ECR ION SOURCE

An 18-GHz superconducting ECR ion source was installed in order to increase beam currents and to extend the variety of ions, especially for highly-charged heavy ions, which can be accelerated by RCNP cyclotrons. The production development of several ions beams and their acceleration by the AVF cyclotron has been performed since 2006.

Figure 2 shows a cross sectional view of the source. The source was designed based on RAMSES [4] at RIKEN, but the inner diameter of the hexapole magnet and of the plasma chamber were extended to 90 and 80 mm, respectively, due to the experience with their development. The mirror magnetic field is produced with four liquid-helium-free superconducting coils, which are cooled by two Gifford-McMahon refrigerators and which are installed in a cryostat chamber covered by iron magnetic shields. Upstream coil 1 (U1) and downstream coil (D) are of the same size and are excited in series by using a common power supply. Central coil (C) and upstream coil 2 (U2) are excited by using independent power supplies, and the mirror magnetic field distribution is controlled quite flexibly. Typical simulated (by TOSCA) magnetic field inductions created on the axis by each coil are shown in Fig. 3. Typical operating currents are 36.3 A, 36.9 A, and 60.5 A for the U1+D, C, and U2 coils, respectively. The maximum current for each coil is 66 A.

The permanent magnet hexapole is of the Halbach type, with 24 pieces of NEOMAX-44H material. The radial field strength is 1.0 T on the stainless-steel plasma chamber's inner diameter. The diameter and the length of the plasma chamber are 80 mm and 380 mm, respectively.

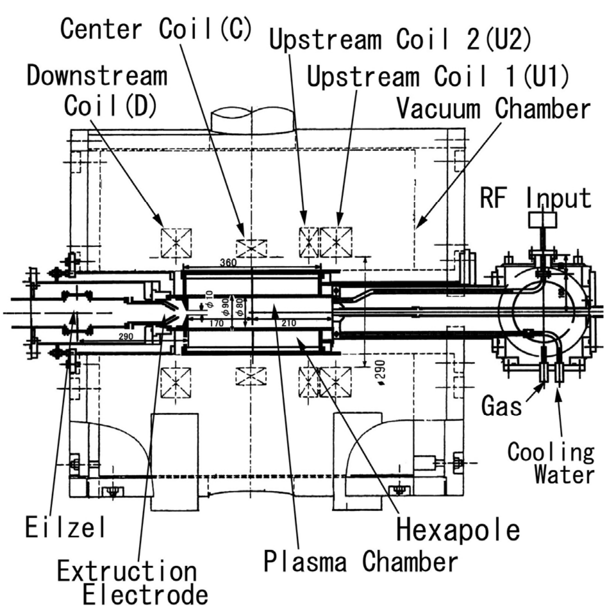

Figure 2: Cross-sectional view of a liquid-helium free18-GHz superconducting ECR ion source.

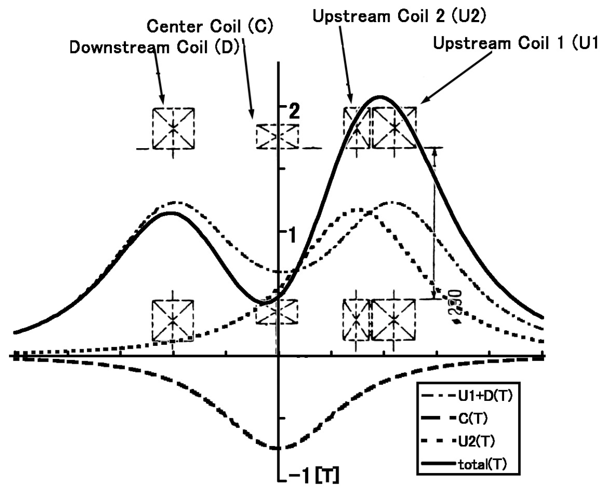

Figure 3: Simulated magnetic field distribution.

In order to improve the performances of the source, a liner was inserted. Tests have been performed with two different thicknesses and materials (1 and 3.5 mm; pure aluminium and aluminium coated with Al_2O_3). In the latter case, it was difficult to get stable operation due to discharge or degassing from the liner.

A bias probe was installed on the beam axis on the injection side. The maximum applicable voltage is -500 V relative to the plasma chamber, and the probe position is variable between 120 and 220 mm from the center of the C coil. The optimum position is located at 170-190 mm, which corresponds to the position of the maximum mirror field. The extraction system is composed of two electrodes and can be moved along the beam axis. An einzel lens is placed downstream of the extraction electrode.

The ion beams extracted from the source are analyzed by using a dipole magnet (AM) and are measured in a Faraday cup (FC) placed at the image focal point of the analyzing magnet. Figure 4 shows the typical charge-state distribution of ^{86}Kr ions obtained by using oxygen as a gas mixing. Table 1 summarizes the performance of the source. $^{86}Kr^{21+, 23+}$ ions were accelerated for the first time by using the AVF cyclotron and were delivered to user's experiments.

In order to produce metallic boron-ions, a test by using the MIVOC (Metal Ion from VOlatile Compounds) method [5] was performed using o-carborane ($C_2B_{10}H_{12}$). Its vapor pressure was around 1-2 Torr at the room temperature. The stable flow of the vapor from the o-carborane powder to the plasma chamber enabled us to produce a stable boron-ion beam. The o-carborane was put in a glass vessel directly connected to the plasma chamber via a buffer tank. A helium support gas was used as the mixing gas. Different support gases were tested to optimize the $^{11}B^{5+}$ intensity. With oxygen, we were not able to produce $^{11}B^{5+}$; with hydrogen, the current was divided by three with respect to the current for helium.

spread before injection. Two 90-degree dipole magnets have a bending radius of 1200 mm. They have round pole faces to reduce the ions' optical second-order aberrations. The momentum dispersion of the analyzing section is designed to be 12.6 m. The parameters of the AVF cyclotron and the transfer beam line to the ring cyclotron can be optimized by referring to the measured beam characteristics.

SUMMARY

The upgrade of the RCNP cyclotron cascade has been successfully started and is being continued. The beam quality and the intensity of 300-MeV protons have been improved by using flat-top acceleration in the AVF cyclotron. Developments are being performed to apply the system to other beams. An 18-GHz superconducting ECR ion source has been commissioned to increase the beam intensity of highly-charged heavy ions; a 7.5-MeV/u $^{86}Kr^{23+}$ beam was delivered to experiments. A new beam line has been installed to diagnose the beam characteristics from the AVF cyclotron and to help match it to the acceptance of the ring cyclotron. It also makes 10 – 400-MeV protons and 1 – 100-MeV/u heavy ions available for a variety of research in nuclear physics, fundamental physics, and interdisciplinary studies.

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