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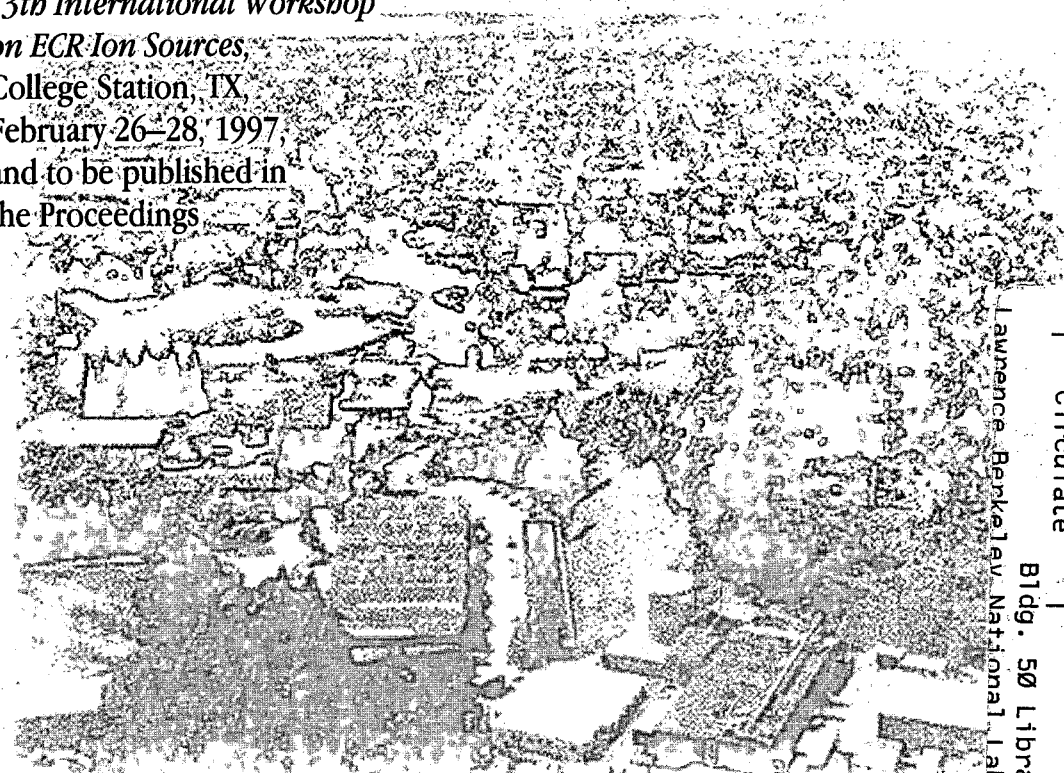# ERNEST ORLANDO LAWRENCE
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Accelerator and Fusion
Research Division

May 1997

DISCLAIMER

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Design of a 2.45 GHz ECR Ion Source for Production of Low and Medium Charge States Ions

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Abstract

At Lawrence Berkeley National Laboratory we are constructing an ECR ion source test facility for nuclear science experiments. For this purpose a single-stage 2.45 GHz electron cyclotron resonance ion source has been designed and fabricated. It features an axial magnetic field with a mirror ratio of up to 5.5 and a hexapole field produced by a novel Nd-Fe-B permanent magnet assembly. In order to enhance the ion confinement time the source plasma volume has been enlarged as much as possible while still maintaining a high mirror ratio. This paper describes the design of the source. Ion optics simulation of the extraction system currently under design will also be presented.

1. Introduction

At Lawrence Berkeley National Laboratory we are developing an 2.45 GHz ECR ion source for the production of low and medium charge state ion beams for the nuclear science program as well as for industrial applications. The ion source test stand currently under construction consists of the following components: an ECR ion source, a diagnostic spool (Faraday cup and emittance scanner) and a transport system (quadrupole triplet and analyzing magnet).

In this paper we describe the design of the ion source. In addition ion optics simulations for the extraction system will be discussed.

2. Design of a 2.45 GHz ECR ion source

2.1 General layout of the ECRIS

The ion source was designed around an available power source of 2.45 GHz and 1 kW. Since our goal is to produce medium charge state ions, this choice of 2.45 GHz operation frequency (wave length 12.2 cm) has several consequences for the layout of the ion source. The plasma chamber has to be relatively large to ensure efficient propagation of the 2.45 GHz microwaves into the plasma chamber. A plasma chamber diameter of 13.5 cm was chosen (see Fig. 1). In order to compensate for the lower achievable electron plasma densities at this low microwave frequency, the plasma confinement has to be enhanced. In an ECR ion source, the ion axial confinement time is proportional to the length of the mirror and the mirror ratio. The radial confinement is proportional to the diameter of the plasma chamber [1-3]. Therefore the magnet configuration has been optimized for an

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enhanced axial magnetic mirror ratio of 1:5.8 at the injection and 1:4.5 at the extraction side. The radial confinement is achieved by a correspondingly strong hexapole structure. The plasma chamber has a diameter of 13.5 cm and the mirror length is 28.3 cm, providing a relatively large plasma volume of 5 liters. In addition, the aluminum chamber walls and a biased disk will provide cold electrons for the discharge, which results in longer ion confinement time and increase the plasma stability [4]. In the current setup the microwave power is limited to 1 kW, but we are planning to upgrade the microwave system for higher input power.

The schematic view of the ion source is shown in Fig. 2. The design involves one plasma stage only. The microwaves are coupled via a coaxial line into the plasma chamber. A biased copper disk is mounted at the tip of the antenna. The plasma chamber is double walled to accommodate cooling water which is guided through the extraction flange. A picture of the double walled plasma chamber with the sleeve for the hexapole magnets is shown in Fig. 3.
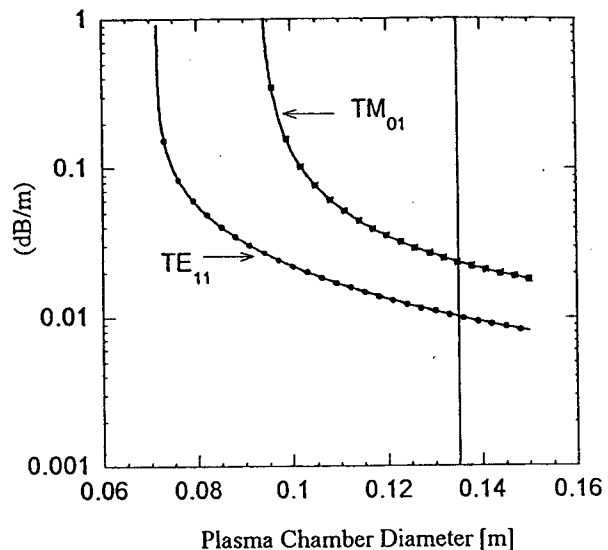
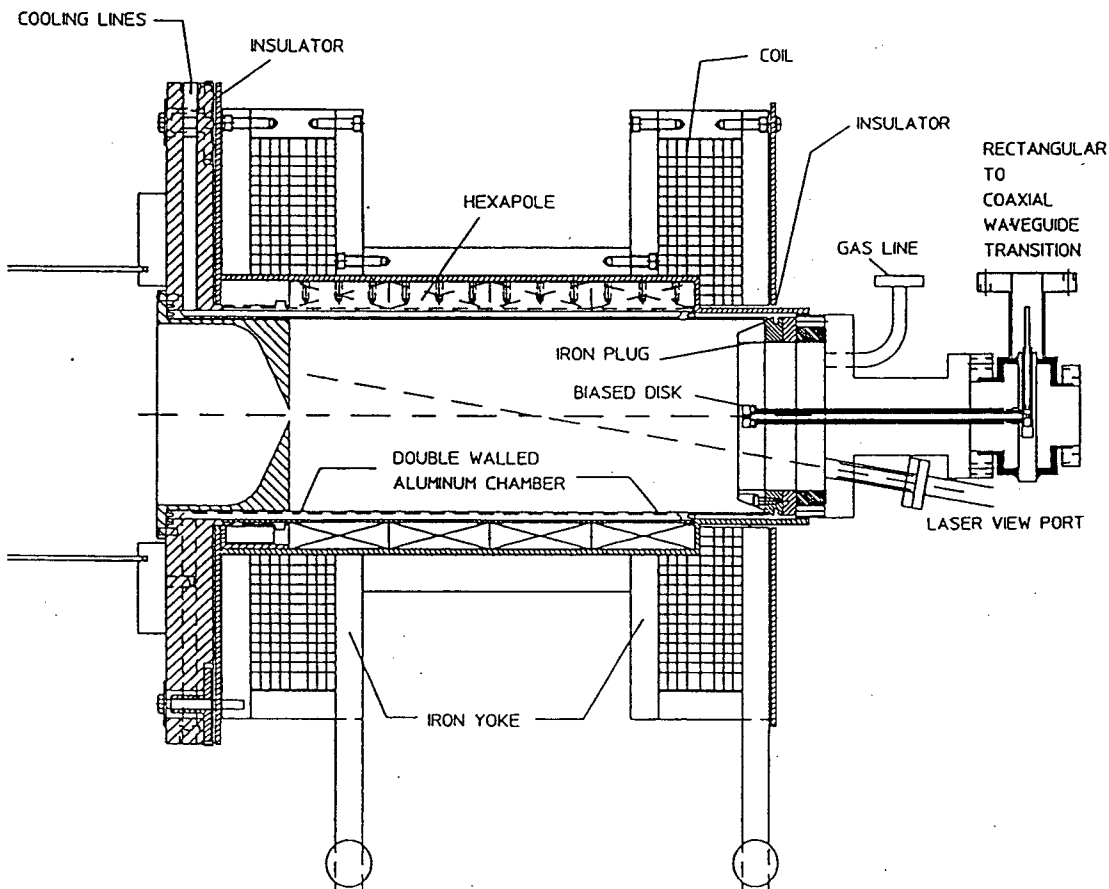Fig.1   Attenuation of the 2.45 GHz wave in the plasma

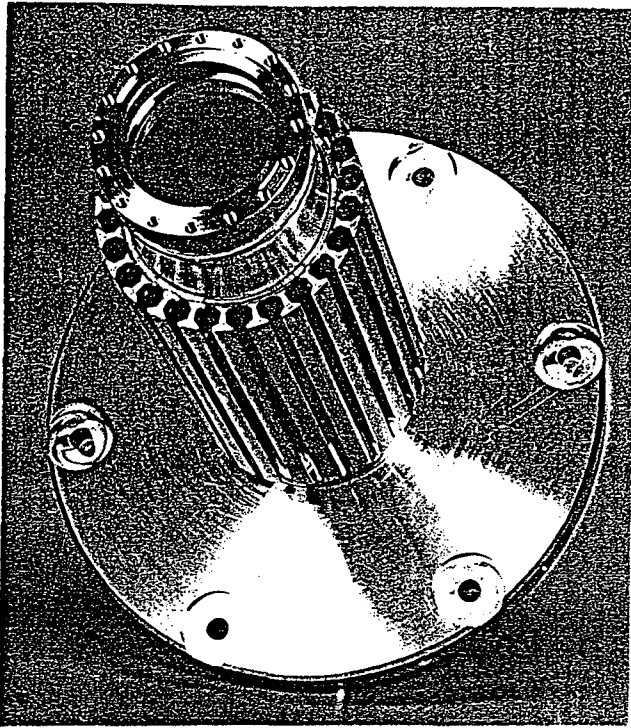Fig.2   Design drawing of the 2.45 GHz ECR ion source.

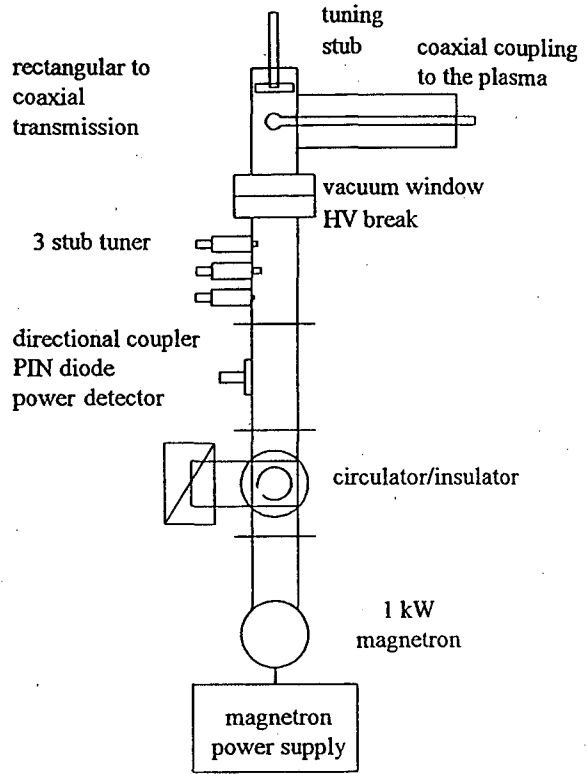Fig.3   Picture of the double walled plasma chamber.

Fig.4   Schematic Sketch of the 2.45 GHz microwave system

2.2 Microwave system

A 2.45 GHz magnetron delivering up to 1 kW of microwave power is coupled via a 90 degree rectangular-to-coaxial wave guide transition into the plasma chamber. The magnetron is protected by a water cooled insulator. Matching of the microwave power to the plasma is optimized by a three stub tuner. The reflected power can be monitored with a 50 dB directional coupler and power detector. A Teflon vacuum window provides an electrical insulation for the microwave-line from the discharge chamber up to 30kV (Fig. 4.).

The design drawing of the rectangular to coaxial wave guide transition is shown in Fig. 5. The biased disk is mounted on the antenna tip. A moveable tuning plate allows tuning for an optimal match of the wave guide transition.
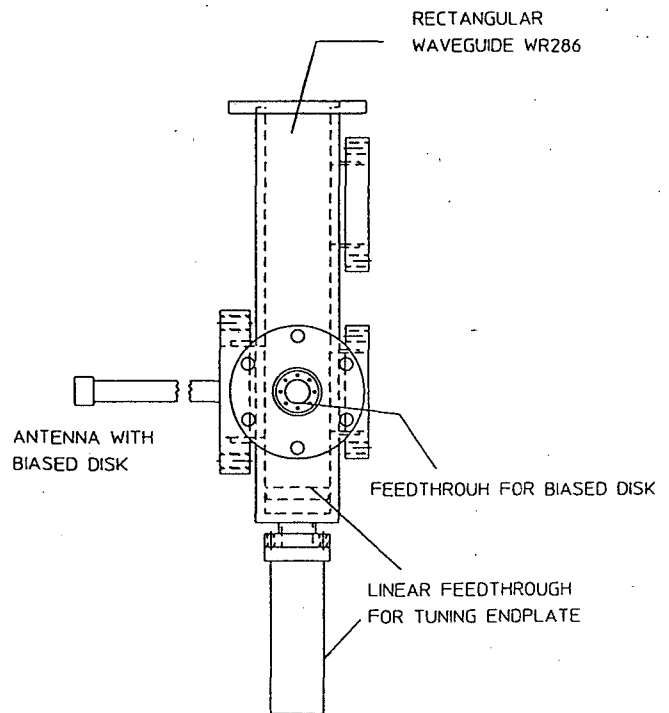

Fig.5   Design drawing of rectangular to coaxial wave guide transition

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2.3 Magnetic System

The axial magnetic mirror field is produced by two water-cooled copper pancake coils (with a 6.7x6.7 mm^2 conductor cross section and a 3-mm-diam bore for water cooling). The magnetic mirror ratio is enhanced by encasing the solenoids with soft iron (see Fig.6).The maximum magnetic field on axis is 0.5 T. The mirror ratio is 1:5.8 at the injection side and 1:4.5 at the extraction side with additional iron pieces installed. Fig. 8 shows a comparison of the measured magnetic field without the additional iron on axis and the calculated B-field at 450 A coil excitation current. The mirror length is 28.3 cm, corresponding to the 28 cm long linear hexapole structure.
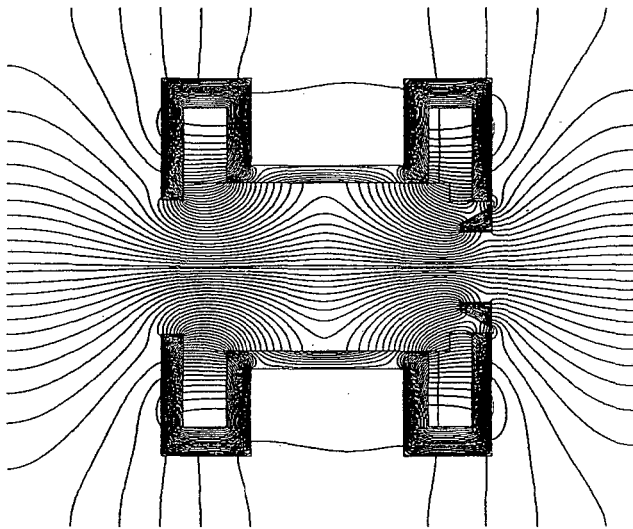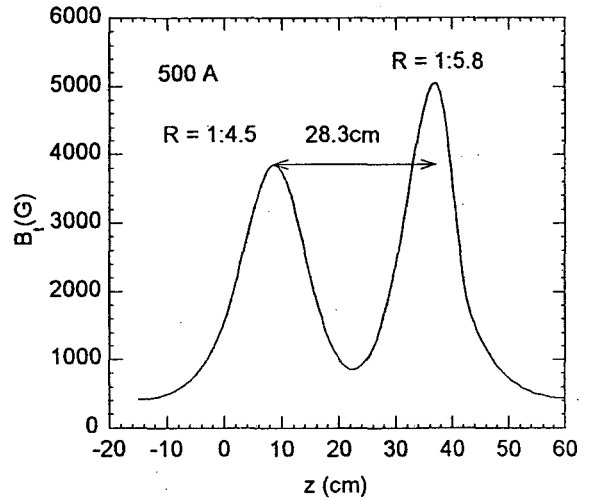

Fig. 7 Poisson computation of the axial magnetic field for a total power consumption of 26 kW.

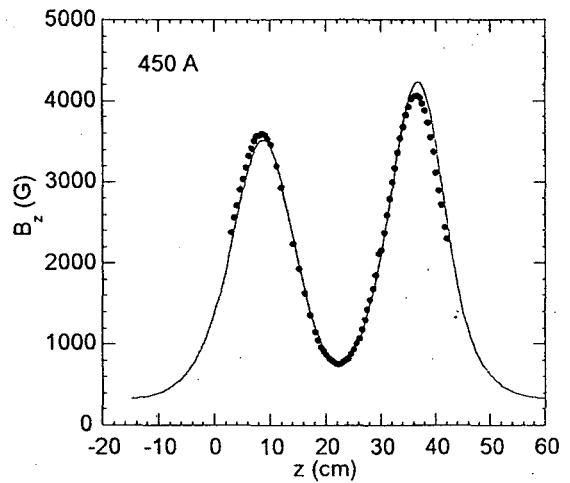*Fig. 6 Poisson computation of the axial magnetic field.*

Fig. 8 Comparison of the calculated (line) and measured magnetic field (dots).

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A corresponding strong permanent magnet design was developed, which was optimized with respect to costs and field strength as well as simplicity of the construction. The hexapole-field is formed by 24 rows of equally shaped and properly orientated NdFeB magnets.
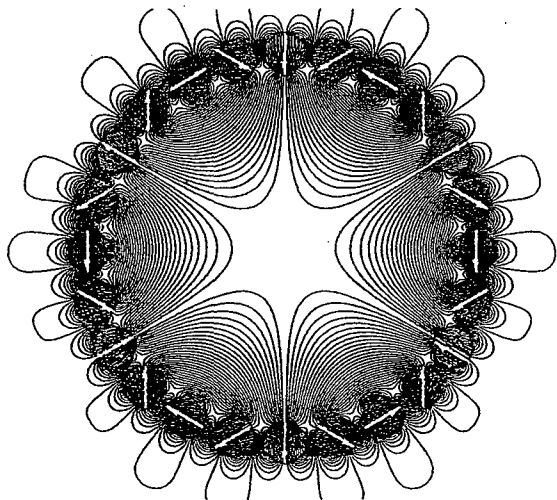

Fig. 9 Poisson calculation of the radial magnetic flux lines of the hexapole

Fig. 10 Comparison Poisson Simulation/Measurement of the radial magnetic field..

The octupole shape of the magnets permits a gradual change in the orientation of the magnetic field of the hexapole from one section to the next (see Fig. 9), increasing the achievable field strength and uniformity of the field. Apart from the 2.45 GHz ECR resonance zone, the permanent magnet hexapole field permits the formation of higher frequency resonance zones, which facilitates operation of the ion source at higher frequencies. [Fig. 10]

3. Extraction System

The design of the extraction system was optimized by using the 2D ion optics code IGUN[5]. The system consists of three electrodes (accel-decel type), followed by an einzel lens to focus the beam into the Faraday cup of the diagnostic spool or to the focal point of the quadrupole triplet. The ion source insulation allows extraction voltages of up to 20 kV with an accel-lens voltage of up to -20 kV.

For a 2.45 GHz ECRIS, the achievable charge state distribution generally peaks at low charge states. Therefore the velocity of the extracted ion beam is low and the influence of the space charge becomes high. To avoid beam envelope growth due to space charge, an additional focusing element has to be added to the extraction system as close as possible. In most cases space at the plasma electrode is limited since it is located inside the solenoid of the magnetic mirror. Therefore we utilized the accel-decel extraction system as a focusing element. For this purpose the accel electrode has to be biased at a high negative potential. Experiments with a 2.45 GHz ECRIS [6] for intense He and Li ion beams have shown that the ion beam transmission can be increased considerably if the accel electrode is used as a first focusing lens launching the beam into the next focusing einzel lens system [7]. A similar approach is used for the present extraction system. The simulations have been carried out with an Ar beam of an
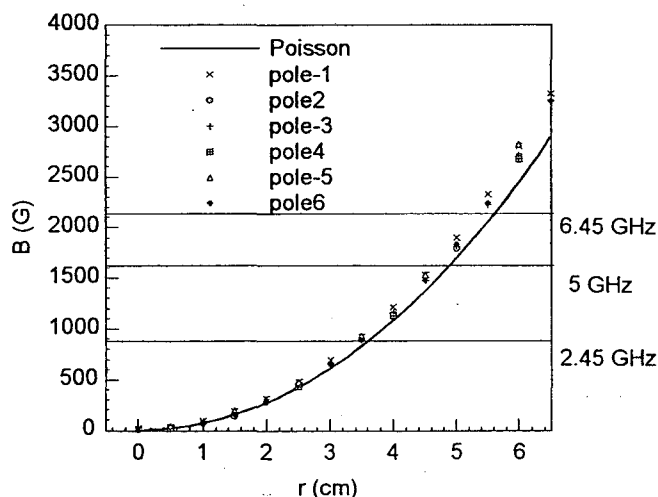
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UP=20024.4 eV
TE=5.0 eV
2 mA
MASS=30.0,
20000 V   -20000 V   0 V   0 V   18000V   0 V
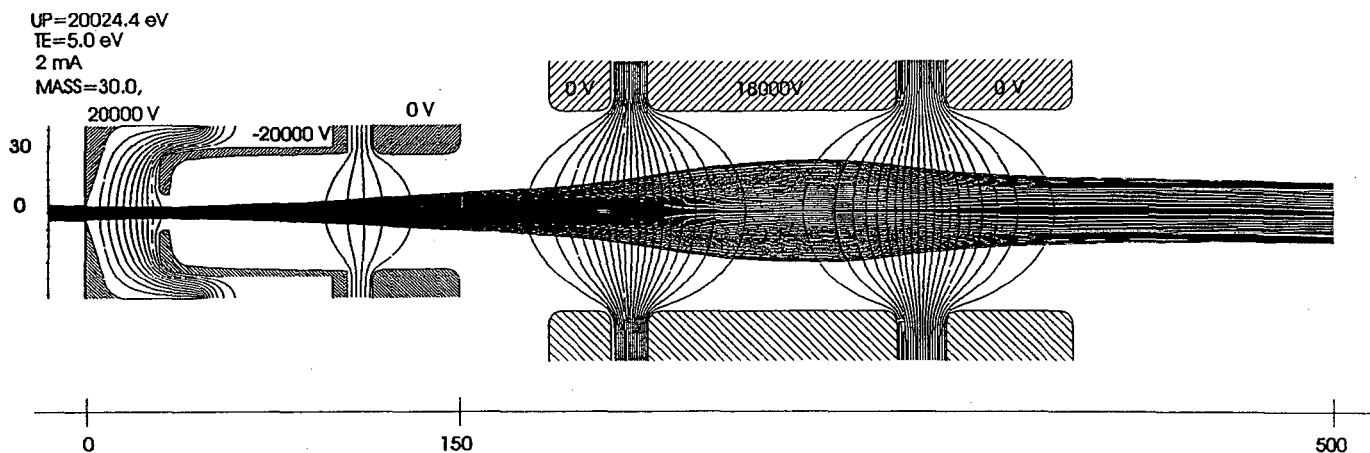
30

0

0   150   500

Fig. 11 IGUN Simulation of the ECR Extraction System including the einzel lens. The dimensions are shown in mm.

average mass to charge of 30, which assumes a charge state distribution of about 50% singly charged and 50% doubly charged ions. The extracted ion beam current density used for all calculations was 6.8 mA/cm^2 (6 mm extraction hole and 2 emA of ion beam current). Fig. 11 shows the IGUN simulation for the extraction system.

The accel lens is used as a first focusing lens transporting the beam out of the coils and launching the beam into the einzel lens. Since the first two electrodes are movable, the position of the accel electrode can be optimized with respect to the plasma meniscus shape. In the accel lens, the effective beam energy is 40 kV. This will minimize the blowing up of the beam due to space charge. We will compare the experimental results with the computational values.

4. References

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