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 0.94 T 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 eA 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 \( X^{(q+1)+} + Y^+ \rightarrow X^q + Y^{(q+1)+} + \Delta E \). 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 20 nm 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_m/B_i 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 2x10^-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 μm. 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 6x10^-6 mbar. The inlay in the graph
shows the stability of the plasma measuring a
single transition line in a Neon plasma (NeII
2s^22p^52s2p^63p^2(3D-3S) 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.
FIGURE 3: Detailed line spectrum obtained from an oxygen plasma in the spectral range between 10 and 28 nm. The inlay shows the photon emission of a single NeII transmission over a period of 7 hours to show the stability of the plasma.

TABLE 1: Maximum ion beam intensities in eμA extracted at 9kV for various elements in different charge states. All intensities are measured in a Faraday cup without taking the extraction efficiency into account.

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<th>q / Species</th>
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<th>C</th>
<th>N</th>
<th>O</th>
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<td>13</td>
<td>40</td>
<td>100</td>
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<tr>
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<td>2.2</td>
<td></td>
<td>4.2</td>
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DISCUSSION AND OUTLOOK

In respect of the use of compact ECR ion sources for the on-line production in radioactive beam facilities, where the number of radioactive atoms to be ionized is limited, efficiency measurements using a calibrated leak have been performed. Preliminary data show a total ionization efficiency for Neon of about 30%. This number already takes the very poor transmission efficiency of the ion source test bench of around 10% into account. Part of that problem is the small diameter of the puller electrode and insulation flange which results in a loss of a part of the beam directly after the extraction. The new puller electrode assembly has already been built but not yet tested.

We showed intense extracted ion beams up to 320 eμA for He⁺ and the production of useful beams of
highly charged ions, i.e. 250 enA of Ar\textsuperscript{10+} and 150 enA of O\textsuperscript{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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