

A high charge state all-permanent magnet ECR ion source for the IMP 320 kV HV platform

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Abstract

A 320 kV high voltage (HV) platform has been constructed at Institute of Modern Physics (IMP) to satisfy the increasing requirements of experimental studies in some heavy ion associated directions. A high charge state all-permanent magnet ECRIS-LAPECR2 has been designed and fabricated to provide intense multiple charge state ion beams (such as 1000 eμA O⁶⁺, 16.7 eμA Ar¹⁴⁺, 24 eμA Xe²⁷⁺, etc.) for the HV platform. LAPECR2 has a dimension of Ø 650 mm × 560 mm. The powerful 3D magnetic confinement to the ECR plasma and the optimum designed magnetic field for the operation at 14.5 GHz makes it possible to obtain very good performances from this source. After a brief introduction of the ECRIS and accelerator development at IMP, the conceptual design of LAPECR2 source is presented. The first test results of this all-permanent magnet ECRIS are given in this paper.

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1. Introduction

Invented by the end of 1960s [1], electron cyclotron resonance ion source (ECRIS) has become one indispensable machine in the fields of accelerator, atomic physics and material physics research, etc. This kind of machine adopts a 3D magnetic field named as the famous Min-B field, which is a superposition of the axial mirror field and the radial multipolar field, to confine the high temperature ECR plasma. Generally, the axial mirror field is supplied by a set of copper solenoidal coils, superconducting solenoidal coils or permanent magnet rings. And the radial multipolar field can be generated by permanent magnet or superconducting coils. Then there are several possible

combinations between the axial magnet and the radial multipolar magnet. The combination of axial permanent magnet rings and radial permanent multipolar magnet makes the magnetic body of an all-permanent magnet ECRIS. Because of its characteristic magnet body structure, all-permanent magnet ECRIS owns the special features like simplicity, structure compactness, electricity free (except the power for microwave generator and beam extraction power supply), no need for high pressure deionized water cooling, easy handling and long term operation stability, etc. Owning these virtues, all-permanent magnet ECRISs are very suitable to be equipped to high voltage platforms, miniaturized experimental platforms, ion implantation machine and so on. However, their usage has been limited to relatively very small areas because of the intrinsic drawbacks such as difficulties in obtain sufficiently high magnetic field, inflexibility of magnetic fields, and high costs of permanent magnet materials (such as Samarium Cobalt). Thanks to

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the advancement of rare-earth magnet technologies, it is nowadays possible to obtain high field permanent magnet rings with reasonable prices. Furthermore, the advancements in the theory and technologies of ECRIS have given lots of instructions to the building of a good performance ECRIS. Especially, the famous scaling laws that govern the magnetic configuration of this type of device make the design of a high performance all-permanent magnet ECRIS easier and more reliable. Under the guidance of scaling laws [2,3], many good performance all-permanent magnet ECRISs have been built around the world one after the other. The famous NANOGAN series [4] and the BIE series [5] are some of them. With better understanding the working mechanism of an ECRIS, some very high performance all-permanent magnet ECRISs have been built in some laboratories such as the SOPHIE source in CEA/Grenoble [6]. Very intense medium charge state ion beams (such as 0.5 emA Ar^{8+}) and very high charge ion beams (such as Xe^{30+}) have been produced by the today's high performance all-permanent magnet ECRIS, which makes this type of ECRIS more and more popularly be utilized in many special areas.

The accelerators (together with the latest built cooler storage rings [7]) at IMP and the available low energy multiply charged state ion beam platform can only provide the experiments a large variety of ion beams in the energy range of 5 keV/q to 30 keV/q and several MeV/u to hundreds of MeV/u, where exists a large energy gap between the low energy and the high energy ion beams. To further extend the present energy range and also to promote the research advancements in the fields such as atomic physics, material physics, biological physics, etc., a 320 kV HV platform has been built at IMP. Presently, there are mainly five multiple charge state ECRISs under operation at same time at IMP [8], i.e. one superconducting ECRIS SECRAL, two room temperature ECRISs, and two all-permanent magnet ECRISs. Considering the many advantages that all-permanent magnet ECRIS has, a high charge state all permanent magnet ECRIS LAPECR2 (Lanzhou All-Permanent magnet ECR ion source no. 2) has been designed and fabricated at IMP for the HV platform. After about three years' fabrication and commissioning, many preliminary but very promising results have been obtained from LAPECR2.

2. Conceptual design of LAPECR2

There are five experimental terminals located just after the acceleration column of the 320 kV HV platform [9]. These terminals are separately dedicated to the physical studies of atomic physics, material physics and biophysics. To fully satisfy the requirements of the above mentioned physical research, intense medium charge state ion beams such as hundreds of microamperes of C^{4+} , O^{6+} and Ar^{8+} as well as very high charge state ion beams such as Ar^{16+} , Xe^{30+} should be delivered from the source LAPECR2. Namely, the performance of LAPECR2

should be approximately close to the conventional high performance ECRIS LECR2. To produce the equivalent performance of LECR2, the main parameters of LAPECR2 should be designed close to those of LECR2. With the development of NdFeB permanent magnet material techniques, it is possible to design and fabricate an all-permanent magnet body with reasonable costs to produce very high magnetic field. LAPECR2 was designed to be operated at 14.5 GHz with several key aspects being taken under consideration at the same time, for instance: (i) plasma chamber should be as large as possible to feed more rf power and also to obtain longer ion lifetime; (ii) large ECR resonance zone is favored; (iii) an economical compromise between the magnetic field and the magnet body compactness.

For an all-permanent magnet ECRIS, the typical disadvantages are the insufficiency and inflexibility of the magnetic field. By adopting high remanence permanent magnet material and reasonable designing of the magnet configuration (sometimes iron yokes can even be added), sufficiently high magnetic field could be achieved inside the working region. As for the magnetic field configuration, the latest developed scaling laws [3] that govern the design of a high performance ECR ion source provide the theoretical bases in the design of LAPECR2. And the several successful high performance all-permanent magnet ECR ion sources are also the good references [4–6]. Besides, the typical tricks and skills such as plasma chamber inner aluminum liner, negatively biased-disk and axial direct microwave power feeding in TE10 mode have been adopted in the design.

3. Magnetic body of LAPECR2

The magnetic field of LAPECR2 is the superposition of a axial mirror field and a radial hexapole as that in a conventional ECRIS. As demonstrated in scaling laws, the general rules for the axial magnetic field configuration are: $B_{\text{inj}} < 4B_{\text{ecr}}$ (B_{ecr} is the resonance magnetic field determined by the rf frequency) at injection, $B_{\text{ext}} \approx B_{\text{rad}}$ (B_{rad} is the radial magnetic field at the inner wall of the plasma chamber) at extraction, while the minimum- B field is such that: $0.30 < B_{\text{min}}/B_{\text{rad}} < 0.45$; the radial magnetic field value has to be close to: $B_{\text{rad}} = 2.2 B_{\text{ecr}}$. For LAPECR2, since the optimum operation frequency is 14.5 GHz, the corresponding key parameters of the magnetic field configuration are: $B_{\text{inj}} \approx 2$ T, $B_{\text{ext}} \approx 1.05$ T, $B_{\text{rad}} = 1.15$ T, $0.35 \text{ T} < B_{\text{min}} < 0.52$ T.

3.1. Axial magnetic rings

As demonstrated in Fig. 1, the axial magnetic field of LAPECR2 is supplied by five magnetic rings. Each magnetic ring is composed of 24 elementary magnets. To obtain high magnetic field, high remanence N46H type NdFeB material ($B_r = 1.36$ T) is adopted for all axial magnetic rings. To realize a sufficiently high magnetic field inside a

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