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The modifications of the JYFL 6.4 GHz ECR ion source

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Abstract A new JYFL 14 GHz ECRIS was completed in spring 2000 for the nuclear physics program at the Department of Physics, University of Jyväskylä (JYFL). The old JYFL 6.4 GHz ECRIS (built in 1990–1991) is now also available for the material physics experiments and for the research and development work of the ECR ion sources. During the last year remarkable modifications to the structure of the source have been undertaken. In the first phase, which was completed in fall 2001, the axial magnetic field was optimized using the old power supplies and the coils. The radial magnetic field was improved in spring 2002 by installing an iron cylinder around the hexapole permanent magnets. According to the measurements the improvement of about 25% to the radial magnetic field was achieved. The research work to improve the ion beam quality has been started.

Key words ECR ion source • ion beams

Introduction

The JYFL 6.4 GHz ECRIS [2] was completed in 1991. The ion source was similar to the 6.4 GHz RT-ECRIS [1] at the National Superconducting Cyclotron Laboratory, Michigan State University (NSCL/MSU). The ECRIS research and development work was strongly limited due to the effective use of the JYFL 6.4 GHz ECRIS for its main purpose – delivering the ion beams 6000–7000 h/year for the nuclear physics experiments.

The JYFL 14 GHz ECRIS was completed for the nuclear physics program in spring 2000 [7]. The ion source is based on the AECR-U at the LBNL [10] and its magnetic field configuration is similar to ARTEMIS [6] at the NSCL/MSU. The new source is performing well, as the intensity of 627 μA for O^{6+} ion beam at the acceleration voltage of 10 kV indicates. It has been found also that the JYFL 14 GHz ECRIS can be operated with a very low material consumption rate after the careful tuning of the source. For a titanium run of 282 h the consumption rate was 0.06 mg/h with 18–19 μA of Ti^{10+} ion beam [5] produced using the MIVOC method [4]. This gives a very high value of 7% for the production efficiency of Ti^{10+} ion beam. Since the summer 2001 no development work with this source has been done.

The new source gave a possibility to start an efficient research and development work using the JYFL 6.4 GHz ECR ion source. In this article, the activities performed with our old 6.4 GHz ECRIS will be described.

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The basic behavior of the ion source and its extraction system will be studied with the aid of the old 6.4 GHz

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ECRIS. The ion source is available also for the material science program at the JYFL. In addition to this project, the old ion source is needed with the JYFL 14 GHz ECRIS when beam cocktails are produced for the irradiation of different electronic components. It is used also as a backup source for the K-130 cyclotron. To serve all the above mentioned programs the old 6.4 GHz ion source was upgraded and the work to improve the ion beam quality was started.

Upgrade of the source

In order to improve the performance of the JYFL 6.4 GHz ECR ion source, the magnetic field configuration was optimized in two steps. In order to keep expenses low, the upgrade was realized by using the old coils, power supplies, permanent magnets and the plasma chamber. In the first step, the axial magnetic field was increased by changing the grouping of the coils and the iron configuration. This step was realized in 2001 and gave a remarkable improvement to the axial magnetic field. The maximum B-field in the injection and in the extraction increased from the value of 0.33 T and 0.27 T to the value of 1.2 T and 0.6 T, respectively [8]. These values fulfill the experimentally found scaling rules [3] for the optimum operation at the 6.4 GHz ECR ion source.

In the second phase the radial magnetic field was upgraded by installing an iron cylinder around the hexapole permanent magnets. This idea was described in Ref. [8] and the work was completed in spring 2002. The effect of the cylinder to the hexapole field was measured to be about 25%. Figure 1 shows the assembly of the iron cylinder.

The total expenses of the project (excluding the cost of salaries) were less than 10 kEUR including the material costs and the work done outside the laboratory. As Fig. 2 shows a remarkable improvement to the performance was obtained. For example, the intensity of O^{7+} ion beam increased by the factor of about 50. The experiments after the upgrade have shown that in some cases the maximum ion current is now limited by the extraction system of the ion source.

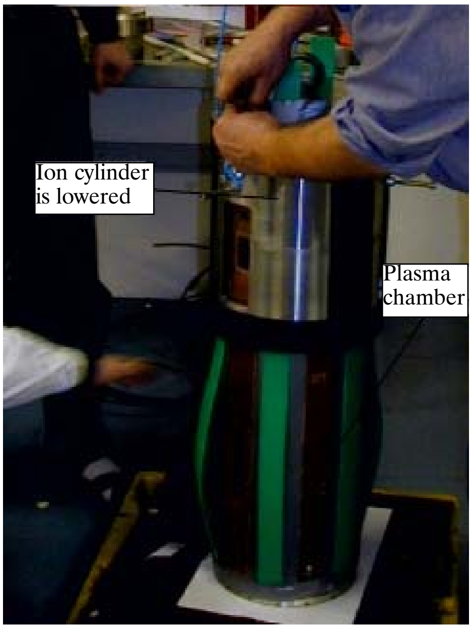

Fig. 1. The assembly of the iron cylinder.

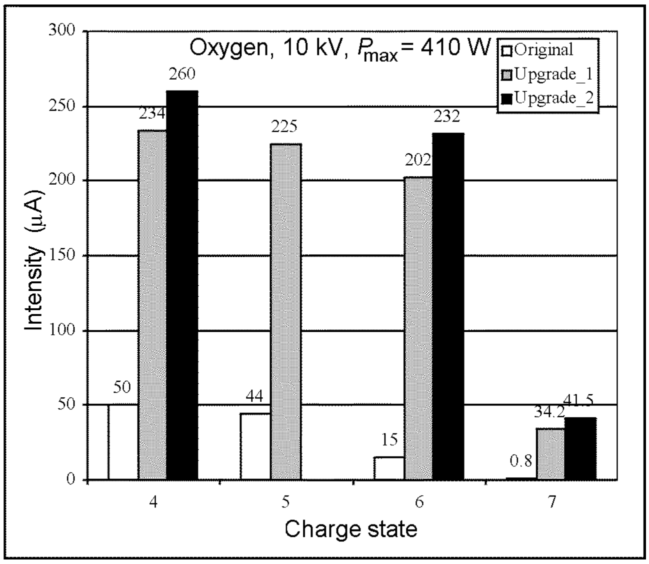

Fig. 2. The intensity of oxygen ion beams before and after the first and second phase upgrade.

Extraction of JYFL 6.4 GHz ECRIS

In the present extraction geometry, the minimum length of the acceleration gap is 36 mm (Fig. 3). The Puller-electrode aperture is 10 mm in diameter. No Puller voltage was used because its effect before the upgrade was found to be almost negligible. After the Puller-electrode the beam is transported through the Einzel lens.

Several experiments have been carried out to determine the conditions for the space charge limited ion beam production. The intensity of the ion beams was measured as a function of the acceleration voltage. The measured values were compared to the behavior estimated by Child–Langmuir law, which gives the maximum current density

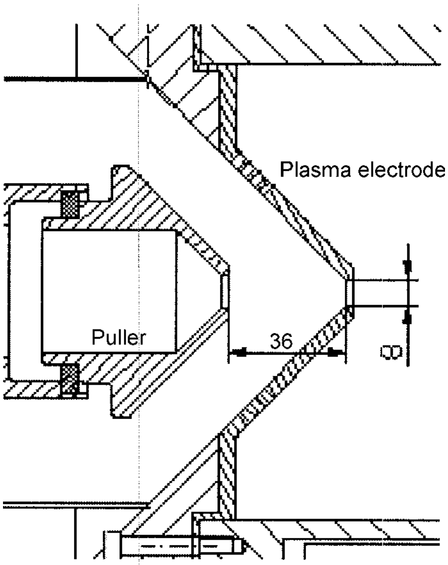

Fig. 3. The acceleration area of the JYFL 6.4 GHz ECRIS.

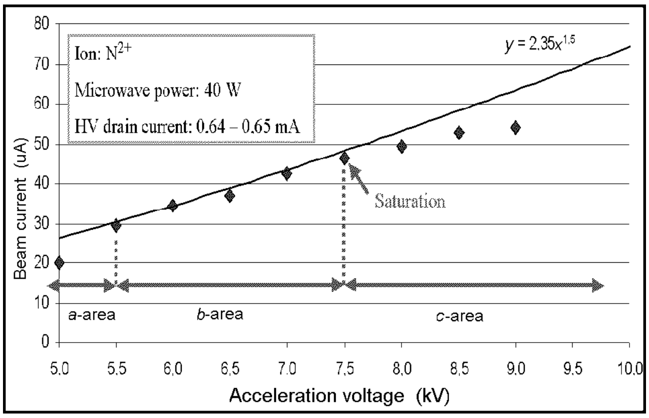

Fig. 4. The ion beam intensity as a function of the acceleration voltage.

at the distance *d* (extraction gap) from the exit hole (plasma electrode).

Figure 4 shows the intensity of N^{2+} ion beam as a function of the acceleration voltage. The triangles and the solid line correspond to the measured and the estimated ion beam intensities. The estimations were done with the aid of the Child–Langmuir law. As Fig. 4 shows the ion beam intensity behaves according to the Child–Langmuir law when the acceleration voltage is approximately 5.5–7.5 kV (*b*-area in Fig. 4). At low values of the extraction voltage (*a*-area) the ion beam spreads out and collides with the Einzel lens. The space charge limited current occurs as long as the intensity follows the Child–Langmuir curve. After this point the current density is limited by the tuning and the performance of the ion source. The point where this happens is determined here as a saturation point (Fig. 4).

Figure 5 gives a rough estimation for the maximum ion current, which can be extracted through the puller hole. All the measurements have been done for N^{2+} ion beam with different source tunings. For example, at 10 kV acceleration voltage (grounded Puller-electrode) the maximum ion current is about 1.2 mA. Beyond this value the ion beam is space charge limited. The deviation in the saturation points (for example, *a* and *b* in Fig. 5) is due to the different tuning of the ion source and consequently the different charge state distribution (different average charge state). The results obtained support to connect the high voltage power supply to the Puller-electrode in order to increase the electric field in the acceleration gap.

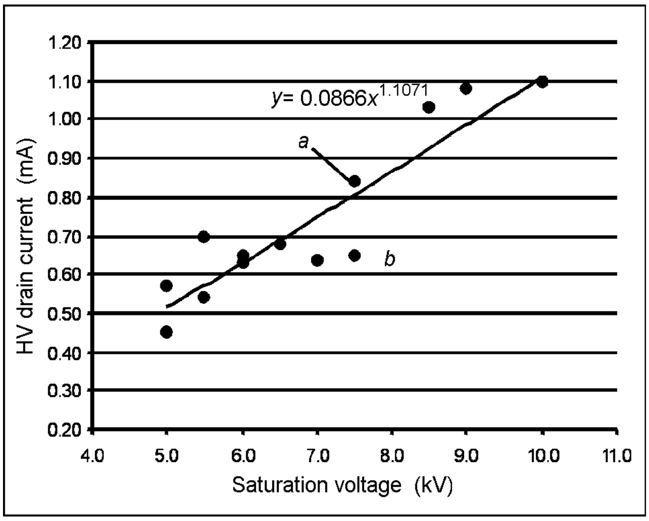

Fig. 5. The drain current as a function of the saturation voltage.

In the spring 2002 the LBNL-type emittance scanner [9] was built and assembled into the beam line of our ion sources. The measurements to understand the behavior of the emittance have been started. It has been found that the emittance value is typically between 130–250π mm·mrad depending on the source tuning and the charge state. Here the emittance value is given in phase space area occupied by the beam – not necessarily elliptic. The acceptance of the K-130 cyclotron is 100π mm·mrad.

Discussion

The 10 years old JYFL 6.4 GHz ECRIS has successfully been upgraded. A remarkable improvement to the performance of the ion source has been achieved (factor of 50 for O^{7+}). The idea to use an iron cylinder around the hexapole structure to improve the radial magnetic field has been proven to be effective in the case of the old fashioned permanent magnet configuration. The improvement of about 25% in the radial magnetic field *B* was measured.

After the upgrade process of our old 6.4 GHz ECRIS, the total ion beam intensity can exceed the value of 2 mA when the ion beams like O^{6+} and Ar^{8+} are produced. According to our measurements the space charge limited ion beams can be produced in the extraction gap and consequently a part of the ion beam is lost. The first measurements have shown that normally the emittance of the beam is much larger (30–150%) than the acceptance of the K-130 cyclotron. These experiments gave a strong motivation to start the development work for the extraction area of our ECR ion sources.

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