Preliminary Tests of the DECRIS-4 Ion Source

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Abstract The ECR ion source DECRIS-4 has been designed and constructed at the FLNR JINR to be used as a second injector of heavy multiply charged ions for the U-400 cyclotron. The design of the magnetic structure of the source was based on the idea of the so-called “magnetic plateau”. The axial magnetic field is formed by three independent solenoids enclosed in separated iron yokes. As a result the superposition of the coils and hexapole magnetic fields creates the enlarged resonance volume. The first experiments showed that the source was able to produce more than 300eμA of Ar^{8+} when only 100W of microwave power was used. During the last experiment almost 500eμA of Ar^{8+} was extracted with the same power. In this paper we will present the preliminary results with other gaseous ions, such as oxygen, krypton and xenon.

Key words ECR ion source, multiply charged ions

1 Introduction

The electron cyclotron resonance (ECR) ion source DECRIS-4 for the U-400 cyclotron was started in the end of 2003 with the development of the magnetic structure, which was completed in the beginning of 2005. The design of the source was aimed to improve the efficiency of cyclotron exploitation, where the ^{48}Ca ion beam is accelerated about of 95% of operational time[1]. For this reason the increasing of the ionization efficiency, the prolongation of the micro-oven “lifetime,” the improvement of the beam transport efficiency, and so on were the main goals of this ion source design.

2 DECRIS-4 design

The main feature of the ion source design is the use of so-called “magnetic plateau” which allows the enlargement of a resonance zone volume. This idea was suggested by Alton and Smithe[2] and successfully realized by authors and later by the Munster University team[3]. The scheme of the magnetic structure and the axial magnetic field distribution when coils are exited with the nominal current (900A for two main coils) are shown in Fig. 1.

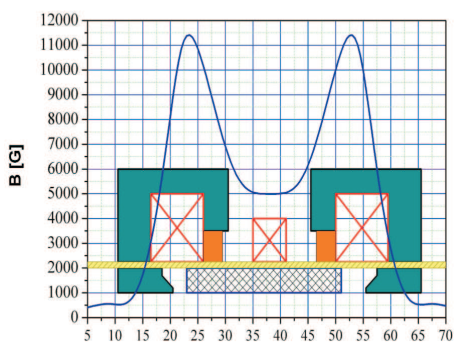

Fig. 1. The scheme of the magnetic structure and the axial magnetic field distribution.

The axial magnetic field is formed by three independent solenoids enclosed in separated iron yokes. The “flat” minimum of the axial magnetic field in

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the geometrical center of the ion source is created with the help of the middle coil. Two movable soft iron rings keep this minimum as "flat" when the main coils current is in the range from 800 to 1000A. The position of the rings depends on the coil current and is assigned experimentally. Because of the symmetry of the magnetic system the maximal magnetic field at the axis is up to 1.3T on both sides which provides a mirror ratio of about 2.5. The length of the "flat" minimum is about of 60mm.

The hexapole for the radial confinement has a Halbach structure and consists of 24 geometrically identical permanent-magnet sectors with the corresponding easy axis direction. The magnetic field on the plasma chamber wall (r=37mm) is 1.05T.

The stainless-steel plasma chamber is made as water-cooled double wall tube. The internal diameter of the plasma chamber is 74mm. UHF coupling is performed by the standard waveguide. The movable bias-electrode is used for precise cavity tuning. The main parameters of the ion source are collected in Table 1.

Table 1. The main parameters of DECRIS-4.

microwave frequency	14GHz
$B_{\rm inj}$, $B_{\rm extr}$	1.3T
$L_{\rm mirror}$	290mmx
maximum current (main coils)	1000A
water cooling pressure	15bars
plasma chamber internal diameter	74mm
hexapole field on the plasma chamber wall	1.05T
maximum extraction voltage	30kV

3 Experimental results

The preliminary tests of the DECRIS-4 ECR ion source were carried out with Ar in the middle of 2005. The first experiments showed that the source was able to produce more than 300μA of Ar^{8+} when only 100W of microwave power was used[4]. The tests of the source with other gases were continued in the end of 2005. Some results with oxygen, krypton and xenon are presented in Fig. 2, where ion yields of DECRIS-4 and DECRIS-2m ion sources are compared. DECRIS-2m has an ordinary magnetic field distribution and approximately the same level of the axial and radial magnetic fields. All experiments with both ion sources were carried out at the same test bench.

Unfortunately two big problems arose during the source tests. First one was the limitation of the maximum microwave power at the level of about 100 – 150W. The old klystron amplifier installed at our test bench delivers very unstable output power when it becomes higher than 100W. For this reason all of our measurements were made in the restricted range of UHF power. The second problem deals with the main coils power supplies. DECRIS-4 was designed for U-400 cyclotron where 1400A, 100V power supplies are used. The voltage of power supplies, which are installed at our test bench is less than required to rich the maximum coil current of 1000A. As a result the coil current was limited by the level of 925A and 850A at the injection and extraction side correspondingly.

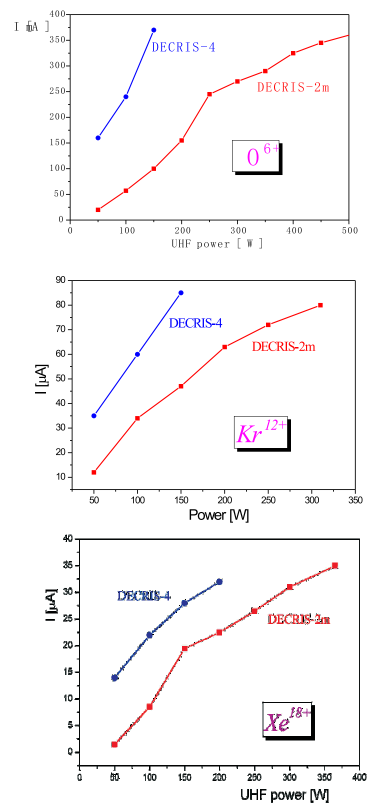

Fig. 2. Comparison of O^{6+}, Kr^{12+} and Xe^{18+} yields from the DECRIS-4 and DECIS-2m ion sources.

Taking into account these limitations the most important tuning parameter in our case was the minimum magnetic field value in the center of the ion source.

The axial magnetic field distribution when the ion source was optimized for the maximum yield of medium charged state ions is shown in Fig. 3. The axial injection field is limited by power supply voltage, the axial extraction field corresponds to the twice $B_{\rm ECR}$ and only $B_{\rm min}$ has unexpected configuration. In accordance with the modern guidelines for optimum performance the minimum field should be around 80% of the resonance field. In case of a "flat" minimum we expected $B_{\rm min} \approx B_{\rm ECR}$. One of the possible explanations of this minimum field configuration is the Doppler broadening of the resonance sheath which expands the physical volume of the resonance zone, as was proposed in Ref. [5].

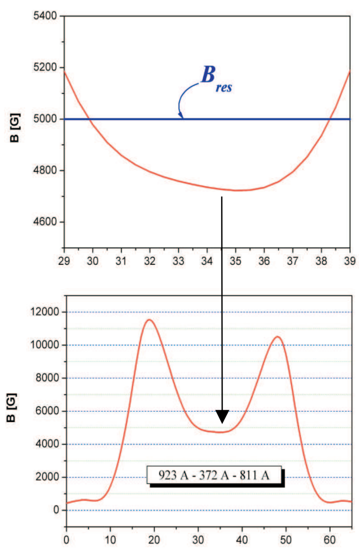

Fig. 3. Axial magnetic field distribution optimized for maximum yield of Ar^{8+}.

One additional feature of the DECRIS-4 ion source consists in the possibility to move the whole magnetic structure along the axis with respect to the plasma chamber to optimize the plasma electrode position during the source operation. The beam intensities of Ar ions (Ar^{8+} and Ar^{11+}) were measured as a function of a plasma electron position. The results of this very preliminary experiment are shown in Fig. 4.

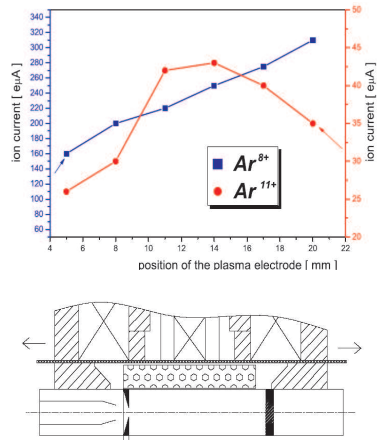

Fig. 4. Effect of plasma electrode position.

The last very short (one week only) experiment with DECRIS-4 was carried out in July of 2006. To improve the transport efficiency of the beam line the additional einzel lens was installed in the extraction box between the puller and solenoid lens. Finally the Ar^{8+} beam intensity about of 500μA was obtained with good stability at the extraction voltage 20kV. The results of this experiment plotted in Fig. 5 as "stars".

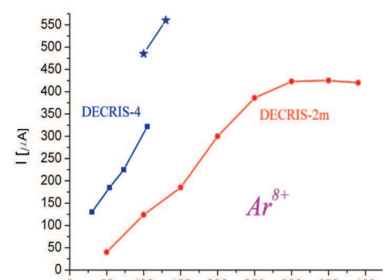

Fig. 5. Comparison of Ar^{8+} yields from the DECRIS-4 and DECIS-2m ion sources.

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