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A 2.45 GHz electron cyclotron resonance proton ion source and a dual-lens low energy beam transport[a)]

W. H. Zhang,[1,b)] H. Y. Ma,[1] Y. Yang,[1,2] Q. Wu,[1] X. Z. Zhang,[1] H. Wang,[1] B. H. Ma,[1] Y. C. Feng,[1] X. Fang,[1] J. W. Guo,[1] Y. Cao,[1,3] X. X. Li,[1] Y. H. Zhu,[1] J. Y. Li,[1] S. Sha,[1,3] W. Lu,[1,3] S. H. Lin,[1,3] X. H. Guo,[1] H. Y. Zhao,[1] L. T. Sun,[1] D. Z. Xie,[1] S. X. Peng,[4] Z. W. Liu,[1] and H. W. Zhao[1]

[1]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[2]*School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
[3]*Graduate University of Chinese Academy of Sciences, Beijing 100049, China*
[4]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*

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The structure and preliminary commissioning results of a new 2.45 GHz ECR proton ion source and a dual-lens low energy beam transport (LEBT) system are presented in this paper. The main magnetic field of the ion source is provided by a set of permanent magnets with two small electro-solenoid magnets at the injection and the extraction to fine tune the magnetic field for better microwave coupling. A 50 keV pulsed proton beam extracted by a three-electrode mechanism passes through the LEBT system of length of 1183 mm. This LEBT consists of a diagnosis chamber, two Glaser lenses, two steering magnets, and a final beam defining cone. A set of inner permanent magnetic rings is embedded in each of the two Glaser lenses to produce a flatter axial-field to reduce the lens aberrations.
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I. INTRODUCTION

In the production of intense singly charged ion beams, 2.45 GHz ECR proton ion source has many advantages. Due to the intense ion beams transmitted at low-energy, the space-charge force can lead to a severe emittance growth caused by aberrations that deteriorate the beam quality and transport efficiency. Therefore, optimization of LEBT is of great importance in transporting the low-energy intense beams. The low-energy beam transport (LEBT) system consists of a beam line, focusing and steering components. Optimization of the LEBT has begun since 1980s in Saclay,[1–3] France and has been continuing with worldwide efforts.

A 2.45 GHz ECR proton ion source and a dual-lens LEBT have been designed and constructed at IMP. The LEBT uses two Glaser lens combined with a set of embedded permanent magnetic rings to reduce the spherical aberration of the space-charge dominated beam. The design features of the system and the preliminary results are presented below.

II. THE ION SOURCE

The goal of the 2.45 GHz ECR ion source is to produce intense proton beams for accelerator driven subcritical system (ADS) – an underplanning project at China. The source magnetic field is provided by a set of permanent magnets with two small electro-solenoid magnets at the injection and the extraction to fine tune the magnetic field. Figure 1 shows the layout of the source and shown in Fig. 2(a) is the source axial field profile. A set of irons is used to enclose the permanent magnet rings to provide magnetic flux circuit and reduce the stray fields at the extraction region. Figure 2(b) shows the distribution of the stray field at the extraction region in which the field strength is under 20 Gs from $r = 7$ to 25 cm. A low stray magnetic field at the extraction can greatly reduce the high voltage sparking.

The RF power is provided by a 3 kW 2.45 GHz microwave amplifier that can produce both cw and pulse output but 1 ms of 50 Hz pulse is used in the source operation. The RF is launched into the source via a double-ridged transition waveguide. Based on Bhushan Mital's formula,[4] the double-ridged waveguide has been fabricated with three equal

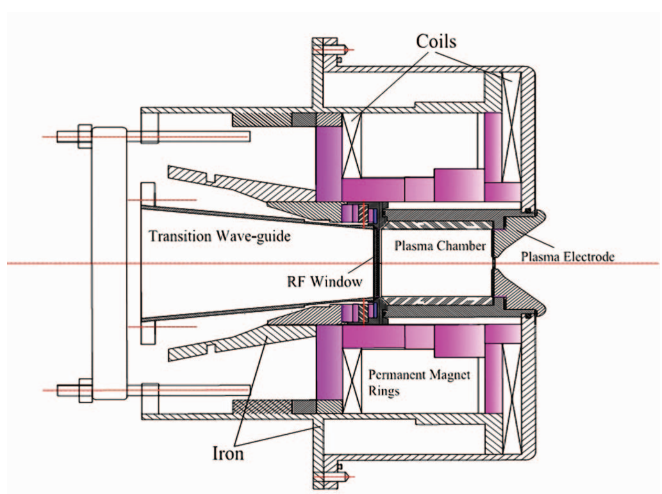

FIG. 1. (Color online) A cross-sectional view of the 2.45 GHz ECR proton ion source.

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[b)]Electronic mail: zhangwh@impcas.ac.cn.

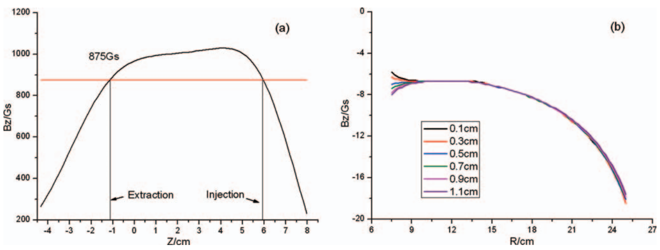

FIG. 2. (Color online) (a) The source axial field profile. (b) Distribution of the stray field at the source extraction region.

impedance sections. Polytetrafluoroethylene is inserted fully into the section just right next to the source to reduce the formation of intense electric field.

The ion beams are extracted at 50 kV through a three-electrode extraction system to minimize beam loss and electron back streaming. Shown in Fig. 3 is a simulation of a 75 mA/50 kV proton beam with the three-electrode system in which no beam loss is anticipated.

III. LEBT

A. Overall layout

The 1183-mm-long LEBT consists of a diagnosis chamber, two 24 cm long Glaser lens G1 and G2 with a set permanent rings embedded, a beam defining cone, an AC current transformer (ACCT) and an electron trap. The layout of LEBT is graphically shown in Fig. 4. Beam diagnosis device provides an online beam monitoring and matching the downstream radio frequency quadrupole (RFQ). In addition, a set of two-dimensional steering magnets is also embedded in the G1 and G2 lenses to shorten the length of LEBT. Contaminant ions, such as H_2^+, and H_3^+ will be stopped at the beam defining cone after the G2 lens to minimize the undesired ions into the RFQ. An electron trap is located after the beam defining cone to repel the electrons created in the LEBT. Before the whole system is linked to the RFQ, a temporary diagnosis chamber (2nd chamber) is placed at the end of the LEBT to measure the beam parameters.

B. Glaser lens

To reduce the spherical aberrations caused by the Glaser lens, a set of permanent magnetic rings is embedded in the inner bore of each of the lenses, as shown in Fig. 5, to produce a flatter focusing magnetic field. Figure 6 shows the longitudinal fields Bz for the cases with/without the permanent magnet rings. Due to fabrication defects, the concentricity of the permanent magnet rings and the outer solenoid are slightly off, field measurement of G1 has shown the maximum deviation from the geometric centre to the magnetic centre is about 1.6 mm in the y direction.

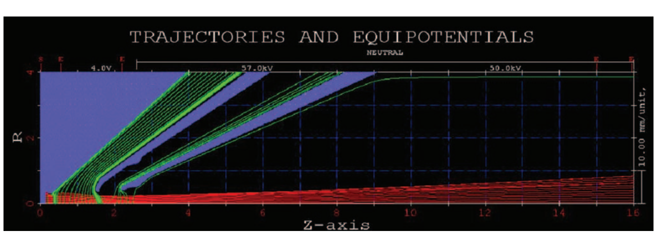

FIG. 3. (Color online) PBGUNS simulation for a 75-mA, 50 keV proton ion beam extraction.

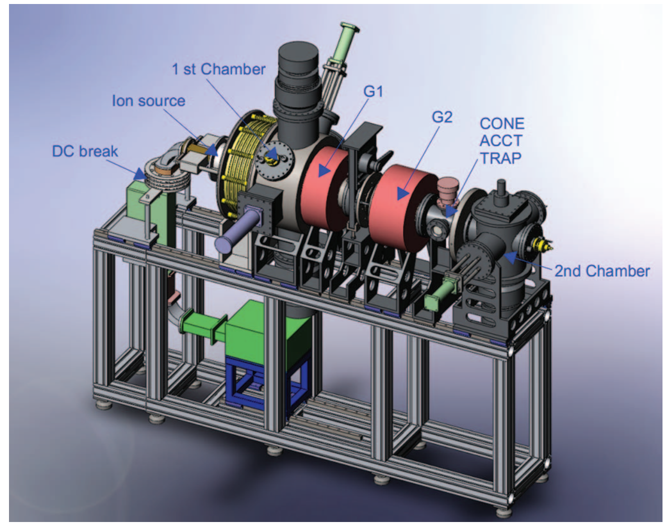

FIG. 4. (Color online) Layout of the LEBT.

C. Beam transmission simulation

In order to improve the beam acceptance of the LEBT, the distance between the exit of ion source and G1 is reduced to 291 mm by sinking the ion source 100 mm into the ceramic insulating ring and embedding G1 50 mm into the diagnosis chamber.

Severe space charge force could lead to beam divergence and emittance growth. Simulation was carried out for a proton beam of 60 mA at 50 kV. Figure 7(a) shows the beam envelope of the particle simulation from ion source exist to the entrance of the RFQ and Fig. 7(b) shows the particle distribution in phase space (x-x′) (cm-mrad) at the end. The deformation of the boundary of the beam phase space after passing through the lenses is clearly seen with a "S" shape.

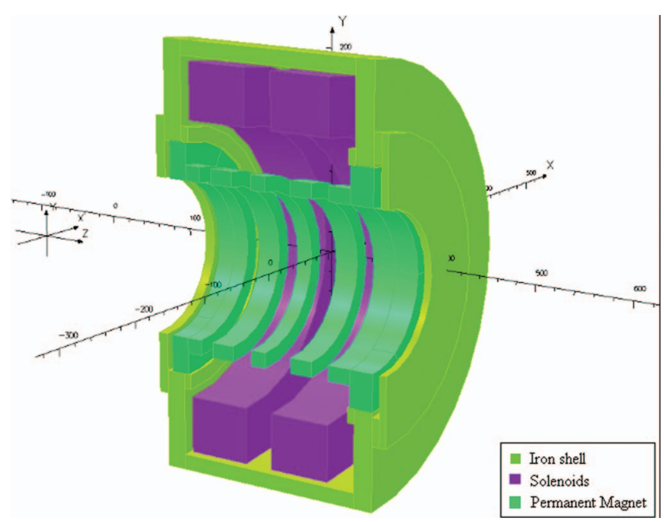

FIG. 5. (Color online) A set of permanent magnets embedded in the Glaser lens.

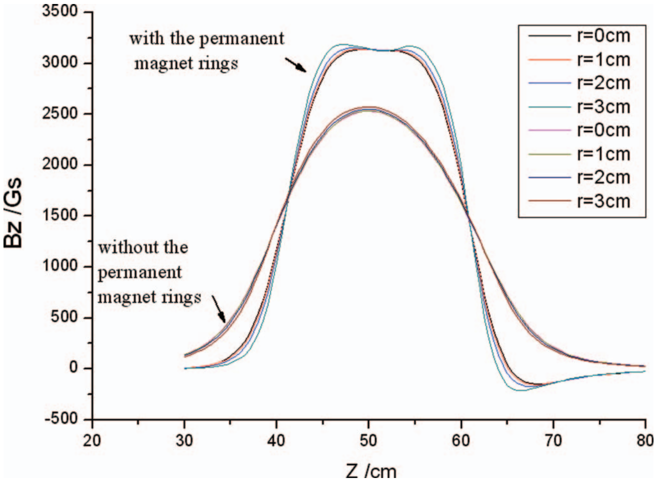

FIG. 6. (Color online) Map of $B_z(z)$ at radius of 0–3 cm.

IV. PRELIMINARY RESULTS

The project is on schedule with the system construction completed and preliminary tests have been carried out recently. The ion source has produced proton ion beams of total currents of 73–95 mA through a ϕ6 mm aperture at 900 W RF power, it is not yet saturated as higher current can be achieved with increasing RF power. As shown in Fig. 8, beam noise at the top of the pulse is somewhat severe that may be related to the plasma stability and should be improved in the near future.

Beam transport through the LEBT is carried out without space charge compensation. About 34 mA has been measured by the ACCT and Faraday cup located in the temporary diagnosis chamber, the 2nd chamber in Fig. 5, at an output of 47 mA total beam extracted from the ion source which leads to a transmission efficiency of about 70%. Beam emittance and other diagnosis device will be completed in the near future and so that beam quality measurement can be carried out.

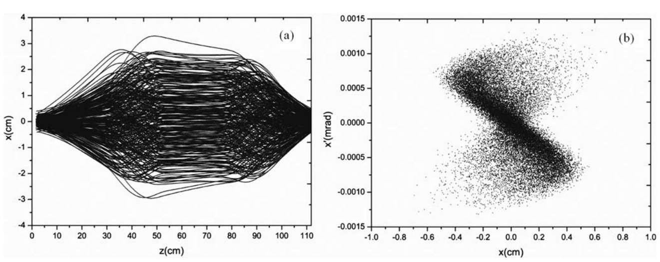

FIG. 7. (a) Particle trajectory along the LEBT and (b) phase space (x-x′) at the RFQ match point.

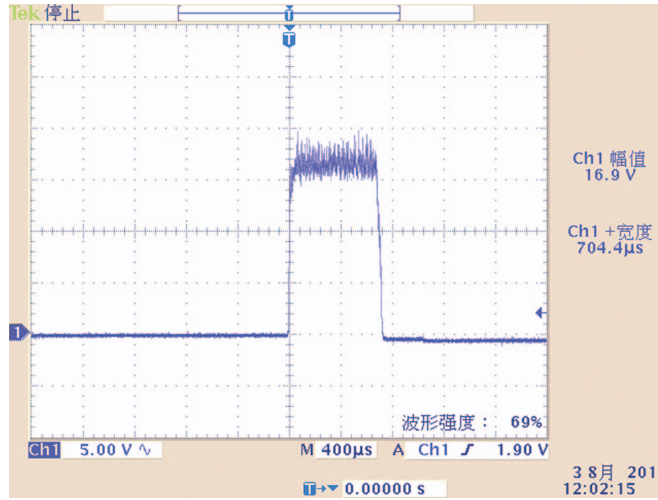

FIG. 8. (Color online) Profile of the beam pulse extracted from the proton ion source.

V. SUMMARY

A new 2.45 GHz ECR source for the production of intense singly charged ion beams and a dual-lens LEBT system have been designed and fabricated. The main magnetic field of the ion source is provided by a set of permanent magnets and with two small electro-solenoid. The structure of LEBT is a dual-lens design with two profiled improved Glaser lenses to reduce aberrations. Preliminary test results show the source with a ϕ6 mm plasma aperture and at 70% transport efficiency through the LEBT, about 80 mA H^+ beam of 50 keV can be achieved. Further source and LEBT improvements are needed and undertaking.

ACKNOWLEDGMENTS

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