The present status of the Shanghai electron beam ion trap

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Abstract In this report, an introduction to the structure of Shanghai EBIT, a brief description of the status of Shanghai EBIT project, and a short discussion of the first results of Shanghai EBIT are presented.

Key words Electron beam ion trap, Electron collector, Ultra-high vacuum, Superconducting magnets

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1 Construction of the device

EBIT(electron beam ion trap) is an ideal device to produce, trap, and study highly charged ions. Basically it can provide any charge states of any element in the periodic table. After the first development at the Lawrence Livermore National Laboratory in 1986,[1,2] EBITs have been constructed in Oxford,[3] NIST,[4] Tokyo,[5] Berlin[6] and Freiburg[7] (now moved to Heidelberg). Shanghai EBIT project was launched at the beginning of the year of 2002.[8,9] The conceptual design was completed 6 months later. The engineering designs for superconducting magnets, cryogenic system, drift tube assembly, electron collector assembly, transport system and all the relevant adjusting structures were finished before the May of 2003, and those for high voltage system, lowly charged ion injection, highly charged ion extraction system, power supplies were completed by the November of 2003.[10] The installation started in the May of 2004, at Fudan University, and finished by the end of the year with the first extraction of an electron beam. In the April of 2005, first photons were observed from the Shanghai EBIT.

The basic concept of the Shanghai-EBIT is similar to the EBITs installed at other laboratories. Fig.1 is a scaled sketch of the EBIT. A Pierce-type electron gun was designed to produce a high electron beam current of up to 200 mA. We have simulated[11] the electron trajectories to optimize the structure of the gun. It was shown that the perveance is about 0.39×10^{-6} $A/V^{3/2}$. The total paths of the electron trajectories, from the gun to the collector, were also calculated to study the beam transport properties of the machine. In the case of a beam current of 200 mA and an energy of 200 keV, the result shows an electron beam of radius 32 μm in the trap center, which corresponds to a current density of about 6200 A/cm^2.

In an EBIT, the intense electron beam is used to produce highly charged ions by successive impact of electrons on ions. The ions are trapped by the space charge of the electron beam in the radial direction, and by a potential well, formed by the bias of drift tubes (usually three drift tubes), along the axial direction. The electron beam is accelerated by the high voltage between the central drift tube and the electron gun cathode. Slots mounted on central drift tube (usually eight slots) are for spectroscopic purposes and for gas injection. A schematic diagram of the drift tube assembly can be found in Ref.[10]. Surrounding the drift tubes, a pair of superconducting Helmholtz coils is used to produce a strong magnetic field in the central trap region for compressing the electron beam to a high current density. In Shanghai EBIT, the Helm-

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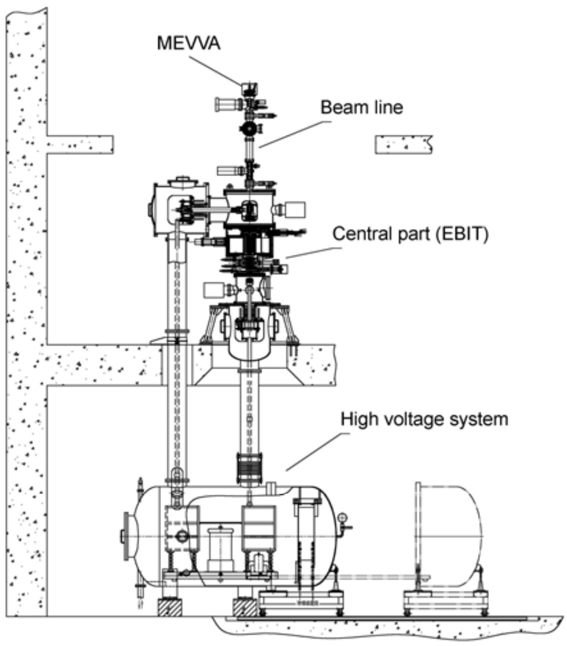

Fig.1 A scale sketch of the Shanghai-EBIT.

holtz coils were designed to produce the magnetic field of up to 5 T, with homogeneity of 2×10^{-4}, within 20 mm distance in the central trap region along the field axis.[10] A cryogenic system is used to maintain the superconductivity and to produce the ultra high vacuum needed in the trap region. This kind of EBIT is usually called cryo- EBIT, different from warm EBIT which is not equipped with cryogenic system.[12] Ultra-high vacuum conditions are needed to ensure that the highly charged ions do not disappear too quickly due to charge exchange in collisions with residual gas atoms. In Shanghai EBIT, the central part of the cryogenic system is the liquid helium container, in which the superconducting magnet coils reside. Outside the liquid helium container there are two cryo-screens, 20 K and 80 K, respectively. Both are cooled by a refrigerator. This design is for reducing the liquid He consumption.

An electron collector works for efficiently collecting the electron beam after the electrons have finished their job. On top of the EBIT a metal vapor vacuum arc (MEVVA) pulsed ion source is mounted to inject lowly charged ions into the EBIT for further ionization. Test-bench experiments with the MEVVA ion source have been successfully completed before being installed on the EBIT. At the first stage, ions of three elements, Fe, Au, and Ge can be produced with beam currents of about 1.5 mA/100μS.

The Shanghai-EBIT is designed for operating at electron beam energy of up to 200 keV. The drift tubes are floated at a voltage platform of 0 to +30 kV, the electron gun and the collector assembly are on a platform floated at 0 to –170 kV. All the relevant power supplies which are envisaged to be floated at the later platform are enclosed inside a metal tank filled with 0.3 MPa SF_6 insulator gas in order to achieve higher breakdown voltage. Two accelerator tubes were made specifically for high voltage insulation. The POISSON Superfish program[13] is adopted to calculate the electric field distribution of the device. It was found that, inside the vacuum region, the maximum field is on the surface of electron gun shield head, which is 60.5 kV/cm. Inside SF_6 the maximum field is on the ground potential end of the accelerator tubes, which is 45 kV/cm. Both are below the EBIT high field specifications.

A fiber optically linked distributed control system was designed to control all the power supplies. A commercial product, from Group3 Technology Ltd., was used to construct the control system. A graphical interface software based on Labview 7.0 was developed, which allows the user to set and monitor the power supplies conveniently.

2 Operation and experiments

The Shanghai-EBIT was first put into operation towards the end of 2004. Recently the EBIT has reached an electron beam energy of 50 keV with a 60 mA beam current at magnetic field of 3 T. The electrons collection efficiency is 99.97%. Several types of noble gases: argon, krypton and xenon have been successfully injected into the EBIT. We choose the optimum injection condition by maximizing the photon intensity of preferred ions. X-ray spectra of injected gas elements, Kr and Xe, and of evaporated cathode elements, Ba and W, were measured by using a high purity germanium detector. Fig.2 shows an example of test spectrum. Gaseous atoms are injected by using a differential pumping system. A primary experiment to observe *KLL*, *KLM*, *KLN* di-electronic recombination of krypton has been done to test the event-mode data acquisition system. A scatter plot showing the intensity distribution with X-ray energy and electron beam energy is displayed in Fig.3. Here both di-electronic and radiative recombination events are clearly visible. Further experiments with this newly constructed EBIT are ongoing.

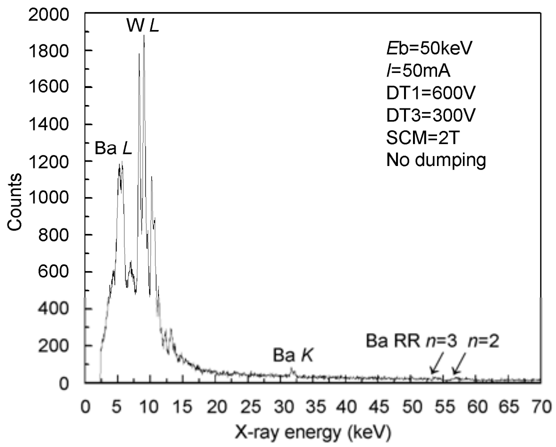

Fig.2 X-ray spectrum of barium and tungsten ions taken at 50 mA electron-beam current and 50 keV beam energy.

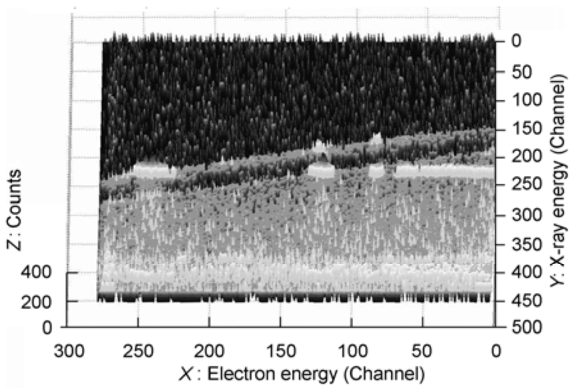

Fig.3 Di-electronic recombination spectrum for the *KLL* resonances of krypton.

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