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STATUS OF THE INS ECR ION SOURCE

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Abstract

An ECR source for the INS SF cyclotron has been constructed. Test operation is being performed in a single stage configuration in order to study the behavior of the source, before it is installed. Some results are presented.

1. Introduction

An ECR ion source for multiply-charged heavy ions has been manufactured and is being tested. The design features of this source have been reported in the last ECR workshop at MSU. After the bench test now under way, it is to be installed at the SF cyclotron of our institute.

Though this source has been designed to be operated in the two stage configuration as most of the other ECR sources, the performance test so far has been carried out in a single stage configuration by forming only one ECR zone at the second stage. It is intended that in this simpler configuration, the role of each stage and the dependence of the charge state distribution on such parameters as the mirror field strength, the microwave power and the gas pressure, might become clearer.

2. Set-up of Test Operation

A schematic view of the test operation system is shown in Fig.1. This system consists of a 45 deg bending magnet with 30 mass analyzing power and a Glaser type magnetic lens which focuses the ion beam on the entrance slit of the bending magnet. Faraday cups are located just behind the entrance and exit slits to measure both the total current and the charge-selected beam intensity.

2.1 Magnetic field

A schematic drawing is shown in Fig.2, where a single stage configuration formed for the test operation is displayed with one hexapole magnet assembly and one ECR zone only in the second stage region of the source. The gas feeding tube is lead directly into the second stage. In addition to the elements, the magnetic field distribution of the mirror coils is also shown. Because of the single stage operation, only two coils --- coil 2 and 3 in the figure --- are excited.
Fig. 1. A schematic view of a test operation system.

Fig. 2. The main features of the INS ECR Source and mirror field distribution.

The solid line shows the calculated axial field strength $B_z$ on axis due to the mirror coils for a typical value used in the test operation and the circles are measured points.

A hexapole magnet is a compact assembly of SmCo5 permanent magnets and is placed inside the vacuum chamber. Each pole is enclosed in a jacket and water-cooled through the voids between inside of the jacket and permanent magnets themselves.
From the measurements of the hexapole field, it can be concluded that the hexapole magnet produces field with strength and shape we aimed. One example of measurements is shown in Fig. 3, where the radial field strength $B_r$ measured at the radius of 13 mm and at an azimuthal angle of 30 deg is plotted along the axial direction.

### 2.2 Microwave system

Microwave power has been fed only to the second stage with a rectangular waveguide. The waveguide is radially inserted into the ECR cavity through a gap of hexapole magnet poles. A Teflon sheet of 3 mm thick is inserted in the waveguide near the cavity to cut the DC high voltage applied to the plasma chamber. This insulation was found to stand a voltage up to 30 kV. A quartz disk of 3 mm thick is also put in between the insulator and the cavity to keep vacuum inside the chamber. A Varian transmitter is used to supply 6.4 GHz microwave power with maximum output power up to 3 kW.

### 2.3 Vacuum system

Two turbo-molecular pumps are used for the second stage chamber and the extractor chamber, with pumping speeds of 1500 l/s and 500 l/s, respectively. A vacuum of low 10⁻⁷ Torr range is achieved in the second stage without gas feed. This satisfies the designed pressure and will be sufficient to keep a gas pressure in the second stage below 10⁻⁶ Torr in usual double stage operation. In the original design, a 1500 l/s turbo-molecular pump is to be attached also to the first stage chamber.

### 2.4 Extraction system

The ion extraction system is composed of three electrodes, an anode, a puller and the ground. The position of the anode electrode is adjustable with respect to the magnetic field along the axial direction within a stroke of 40 mm, the center being at the center of coil 3, as shown in Fig. 2. The gap between the anode and the puller electrode is also variable from 3 mm up to 23 mm. During the test operation, the diameter of the puller electrode hole was 12 mm, and that of the anode hole was 8 mm.

The anode voltage is about 10 kV. It is determined from the beam-injection requirements into the cyclotron. The puller voltage is kept negative to suppress the secondary electrons and to produce electric field at the anode-puller gap strong enough for better ion extraction and focussing. The beam intensity was found to become higher at several kV of the puller voltage.

### 3. Results of Test Operation

The test operation in the configuration described above has been carried out for two months, together with the debugging of the components. Some results were obtained that seem to show the characteristics of the source.

#### 3.1 Mass spectrum

An example of mass spectra of Ne ions at a gas pressure of about 10⁻⁷ Torr and microwave power about 200 W is shown in Fig. 4. From this spectrum, two things can be observed:

i) Electrons are accelerated as much as to produce Ne ions with charges up to 8⁺.

ii) Even in very low gas pressure of about 10⁻⁷ Torr, an ECR plasma could be fired.
3.2 Maximum drain current

At a higher gas pressure and microwave power, at about 10–5 Torr and 1 kW, respectively, a total beam current up to 10 mA was extracted from the chamber. This amount of ions might be expected to diffuse from the first stage to the second in the two stage operation of the original design, because each stage of our source has a similar dimension.
3.3 Dependence of ion current on ECR zone

By varying the coil current, the shape and position of the ECR zone can be changed. Dependence of the Ne\(^+\) current on their change was measured in several ways. Two examples are described below.

i) Dependence on the size: When the current is supplied to the coil 2 and 3 symmetrically, i.e. the coil 2 and the coil 3 currents are the same, the center of the ECR zone is fixed at a midpoint of the coil 2 and 3 as shown in Fig. 5. By keeping this condition, only the size of the ECR zone can be changed by varying the current. As the current increases, the ECR zone becomes smaller and at last vanishes. As the current decreases, the ECR zone grows and at last reaches the cavity wall.

The dependence of the Ne\(^+\) current on the ECR zone size was measured under the condition of gas pressure about 10−5 Torr, microwave power 200 W and extraction voltage +8 kV. The curve obtained in this condition indicates that the current increases slowly as the ECR zone becomes smaller, comes to a peak and that it decreases rapidly as the ECR zone approaches the vanishing point.

ii) Dependence on the position: When the current is supplied to the coil 2 and 3 anti-symmetrically, i.e. the sum of the coil 2 current and the coil 3 current is kept constant, the size of the ECR region is kept relatively constant as shown in Fig. 6. By raising one coil current and reducing the other coil current by the same amount, only the position of the ECR zone can be changed in the axial direction. The ECR zone moves toward the coil with lower current.

The dependence of the Ne\(^+\) current on the ECR zone position was measured under the same condition as mentioned in paragraph i). When the ECR zone is distant from the extraction electrode, the Ne\(^+\) current is nearly constant except for minor fluctuation. As it becomes closer, the current begins to increase.

From these examples, it seems that the smaller and the closer to the extractor the ECR zone is, the more the ion current becomes. However, from our limited experience, it is still not clear if this tendency holds in general. Some other measurements suggest different tendency appears, if such conditions as gas pressure, extraction voltage and extraction gap are changed.

At present, it seems to be appropriate to consider the dependence of the ion current on the ECR zone as follows:

(i) The ion current changes very delicately as the shape and position of the ECR zone changes. The tendency of the change of the ion current seems to be dominated by many factors.

(ii) On the other hand, the increase and/or decrease of ion current by the change of the ECR zone is not remarkable. The gain does not exceed about 30% in many cases.

3.4 Dependence of ion current on gas pressure and microwave power

At several gas pressures, dependence of the ion current on microwave power was measured for the ions in charge states of +1, +2 and +3. In Fig. 7, ratio of each charge state is plotted against the microwave power. The solid line means the ratio of the Ne\(^2+\) current to the Ne\(^+\) current, the broken line that of Ne\(^3+\) to Ne\(^2+\). Such a ratio, so to say a successive ionization ratio, might be an index to measure the efficiency of ionization to a higher charge state.

From the figure, several remarks can be derived:

(i) At every gas pressure, the ratio of Ne\(^3+\)/Ne\(^2+\) is smaller than that of Ne\(^2+\)/Ne\(^+\). This means the higher the charge state is, the more difficult the further ionization becomes.

(ii) Each ratio increases as the gas pressure becomes low.

(iii) At lower gas pressure, each ratio increases as the microwave power increases. This implies additional microwave power results directly in further ionization through effective acceleration of electrons.
Fig. 5. Dependence of Ion Current to ECR Zone Size.

Fig. 6. Dependence of Ion Current to ECR zone Position.
At higher gas pressure, each ratio saturates at some value of the microwave power. Further consumption of microwave power does not result in further ionization. In this situation, since the mean free path of the electrons is short, an additional acceleration is not sufficient to produce the ions in higher charge states.

These observations agree with the conventional recipe of ECR source operation: high pressure and low power in the first stage and low pressure and high power in the second stage.

3.5 Typical ion current obtained in the test operation

H₂ and Ne gas were used in the test operation. The typical ion current obtained is shown in Table 1 with the operating condition. In this step of the test, the ion intensities are not satisfactory yet. Several causes can be expected that limit the performance of our source at present:
(i) The test was done in the single stage configuration.
(ii) The strategy for optimizing the ionization condition is still not clear from the two months of experience.
(iii) As the X-ray shield is incomplete, the microwave power had to be limited.
(iv) The bending magnet available for the test system has the focusing property only in the radial direction. The ion beam diverges in the axial direction of the magnet, so considerable part of the beam might be lost.

These problems are expected to be solved sooner or later before the source is installed at the cyclotron.

Fig. 7. Dependence of Ion Current to Gas Pressure and Microwave Power.
Table 1 Ion current from INS-ECR-Source on single stage operation (Aug.'88)

<table>
<thead>
<tr>
<th>Ion</th>
<th>Current (mA)</th>
<th>Microwave Power (W)</th>
<th>Gas Flow rate (cc/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁺</td>
<td>11.3</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>H₂⁺</td>
<td>8.2</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>H₃⁺</td>
<td>12.0</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>H²⁺</td>
<td>4.9</td>
<td>500</td>
<td>6.00</td>
</tr>
<tr>
<td>H²⁺</td>
<td>10.3</td>
<td>600</td>
<td>0.10</td>
</tr>
<tr>
<td>H²⁺</td>
<td>5.5</td>
<td>800</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Current at 6 kV extraction voltage.