REDESIGN AND DEVELOPMENT OF THE SHANGHAI ELECTRON BEAM ION TRAP

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Abstract

Over the last few years the Shanghai Electron Beam Ion Trap (EBIT) has been successfully redesigned and rebuilt. The original machine, developed under collaboration with the Shanghai Institute of Nuclear and Applied Physics, first generated an electron beam in 2005. Shanghai EBIT could be operated with electron beam energies between 1 and 130 keV and currents up to 160 mAmps. After several years of operation, it was found that some improvements/modifications to the old design were necessary. This contribution will discuss several of the main aspects of the redesigned Shanghai EBIT. So far it has been operated up to an electron energy of 40 keV with a current density of over 2400 A/cm^2. The new EBIT is made primarily from Titanium instead of Stainless Steel and has an order of magnitude better background vacuum, a more efficient and economical cryogenic system, and also excellent optical alignment. Finally the magnetic field in the central drift tube region can reach up till 4.8 T.

INTRODUCTION

EBITs are unique facilities widely applied to studies of highly charged ions [1]. They can act as both light sources and ion sources, and in principle, provide ions of any charge state of any element. EBITs have been rapidly developed over the past 25 years, since the initial setup of an EBIT at the Lawrence Livermore National Laboratory (LLNL) [2]. Currently there are about 12 EBITs around the world [3-13]. The original Shanghai EBIT, belonged to the class of high energy EBITs such as the Super-EBIT in Livermore [14, 15], and achieved a highest electron beam energy of 130 keV with a beam current of 160 mAmps [16, 17].

After several years of operation we recognized some improvements/modifications to the original design could, and should, be made and the original Shanghai EBIT was shut down. Our efforts finally led to the rejuvenated Shanghai EBIT delivering a first beam with an electron energy of 40 keV and current of 110 mAmps in early 2013. The new design has many innovative changes and some of these will be described in this contribution.

REDESIGNED SHANGHAI EBIT

Overview

A blueprint of the redesigned Shanghai EBIT is shown in Fig. 1. The design and, so far, achieved operating parameters are summarized in Table 1. As in many EBITs, the electron beam is emitted from a Pierce-type gun [18] and a pair of superconducting Helmholtz coils, immersed in liquid Helium (LHe), provide a magnetic field. This field compresses the beam over the central drift tube region to a high and uniform current density. The drift tube assembly produces an electrostatic well for axial trapping of the ions and the space charge potential of the electron beam, along with the magnetic field, provides radial trapping of the ions. Finally a collector electrode decelerates and collects the electrons.

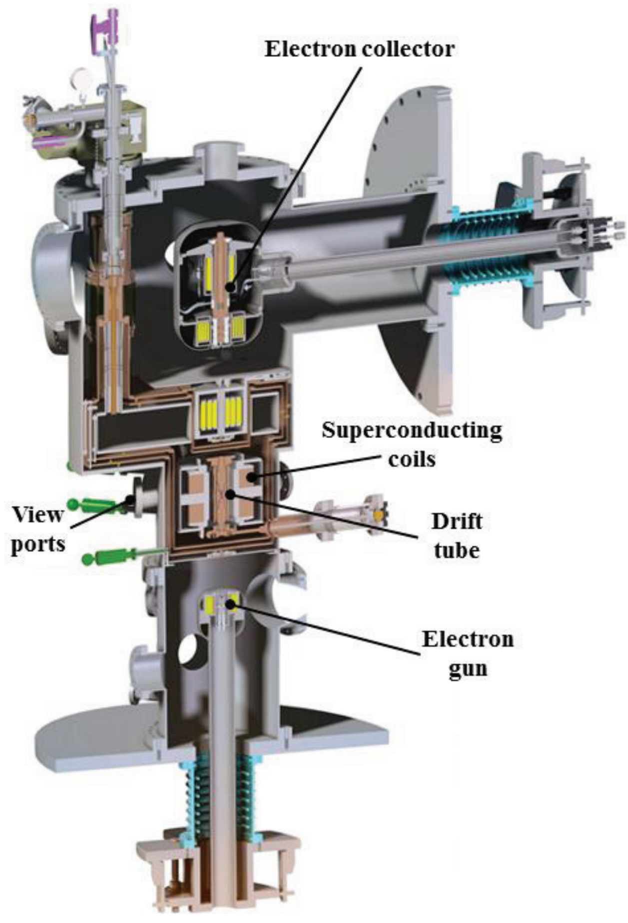

Figure 1: Blueprint of redesigned Shanghai EBIT.

The Material Selection and Magnetic Field

In order to remove the effect of magnetic permeability anywhere along the electron beam path, the vacuum chamber and cryostat of the redesigned Shanghai EBIT are made of commercially available pure Titanium instead of Stainless Steel. This led to many challenges due to welding technics etc., since Titanium welding is not the

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same as that for Stainless Steel. In addition, brazing of different materials, one being Titanium, was difficult due to the small thermal expansion coefficient of Titanium.

The Helmholtz coils [19] employed here were made of ϕ=0.538 mm Nb-Ti/Copper matrix monolith wire [20] which were fixed by a special technique to protect against quenching displacement. The highest magnetic field at the central drift tube region can reach 4.8 T. The uniformity of the magnetic field, along the axis of the electron beam, is 2.77×10^{-4} within the central trap region of 20 mm.

Table 1: Parameters of redesigned Shanghai EBIT

Parameters	Design	Achieved
Electron energy	200 keV	40 keV
Beam current	200~250 mAmps	110 mAmps
Beam radius	30~50 µm	32.8 µm
Beam density	~5000 A/cm^2	2400 A/cm^2
Vacuum	<5×10^{-10} Torr	~7.5×10^{-11} Torr
LHe consumption	<1.5 L/hour	<0.5 L/hour
Magnetic field	5 T	4.8 T

Vacuum and Cryogenic System

Each region of the redesigned Shanghai EBIT, (gun, drift tube, and collector), employs two 300 L/s turbo-molecular pumps, coupled with a second stage 80 L/s turbo-molecular pump.

In order to reduce the LHe consumption, our new EBIT is equipped with a LHe recycling and cooling system [19] which has, up until now at least, shown surprisingly good efficiency. One SHI 1.5 W @ 4.2 K 2-stage G-M refrigerator is responsible for liquefying evaporated He gas while another SHI 5.4 W @ 10 K 2-stage G-M refrigerator is responsible for cooling two of the cryogenic shields used to prevent and reduce thermal radiation from room temperature surfaces. According to the first two EBIT operation campaigns at an electron beam of 30 keV, very close to zero evaporation of LHe has been achieved. The new design with eccentric cryostat structure allows for vertical installation of these two refrigerators which minimizes system vibration and maximizes efficiency and lifetime at the same time.

Since the large cryogenic shields perform as a huge cryopump, after cooling, the vacuum, measured close to a view port, has reached down to around 7.5×10^{-11} Torr. This is over an order of magnitude better than the original machine.

Furthermore, one of eight view ports facing the central drift tube is equipped with a neutral ballistic gas injector which has two differential pumping stages. Typical pressure of the last injection stage is about $1.0\sim3.0\times10^{-8}$ Torr. With such a device, many gas elements can easily be introduced into the trap.

Beam Optics Simulation and System Alignment

The redesigned Shanghai EBIT has a more compactable structure in which the height of electron collector is now 300 mm closer to the drift tube region than in the previous design. To illuminate the possible impact of this on the beam optics, we simulated the electron and ion trajectories with the commercially available software TRICOMP [21]. On one hand, the results indicated excellent confinement of the beam with the appropriate electric and magnetic field configurations through low, medium, and high electron energies. On the other hand, ion trajectory simulations with Au ions injection from a Metal Vapour Vacuum Arc (MEVVA) ion source showed a significant increase in ion injection by a factor of 3 times compared with the original EBIT design.

Furthermore, in order to obtain the highest current density possible and prevent secondary electrons or ions, generated by scattered electrons hitting beam optical components, the electron beam should be well aligned along the axis of magnetic field, the z or vertical axis [22]. A collimating telescope with four degrees (x, y and 2 angles) of freedom and with precise manipulation served for system alignment. The ultimate concentricity of the whole system was measured to be less than 0.05 mm. The non-magnetic vacuum chamber and cryostat combined with the excellent optical alignment, so far no bucking coils (to produce extra guiding fields), have led to excellent beam tuning and hence beam transmission through the EBIT.

CONCLUSIONS

We have successfully redesigned and reinstalled our Shanghai EBIT facility over the past few years. Some important technical highlights are presented here and show good beam optics and spectroscopic research opportunities.

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REFERENCES

[1] J.D. Gillaspy, J. Phys. B: At. Mol. Opt. Phys. 34 (2001) R93.
[2] R.E. Marrs et al., Phys. Rev. Lett. 60 (1988) 1715.
[3] J.D. Silver et al., Rev. Sci. Instrum. 65 (1994) 1072.
[4] J.D. Gillaspy, Phys. Scr. T71 (1997) 99.
[5] N. Nakamura et al., Phys. Scr. T73 (1997) 362.
[6] K. Motohashi et al., Rev. Sci. Instrum. 71 (2000) 890.
[7] C. Biedermann et al., Phys. Scr. T73 (1997) 360.
[8] J.R.C. López-Urrutia et al., Phys. Scr. T80B (1999) 502.
[9] V.P. Ovsyannikov et al., Rev. Sci. Instrum. 70 (1999) 2646.
[10] X. Zhu et al., Nucl. Instrum. Methods Phys. Res. B 235 (2005) 509.

[11] J. Xiao et al., Rev. Sci. Instrum. 83 (2012) 013303.
[12] S. Bohm et al., J. Phys.: Conf. Ser. 58 (2007) 303.
[13] H. Watanabem et al., J. Phys.: Conf. Ser. 2 (2004) 182.
[14] R.E. Marrs et al., Phys. Scr. T59 (1995) 183.
[15] S.R. Elliott, Nucl. Instrum. Methods Phys. Res. B 98 (1995) 114.
[16] M. He et al., J. Phys.: Conf. Ser. 58 (2007) 419.
[17] W. Hu et al., J. Phys. 86 (2008) 321.
[18] J. Rodney et al., IEEE Trans. Electr. Dev. 28(1981) 37.
[19] M. Zhang et al., Cryo. & Supercond. 39 (2011) 7.
[20] See http://www.oxford-instruments.com
[21] See http://www.fieldp.com
[22] Y. Chen et al., Nucl. Tech. 29 (2006) 8.

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