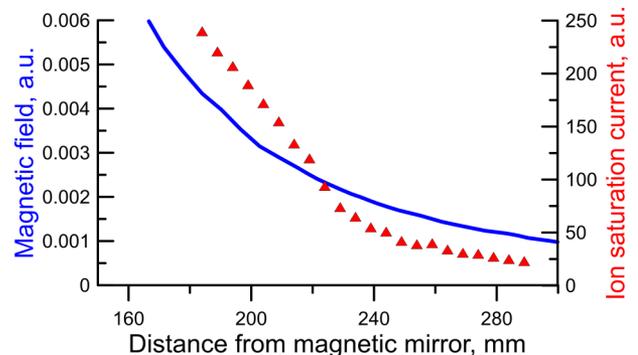


FIG. 5. Ion saturation current at different probe positions behind the magnetic mirror (red dots) and magnetic field distribution (blue line).

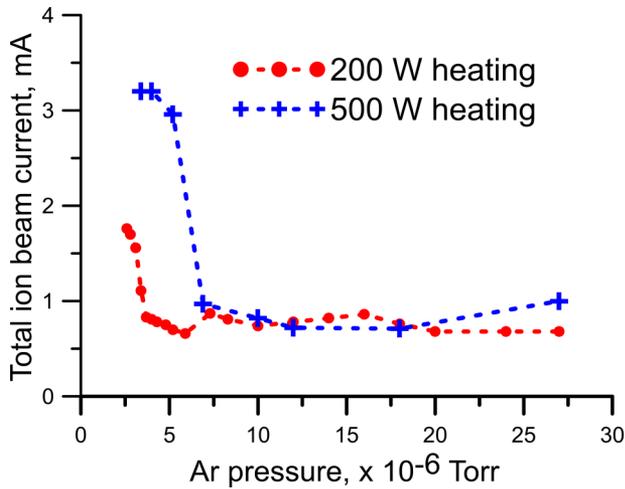


FIG. 6. Extracted ion current dependence on argon pressure for different microwave power levels.

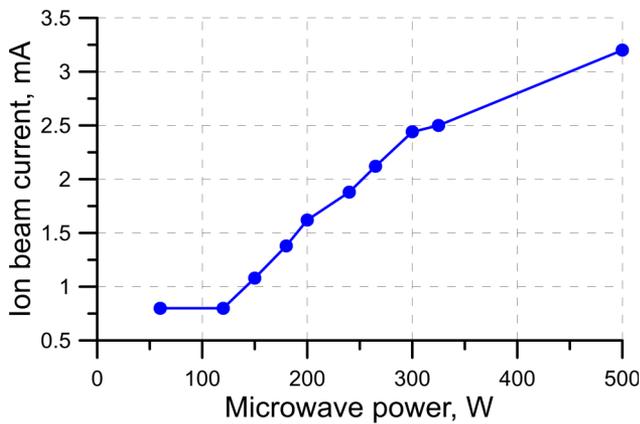


FIG. 7. Extracted ion current dependence on microwave power. Argon pressure = 6×10^{-6} Torr.

with too high pressure for effective ECR heating with the given microwave power.

In this case, one could expect a plasma of cut-off density with electron temperature close to 10 eV without observable pressure dependence. More effective plasma heating was obtained at lower pressure, which led to electron temperature growth and reduction of quasi-gasdynamic plasma lifetime, thus increasing the total current.

The same growing dependence of the extracted ion current was observed with the microwave power increase (see Figure 7).

The maximum beam current reached in the experiments was 3.2 emA through 4 mm hole. It is of note that the total current could be significantly increased by shifting the extraction system closer to the magnetic mirror, up to the values demonstrated in pulsed operation mode at SMIS 37.

IV. CONCLUSION

The first experimental study of CW ECR discharge with quasi-gasdynamic confinement sustained by 24 GHz gyrotron radiation demonstrated that results similar to those obtained in pulsed mode at SMIS 37 could be reached. Stable operation with 1 eA/cm^2 (estimated) of plasma flux density was observed in the experiments. This makes a formation of CW high current beams possible in close future in the frame of upcoming experiments. One of the most important steps will be an increase of the microwave power which becomes possible after an improvement of the plasma chamber cooling.

ACKNOWLEDGMENTS

The work was supported by RFBR under Grant No. 13-08-00845 and the grant of the President of Russian Federation for young scientists under No. #MK-6565.2014.2. The work of Ivan Izotov was supported by the fellowship of the President of Russian Federation for young scientists under No. #SP-7279.2013.2 and was also supported by the Academy of Finland under the Finnish Centre of Excellence Programme 2012-2017 (Nuclear and Accelerator Based Physics Research at JYFL) and researcher mobility under Grant Nos. 267174 and 267227.

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⁹See www.gycom.ru for details about available gyrotrons.