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Development of DRAGON electron cyclotron resonance ion source at Institute of Modern Physics[a]

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A new room temperature electron cyclotron resonance (ECR) ion source, DRAGON, is under construction at IMP. DRAGON is designed to operate at microwaves of frequencies of 14.5–18 GHz. Its axial solenoid coils are cooled with evaporative medium to provide an axial magnetic mirror field of 2.5 T at the injection and 1.4 T at the extraction, respectively. In comparison to other conventional room temperature ECR ion sources, DRAGON has so far the largest bore plasma chamber of inner diameter of 126 mm with maximum radial fields of 1.4–1.5 T produced by a non-Halbach permanent sextupole magnet. © *2012 American Institute of Physics*. [doi:10.1063/1.3669800]

I. INTRODUCTION

Heavy ion research facility in Lanzhou (HIRFL) is a national laboratory dedicated for nuclear physics, atomic physics, tumor therapy research, and other heavy ion applications. HIRFL consists of a storage ring complex and two cyclotrons of sector-focused-cyclotron (SFC) and separate-sector cyclotron (SSC). The medium charge state ion sources (LECR1, LECR2, and LECR3) have successively provided multiple-charged ion beams to HIRFL for more than 10 years.[1,2] Superconducting ECRISs have been leading the way of ECRIS progress on the production of intense heavy ion beams in the past decades. To meet the increasing demands of intense highly charged ion beams, an advanced superconducting ECR ion source SECRAL had been built in 2005 and has been in routine operation since May 2007.[3] Though its maximum operation frequency is 24 GHz, SECRAL has produced very great performance operating at frequency of 18 GHz in comparison to other 18 GHz ECRISs.[4] If the performance is the same, a room temperature (RT) ECR ion source operating at 18 GHz would have many advantages over a superconducting 18 GHz ECR ion source, such as easy operation and lower cost. In addition, the capability of providing intense multiple-charged heavy ion beams at HIRFL needs further enhanced which leads to the development of a new RT ECR ion source: DRAGON, since 2010.[5]

A. DRAGON AND ITS DESIGN FEATURES

In general, a RT ECR ion source consists of a set of water-cooled resistive axial solenoids and a permanent sextupole magnet. The solenoid coils are typically made of hollow-conductor cooled by de-ionized pressurized-water. As the field strengths and forces keep increasing for better source performance, building a strong radial magnetic field with a permanent sextupole magnet is extremely challenging. So far, all the permanent sextupoles are built with a small plasma chamber of inner diameter (ID) less or equal to 80 mm to reach a radial field of 1.2–2 T without/with iron tips.[6] These small plasma chambers are not optimal as evidenced by the larger chambers of the superconducting ECR ion sources at about the same field profiles. The design of DRAGON is to duplicate the field configuration of SECRAL operating at 18 GHz with a plasma chamber of ID 126 mm.[3] At full excitation, DRAGON can produce 2.7 T peak mirror fields on axis at injection, 1.4 T at extraction and a radial sextupole field of 1.4–1.5 T at the plasma chamber wall of ID 126 mm. One of the new features of DRAGON is that all the axial solenoid coils are immersed in and cooled with a 47.7 °C evaporative medium. The other is a non-Halbach-structure permanent sextupole magnet with largest bore ever designed and built for a high charge state RT ECRIS.

Figure 1 shows the schematic layout of DRAGON. Figure 2 shows the axial magnetic field distribution that reaches 2.7 T at the injection with an iron plug field booster and 1.3 T at the extraction. Figure 3 shows the calculated radial field at the plasma chamber of ID of 126 mm reaching 1.5 T with six small iron tips embedded in the plasma chamber cooling channels. The design of DRAGON has been optimized for maximum performance at microwave of 18 GHz for the production of intense multiple-charged heavy ion beams. The overall parameters of DRAGON are very close to those of SECRAL operating at 18 GHz and the Grenoble Test Source (GTS) as listed in Table I. DRAGON's plasma chamber volume is about 6 l, about 15% larger than the SECRAL for a slightly larger ECR volume. The maximum source magnet power consumption is about 460 kW.

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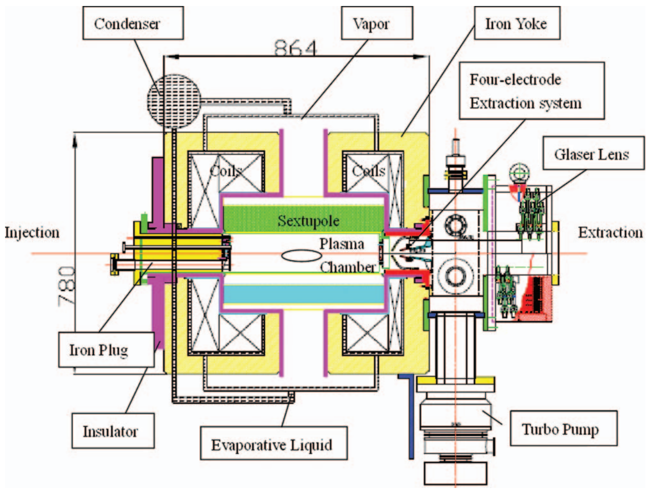

FIG. 1. (Color online) Schematic view of the DRAGON ECR ion source.

II. IMMERSION EVAPORATIVE COOLING SYSTEM FOR THE ECR ION SOURCE

Although there are various schemes for cooling the magnet system with evaporative medium, immersion would be the most effective cooling for the magnet system of ECR ion source. The whole system consists of condenser, liquid-down tube, immersion tank, vapor-flow tube, etc. The detail structure of the evaporative cooling system is shown in Figure 4. When complete the assembly, the coils are put into the immersion tank. Its operational principle is the following: when the coils are excited, the copper resistive loss produces a good amount of heat and the evaporative coolant will carry away the heat by a phase transition with good latent heat absorption, just like the liquid helium cools the superconducting magnet. The boil-off vapor in the immersion tank goes up into the condenser and then be cooled down back to liquid that flows gravitationally back to the immersion tank.

This is a demonstration of new cooling technology, as the funding agency requires, for feasible future conventional magnet development. To date, a prototype of axial solenoid coils and coolant condenser shown in Fig. 4 have been built to test evaporative cooling effectiveness. The achieved exciting current for injection solenoid coils is 300 A that is equivalent of average current density: 13 A/mm^2, slightly higher than using normal hollow copper conducting with high water pressure drop achieved at IMP. The boiling temperature of the testing coolant is 47.7 °C. Optimization of the whole magnet and cooling effectiveness are continuing.

TABLE I. Main parameters of DRAGON, GTS, and SECRAL operating at 18 GHz.

	DRAGON	GTS	SECRAL
Operating frequency (GHz)	14–18	14–18	18
Resonance length	14 GHz: 120	14 GHz: 95	105
(mm)	18 GHz: 135	18 GHz: 145	
Plasma chamber	L: 480	L: 300	L: 420
(mm)	ϕ: 126	ϕ: 80	ϕ: 126
Max. axial injection field (T)	2.7	2.5	2.5
Max. chamber radial field (T)	1.5	1.2	1.4

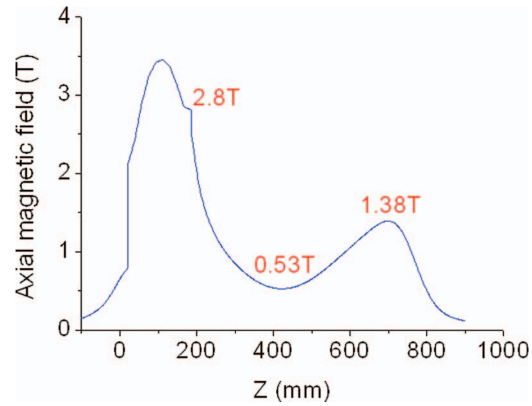

FIG. 2. (Color online) The calculated axial magnetic field profile of the DRAGON ECR ion source.

III. LARGE BORE SEXTUPOLE MAGNET

Fabrication of a large permanent magnet sextupole is extremely challenging, especially at high radial field strength with a large bore. So far, most of the high-field room temperature ECR ion sources use a Halbach-sextupole that is typically made of M equal-size sections with the easy-axis rotating 8 π/M from section to the next.[7] Such an easy-rotation poses a risk of regional de-magnetization when the field approaching certain strength. In addition, the fabrication of such a Halbach-sextupole requires very complex and elaborate magnet-block cutting and assembling. The sextupole magnet of DRAGON ECR ion source uses a non-Halbach high field structure for easier fabrication at a price of about 2% lower radial field at plasma chamber wall. It has a simple easy-axis orientation and shape.[5] The DRAGON sextuple bore is of ID 134.5 mm that is large enough to support a stainless steel water-cooled plasma chamber of ID 126 mm, the same size as in SECRAL. These sextupole are made of N48SH permanent magnets with an outer diameter of 320 mm and of length 526 mm. According to the permanent magnet characteristic, N48SH is chosen for its higher working temperature and

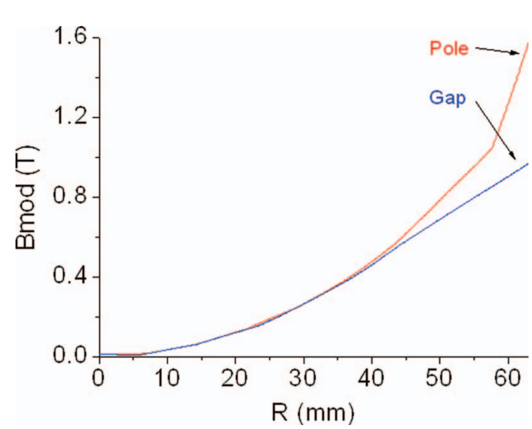

FIG. 3. (Color online) The calculated radial magnetic field profiles of the DRAGON ECR ion source.

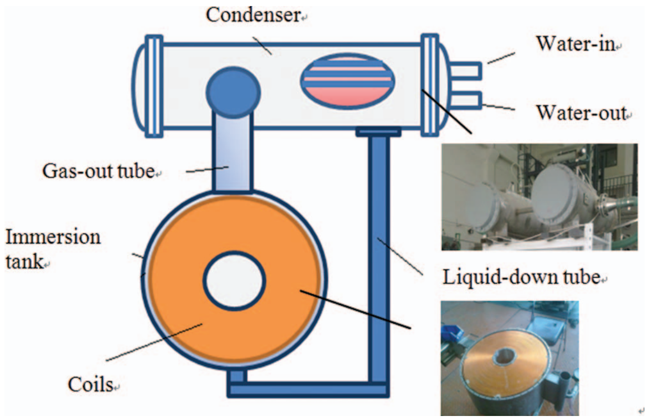

FIG. 4. (Color online) Schematic layout of evaporative cooling system for DRAGON.

possibly more resistant to permanent magnet aging deterioration. Figure 5 shows the layout of sextupole magnet in 3D profile.

IV. ION BEAM EXTRACTION AND BEAM ANALYSIS

The beam transport/analysis line of DRAGON is designed to be able to transport 10–15 emA intense heavy ion beams with high efficiency and high resolution. The beam line consists of a solenoid lens and a 110° analyzing magnet, almost the same as the SECRAL beam line. The turbo molecular pump is directly attached on the extraction flange of the source body in order to enhance the pumping speed for the plasma chamber. The bending radius of the analyzing magnet is 600 mm with pole gap 120 mm. Slits and Faraday-cup are installed at the end of the beam line. A few modifications are made to the extraction of DRAGON, in particular to improve the high-voltage insulation between the inner plasma chamber and outer ground. A better insulation is needed to meet the demands of higher energy of extraction ion beams for HIRFL. DRAGON is thickly insulated with 7 mm thick material so as to achieve 50 kV beam extraction and hopefully to explore beam extraction up to 100 kV with a four-electrodes (accel-accel-decel) beam extraction mechanism. Figure 6 illustrates the layout of the DRAGON ECR ion source and its beam transport line.

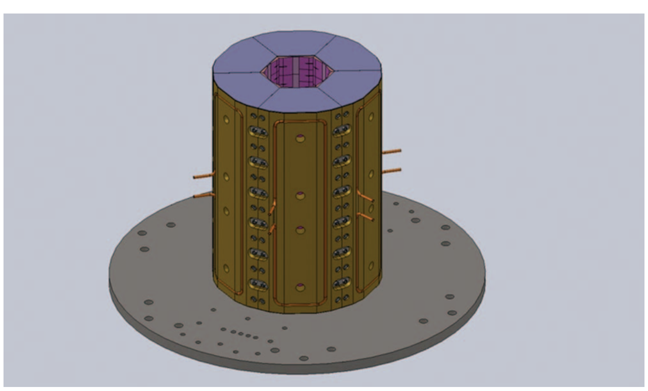

FIG. 5. (Color online) Layout of the assembled sextupole magnet in Solidworks.

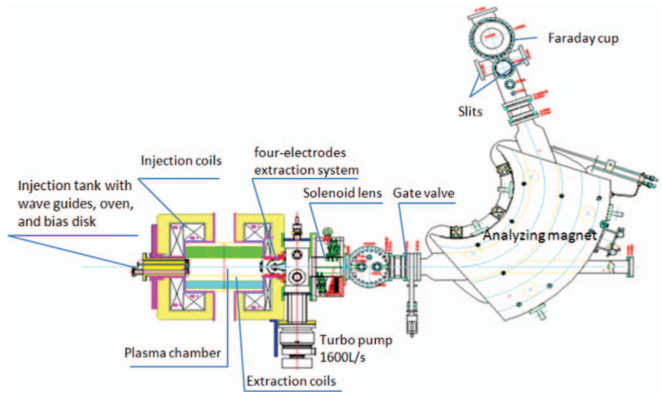

FIG. 6. (Color online) Layout of DRAGON ECR ion source and its beam transport line.

V. CONCLUSION

The development of a high field and large chamber board room temperature ECR for the production of intense multiple-charged ion beams has been reported. Once this source is completed, it is expected to produce at least compatible performance with the existing 18 GHz ECRISs and hopefully better. This new ion source is also a test bench to demonstrate the feasibility of new cooling technology for future magnet development.

ACKNOWLEDGMENTS

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