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Compact, Low-Cost, 14.5GHz All-Permanent Magnet Field ECR Ion Source*

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Abstract A compact 14.5GHz electron cyclotron resonance (ECR) ion source for the production of slow, multiply charged ions has been constructed, with the plasma-confining magnetic field produced exclusively by permanent magnets. Microwave power of up to 175W in the frequency range from 12.75 to 14.5GHz is transmitted from ground potential via a PTFE window into the water-cooled plasma chamber which can be equipped with an aluminum liner. The waveguide coupling system serves also as biased electrode, and two remotely-controlled gas inlet valves connected via an insulating break permit plasma operation in the gas-mixing mode. A triode extraction system sustains ion acceleration voltages between 1kV and 10kV. The ECR ion source is fully computer-controlled and can be remotely operated from any desired location via Ethernet.

Key words low-cost compact ECRIS, all-permanent magnet ECRIS, ECRIS for multiply charged ions

1 Introduction

We have built a compact (overall length app. 50cm) 14.5GHz all-permanent magnet ECR ion source, to replace an earlier constructed 5GHz ECR ion source with normal-conducting mirror magnet coils (total power consumption about 30kW) and a permanent-magnet hexapole field[1]. With the new ion source higher ion charge states are obtained, the extraction efficiency at low acceleration voltage could be improved, and the total electrical power consumption of the ion source setup is practically negligible.

2 Description of the new ECR ion source

A schematic drawing of the ECR ion source is shown in Fig. 1. Magnetic field for plasma confinement is generated by four permanent magnet rings and a Halbach-type hexapole[2]. To minimize its production costs, this magnet system has been kept as small as reasonably possible, and a high fraction of standardized vacuum components has been used. Production of multiply charged ions can be enhanced[3] by operating the waveguide coupling system as a biased electrode, and by inserting an aluminum sheet liner into the 25mm inner diameter plasma chamber.

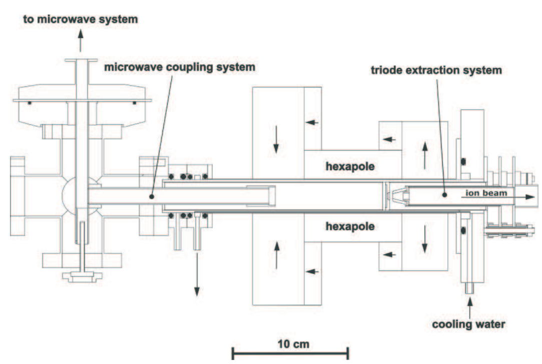

Fig. 1. Schematic drawing of the 14.5GHz all-permanent magnet ECR ion source (top view).

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Two remotely-controlled gas inlet valves are connected via an insulating break and permit plasma operation in the gas-mixing mode[3]. For production of higher ion charge states the water-cooled plasma chamber is evacuated during operation by a small turbomolecular pump at ground potential connected via an insulating break. The whole permanent magnet setup can be shifted along the plasma chamber axis in order to optimize extraction of differently charged ions. A triode "accel-decel" extraction system sustains ion acceleration voltages from typically 1 up to 10kV. All operating parameters of the ion source can be remotely controlled by the LabVIEW[4] based programme CODIAN[5] and a VNC[6] client/server software. Simple hardwired interlock systems permit unattended continuous operation of the ECRIS at reduced microwave power (typically 10W), which assures long-term stability of ion currents especially at low extraction voltage.

2.1 Permanent magnet system

The permanent magnet system has been manufactured by Vacuumschmelze Hanau, Germany, using the high remanence NdFeB alloy "VACODYM 7 655 HR". Design of the system is based on longstanding experience with permanent magnet ECR ion sources developed in Giessen, with magnetic field configurations being optimized by computer simulations[7]. The "minimum-B" magnetic field structure needed for plasma confinement is produced inside the plasma chamber by superposition of an axial magnetic mirror field and a radial hexapole field, providing mirror ratios of 2.1 on the microwave entrance side and of 1.9 on the ion extraction side, respectively, with a maximum field strength of about 0.9T. To keep the resonance zone as far away from the plasma chamber wall as possible, a comparably strong Halbach type hexapole[2] with 80mm outer diameter has been chosen.

2.2 Microwave system

The microwave power supply system consists of a 200W Ku-band compact travelling wave tube (TWT) amplifier (VZU-6992EC by CPI - Communication and Power Industries), fed by a thin film oscillator (OMNIYIG 1518 YIG). It permits continuous operation in the range from 12.75GHz to 14.5GHz at a power of up to 175W. A circulator protects the amplifier from too high reflected microwave power. Transmission into the discharge chamber with electrical insulation from the latter is made through a simple 2mm thick PTFE window. In the vacuum chamber, the microwave guiding system changes from the WR-75 rectangular- to a 13mm ID cylindrical geometry. This part of the microwave guiding system can be biased with respect to the ion source chamber potential by up to 2kV, in order to serve as biased electrode[3] (see Fig. 2). By avoiding coaxial waveguides this setup allows to efficiently transmit the microwave power into our comparably narrow plasma chamber and still maintains the necessary vacuum pumping speed and the option for biased electrode operation. The PTFE window has no direct sight of the plasma which would result in undesired coverage by sputtered metal films. Plasma operation with non-gaseous feeding compounds is possible with minor modification of the present microwave coupling system by adding a suitable oven.

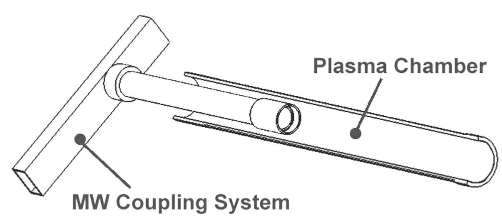

Fig. 2. Schematic view of the microwave coupling system. The shown waveguide system is insulated from the ion source plasma chamber and can serve as biased electrode.

2.3 Ion extraction system

The ion source is equipped with a triode "accel-decel" extraction system, featuring a 5mm diam. extraction aperture in the discharge chamber. Three cylindrically concentric electrodes are supported, precisely positioned and isolated by ceramic spacers. The accel (suppressor) and decel (extraction) electrodes are fixed on the plasma electrode which fits snugly into the plasma chamber, in order to be easily removed from the latter for maintenance. The extraction system can be operated with a potential difference of up to 10kV between the decel electrode and the ion source chamber, and of up to 2kV between accel and decel electrode. Having fixed electrodes the extraction system is operated at "perveance-match" conditions by adapting the accel and decel voltage to the given ECR plasma properties. The ion energy is then chosen by accelerating or decelerating the ions with ion optics at the various experimental stations.

3 Performance of the new ion source

Measurements to characterize the overall performance of the ion source have been carried out with an ion extraction voltage of 5kV, using a 3mm aperture shielded Faraday cup[8] behind a 60° analyzer magnet. Relevant ion source parameters have been adapted to achieve maximum currents for selected ion charge states q, with oxygen as "mixing-gas". For these measurements no ion optics has been used to enhance the focusing of the ion beam. The detected currents with corresponding main parameters of the ion source are given in Table 1.

Table 1. Typical Ar ion currents (3mm Faraday cup — no ion optics for focusing).

argon charge state	FC current [el. nA]
1	2500
2	1850
3	1750
4	1480
6	1300
7	1140
8	1100
9	380
11	50
12	30
13	2

Even higher ion charge states than listed could be observed but not quantified in the same way. Negative biasing proved to be beneficial for extraction of higher charged ions. For lower ion charge states the listed ion currents reached saturation well below the maximum available microwave power (limited to 175W during routine operation). Only for charge states beyond Ar^{11+} it was necessary to deploy full microwave power. Typical Ar mass-to-charge spectra are shown in Fig. 3.

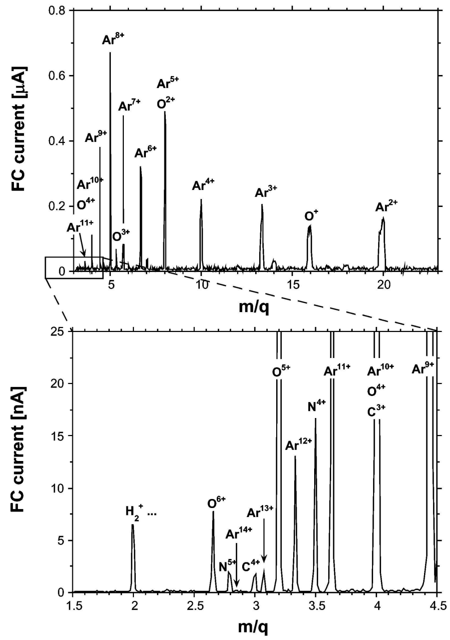

Fig. 3. Typical Argon charge state spectra. Ion source parameters were optimized for Ar^{13+} extraction. Ion currents were measured in a 3mm aperture Faraday cup, no ion optics have been used to focus the ion beam.

4 Conclusion

A new, compact ECR ion source for the production of slow, multiply charged ions with magnetic confinement field generated exclusively by permanent magnets has been constructed and its overall performance explored. The ion source can be remotely controlled and operated via Ethernet, and it is now routinely used in our laboratory for experiments on low-energy multiply charged ion collisions in the gas phase and on surfaces. For improved ion beam stability the source, if not used for experiments, is run continuously at reduced microwave power. It can be operated without maintenance for weeks, with intermissions caused primarily by short-circuits in the extraction system. The operating parameter field of the ion source has so far by no means been fully explored, and therefore its performance may well exceed the here described status.

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