ISBN: 978-3-95450-196-0 doi:10.18429/JACoW-ECRIS2018-THA2

POINT-LIKE NEUTRON EMISSION OBSERVATION USING A NEUTRON GENERATOR BASED ON A GASDYNAMIC ECR ION SOURCE

R.A. Shaposhnikov, S.V. Golubev†, I.V. Izotov, R.L. Lapin, S.V. Razin, A.V. Sidorov, V.A. Skalyga, 603950 Nizhny Novgorod, Russian Federation

Abstract

One of the interesting applications of ECR ion sources is their use as a part of neutron generators. The use of high-current gasdynamic sources with plasma heating by high-frequency gyrotron radiation allows to increase neutron yield, and obtain a point-like neutron emission by sharp focusing of a high-quality deuterium ion beam on a target. Such point-like neutron source could perspective for neutron tomography. In the first experiments at tha SMIS 37 facility the high-current deuterium ion beam was focused by a simple magnetic coil (magnetic field strength up to 3 T) placed behind two-electrode extraction system on a titanium target saturated with deuterium. It was demonstrated that in such system a weakly descending 60 mA ion beam with the convergence of 50 could be focused in 1 mm spot resulting in $8\ \mathrm{A/cm^2}$ of current density at the focal plane. Measured neutron yield from the target placed in the focal region under conditions of the beam energy of 80 keV reached a value of 10^{10} neutrons per second in 1 ms pulse.

INTRODUCTION

Electron-cyclotron resonance (ECR) ion source is one of the most width spread types of systems that are designed to produce ion beams of multicharged ions or protons. One of directions of ion sources development is an increase of extracted ion beam current. The problem of the beam current increase is related to the problem of maximum attainable values of plasma density in a discharge. The solution of this problem can be based on the implementation of the gas-dynamic plasma confinement regime, which is characterized by a high plasma density and its low lifetime. Previous experiments conducted at the IAP RAS were aimed at investigating the possibility of proton beams formation from the ECR discharge in a simple mirror magnetic trap [1].

The experimentally obtained dependence of the ion beam current extracted through the 10 mm aperture on the extraction voltage demonstrated the possibility of obtaining current values up to 500 mA, which corresponds to a current density about $600\ \mathrm{mA/cm^2}$.

A pepper-pot method was used in a purpose to measure the ion beam emittance. This method has been described in detail in [2]. The results of measurements showed the possibility of obtaining beams with normalized emittance at the level of 0.05 pi · mm · mrad. Such a low value of emittance opens the possibility for effective focusing of the ion beam.

IBSimu code [3] was used for ion trajectories simulation in the field of magnetic focusing lens [4]. As a result of numerical simulation, the theoretical possibility of high-current ion beam focusing into a region of the order of 100 μm was demonstrated. The results of numerical calculations demonstrating the possibility of obtaining ion beams with small widths, as well as experimental data on obtaining high-current ion beams, open the possibility of creating a point-like neutron source based on the deuterium-deuterium synthesis reaction, which occurs when a focused beam of deuterium ions hits the deuterium containing target. There is an isotropic neutron emission from the target during the reaction. In this case, the characteristic size of the neutron source is determined by the quality of the ion beam and by the effectiveness of the focusing system.

The main application of the point-like neutron source could be neutron tomography [5].

EXPERIMENTS

Experiments aimed at producing the point-like neutron source were carried out at the SMIS 37 facility (Fig. 1). Gyrotron microwave radiation with a frequency of 37.5 GHz, power up to 100 kW and a pulse duration of 1.5 ms was used for plasma heating and discharge ignition. The plasma was created in a simple mirror magnetic trap operating in a pulsed mode with 0.1 Hz repetition rate. The use of powerful gyrotron radiation allowed to realize a gas-dynamic plasma confinement regime with the lifetime $\tau = \frac{R \cdot L}{2 \cdot V_S}$, where R is the mirror ratio, L is the length of the trap and V_S is the ion-sound speed. The operating gas (hydrogen) was inlet into the discharge chamber in pulsed mode along the axis of the magnetic system through a gas-entry system integrated into the electrodynamic system for microwave radiation injection. A two-electrode system consisting of a plasma electrode with a diameter of 10 mm and a puller electrode with a diameter of 22 mm was used in a purpose of ion beam extraction. The distance between electrodes was 15 mm. A magnetic coil which was used as the magnetic lens was placed behind the extraction system. It's magnetic field was regulated independently of the magnetic field of the trap (the magnetic field strength reached 3 T).

† gol@appl.sci-nnov.ru

ISBN: 978-3-95450-196-0 doi:10.18429/JACoW-ECRIS2018-THA2

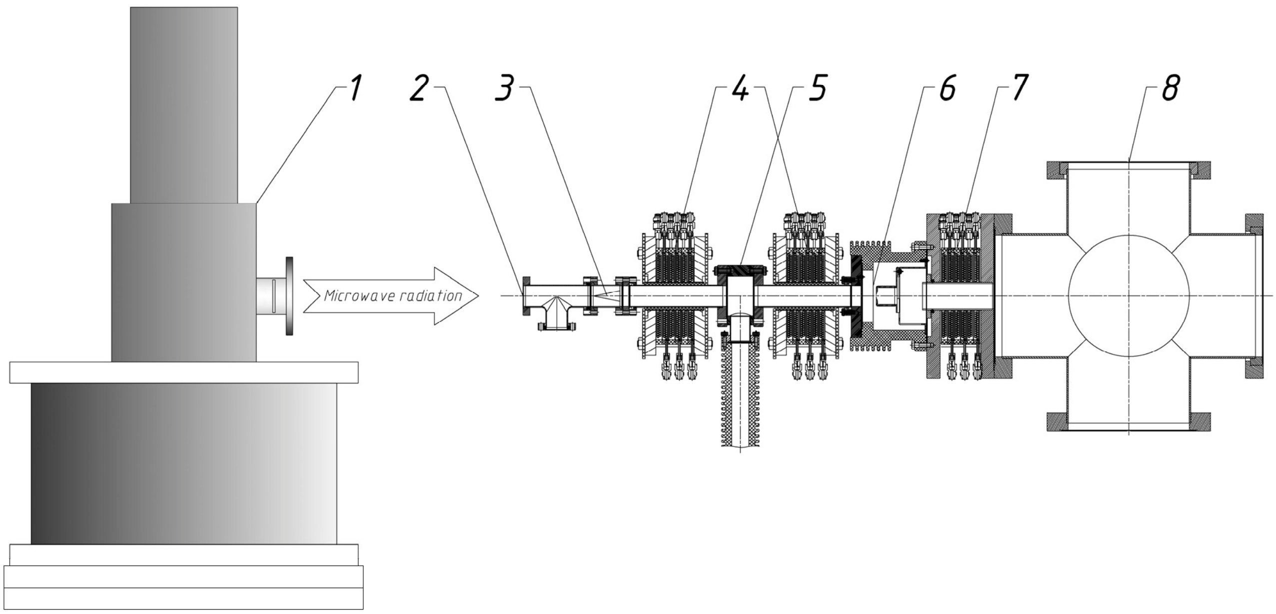

Figure 1: The experimental facility SMIS 37. 1 – gyrotron, 2 - microwave window, 3 - quasi-optical system for microwave radiation coupling into plasma, 4 - pulsed magnetic coils, 5 - discharge vacuum chamber, 6 - extraction system, 7 - focusing lens, 8 - diagnostic chamber.

ION BEAM FOCUSING

The extracted ion beam current in the focal region of the magnetic lens was measured with a Faraday cup. As a result of system parameters optimization the value of an ion beam current at the focus was 50 mA (Fig. 2).

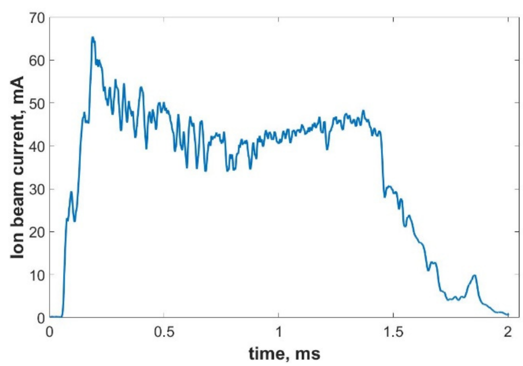

Figure 2: Ion beam current oscillogram at the focus of the lens.

The CsI scintillator located along the axis of the system in the diagnostic chamber after the focusing lens with a diameter of 100 mm was used for the ion beam size diagnostics. Using a special camera "Nanogate" with exposure time of 20 µs a number of photos of the scintillator luminescence were made to determine the beam dimensions. At optimal system parameters, such as the magnetic field of the trap, the magnetic field of the focusing lens, and the extraction voltage, it was possible to achieve focusing of the ion beam in a spot with 1 mm size.

A typical photo of the scintillator glow and a plot of the radial distribution of scintillator luminescence is shown in Figs. 3 and 4. The beam size was determined at half of the glow intensity maximum.

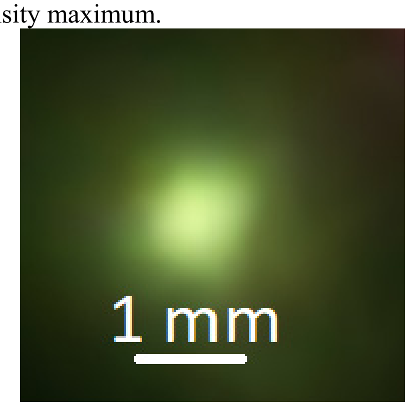

Figure 3: The photo of the scintillator glow at the best focusing parameters.

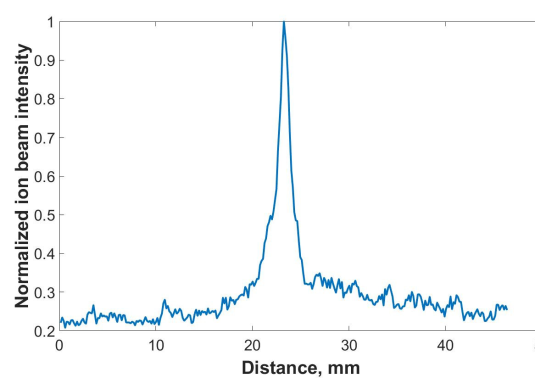

Figure 4: The dependence of normalized ion beam intensity on the radial coordinate.

ISBN: 978-3-95450-196-0 doi:10.18429/JACoW-ECRIS2018-THA2

NEUTRON PRODUCTION

To study the efficiency of neutron generation and to determine the characteristic size of the source, the scintillator was replaced by a titanium-deuterium target, which was irradiated with a focused beam of deuterium ions. Measurements of characteristics neutron flux values were carried out using a calibrated neutron detector. The detector was located at a distance of 1.5 m from the neutron source. These measurements showed that the neutron flux increases with the growth of ion beam current and energy. At the current of 50 mA and energy of 80 keV the neutron flux reaches values of $10^{10}\mathrm{s}^{-1}$ which corresponds to the neutron flux density at the emitting region on the target of $10^{12}\mathrm{s}^{-1}\mathrm{cm}^{-2}$. Spatial distributions of the neutron flux were studied using a set of radiochromic films located behind the lead shield near the target (Fig. 5). Such films accumulate defects caused by x-rays and fast particles including neutrons. Figure 6 shows an image of the transverse neutrons flux intensity distribution. The characteristic transverse dimension of the image at a distance of 0.5 cm from the target is about 1 cm, which is due to the isotropic emission of neutrons from the source with dimensions of 1 mm (the size of the deuterium ion beam on the target).

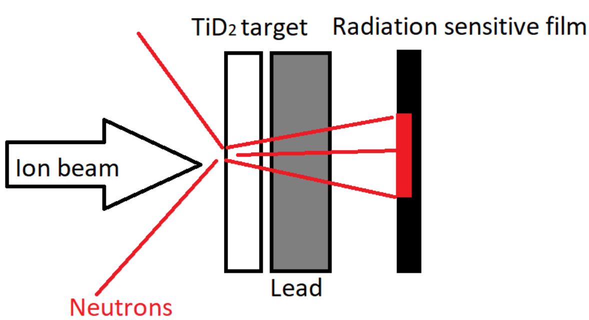

Figure 5: Scheme of the radiochromic film irradiation with the neutron flux.

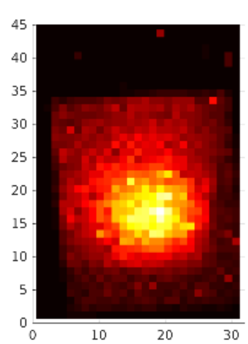

Figure 6: Image of the neutrons flux intensity distribution (dimensions are shown in mm).

CONCLUSION

During the experiments on the focusing of the deuterium ion beam, it was demonstrated the possibility of focusing the extracted beam into a region of 1 mm size. The neutron flux reaches values of $10^{10}\,\mathrm{s}^{-1}$ what corresponds to the neutron flux density at the emitting region of $10^{12}\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$. Such neutron flux density is perspective for neutron tomography of compact (about 10 cm) objects.

ACKNOWLEDGEMENTS

Presented work was supported by the grant of Russian Science Foundation # 16-19-10501

REFERENCES

[1] A. Sidorov, M. Dorf, A. Bokhanov, I. Izotov, S. Razin, V. Skalyga, V. Zorin, A. Balabaev, P Spädtke, J. Roßbach, "Multi-aperture ion beam extraction from gas-dynamic electron cyclo-tron resonance source of multicharged ions", *Review of Scientific Instruments*, vol. 79, p. 02A317 (2008)

[2] A. Septier, *Applied Charge Particle Optics, Academic Press,* New York, 1980, p. 214.

[3] T. Kalvas, et. al., "IBSIMU: A three-dimensional simulation software for charged particle optics", *Rev. Sci. Instrum*. vol. 81, p. 02B703, (2010).

[4] S.V. Golubev, V.A. Skalyga, I.V. Izotov, A.V. Sidirov, S. V. Razin, R.A Shaposhnikov, R.L. Lapin, A.F. Bokhanov, M. Yu. Kazakov, "On the possibility of creating a point-like neutron source", *Radiophysics*, vol. LX,n°10

[5] Ian S. Anderson, Robert L. McGreevy, Hassina Z. Bilheux, "Neutron Tomography", in *Neutron Imaging and Applications*, *Ed. New York, NY, USA: Springer*, pp. 81-86, (2009)