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AN ULTRA COMPACT 10 GHz ELECTRON- CYCLOTRON-RESONANCE ION SOURCE (ECRIS) FOR THE PRODUCTION OF MULTIPLY CHARGED IONS

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There is a growing interest in the use of beams of multiply charged ions produced in special environments like high voltage platforms, Dynamitrons, Van-de-Graaff accelerators or on-line production systems for radioactive beam facilities. A compact 10 GHz ECR ion source (200mm long, 170mm diameter) has been developed and tested. The complete magnetic structure made from permanent magnet material is comprised of four ring magnets producing an asymmetric axial magnetic field with a mirror ratio of 2.5 and a 24 piece hexapole magnet with a maximum radial field of 0.94T inside the plasma chamber of 25mm inner diameter. The coupling of the microwave to the plasma using a resonant transition line from rectangular to circular waveguide shows efficient ECR plasma heating at microwave power levels around 10 watts. Charge state distributions for various elements with intensities up to 320 eμA and their dependence on operation parameters will be presented as well as VUV spectra in the wavelength region down to 15 nm.

INTRODUCTION

There is a steadily increasing interest in the use of compact ECR ion sources, resulting predominantly in their applicability in different fields of atomic physics and as injectors for accelerators using small high voltage terminals with limited space and electrical power available, i.e. Dynamitrons or Van-de-Graaff accelerators. In the Giessen crossed beams ion-ion collision experiment where one of the ion sources is installed on a 400kV high voltage terminal [1], compact ECR ion sources are used [2] to study ionization and charge exchange processes involving multiply charged ions [3] and to obtain more precise knowledge of quasi-resonant charge exchange reactions in isoelectronic ion-ion collision systems ($X^{(q+1)+} + Y^{q+} \rightarrow X^{q+} + Y^{(q+1)+} + \Delta E$). This is important for the understanding of the processes involving impurity ions in tokamak produced fusion plasmas [4]. The ionization and recombination processes occurring in ECR plasmas produce photons which are the basis for well established spectroscopic diagnostics [5,6,7]. These photons also bear the potential of

atomic structure studies and spectroscopic applications, e.g. spectrometer wavelength scale calibration. The spectral range of the extreme ultraviolet (EUV) below 20nm is of special interest here, since the existing Penning discharge sources produce lines with low intensities and are limited to only a few hours of operation due to the lifetime of their cathodes. A fully permanent ECR ion source on the contrary runs at low gas pressures and has a good long term stability and reproducibility [8] because of only two operating parameters, gas pressure and microwave power. The low set-up costs of the ion source allow also small laboratories to study processes involving highly charged ions, i.e. an ion-surface interaction experiment for studying electron emission in coincidence with ions scattered at the surface [9]. Ion sources as modular and easy to maintain as the one presented are also of interest for on-line production systems for radioactive beam facilities. High ionization efficiency for multiply charged ions obtained with ECR ion sources [10,11] are one of the main advantages over standard ISOL sources although ECR ion sources generally have

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larger emittances and beam spreads due to the extraction from a high magnetic field area.

SOURCE DESCRIPTION

A detailed description of the setup of the ion source is given elsewhere [12]. Only recent modifications of the setup instituted in order to improve the performance of the ion source will be discussed. A cross section of the source is shown in Fig. 1. The axial magnetic confinement of the hot plasma electrons has been improved by using larger magnet rings at the microwave injection side. The axial mirror ratio $B_{\max}/B_{\min}$ has been enhanced to 2.5 with a field maximum of 0.8 T and 0.5 T, respectively as shown in Fig. 2. The Halbach-type 24-segment hexapole magnet gives a radial magnetic field of 0.94 T at the inner wall of the plasma chamber. Due to the poor extraction efficiency in previous runs a new insulation flange with a larger opening and a tapered puller electrode assembly has been built (not shown in Fig. 1).

FIGURE 1: Schematic overview of the compact 10 GHz ECR ion source.

RESULTS

The dependence of extracted intensities and charge states on the applied microwave frequency has been investigated after installing the new magnetic system. The magnetron based microwave generator is tunable in the range of 8.75 to 10.5 GHz with a maximum output power of 275 watts c/w. The optimum performance for the current magnetic system was obtained at a frequency of 8.85 GHz. Table 1 shows maximum extracted beam intensities for various gases in different charge states at microwave power levels between 5 and 50

watts. All results were obtained at an extraction voltage of 9kV using a 5mm diameter extraction aperture. The residual gas pressure during these measurements was 2×10^{-6} mbar. First measurements regarding the photon yield from an ECR plasma were performed by using a 32cm grazing incidence spectrometer with a grating of 550 g/mm with maximum efficiency at 15 nm. The resolution of the spectrometer was 0.4 nm at a dispersion of 2 nm/mm using an entrance slit of 100 μ m. Fig. 3 shows a detailed spectrum of an Oxygen plasma in the spectral range between 10 and 28 nm were mainly O IV and O V transitions could be identified. This spectrum was measured using 60 watts of microwave power at a gas pressure of 6×10^{-6} mbar. The inlay in the graph shows the stability of the plasma measuring a single transition line in a Neon plasma (NeII $2s^2 2p^5 - 2s 2p^6 (^2P - ^2S)$) at 44.7 nm over a period of 7 hours. Using this transition line we also found an excellent reproducibility after extinguishing and reigniting the plasma by turning the microwave power off and on. Spectroscopy at higher resolution using a 5m grazing incidence spectrometer has been performed recently and showed intense lines down to 12nm obtained from a Ne plasma. Since the data analysis is still in progress no spectra can be shown at this moment. For all the spectroscopic measurements a modified setup of the source without insulation flange and puller electrode was used.

FIGURE 2: Axial magnetic field on axis.

highly charged ions, i.e. 250 enA of Ar^{10+} and 150 enA of O^{7+} .

First measurements of photon emission from an ECR plasma in the low VUV spectral range for both Neon and Oxygen plasmas showed intense transition lines of highly charged ions down to about 12nm as well as a very stable source performance over several hours.

Further developments at the compact 10 GHz ECRIS will be focused on the production of metallic ions. A miniature high temperature oven is already under construction as well as a new microwave injection system. Using a waveguide to resonator to coaxial line transition we will generate a different wave-mode in the plasma chamber, which allows the study of the microwave heating processes in the plasma in more detail.

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