Shanghai Electron Beam Ion Trap: Design and Current Status

ZHU Xikai*, JIANG Dikui, GUO Panlin, SHENG Shugang, YAN Heping, GONG Peirong, WANG Naxiu, SHI Weiguo, CHEN Yonglin, XU Xiangyi, FENG Shuqing, ZHOU Tuantuan

Shanghai Institute of Applied Physics, CAS, Shanghai 201800
(*) e-mail address: ebit@sinr.ac.cn

Abstract A new electron beam ion trap (EBIT) is under constructing in Shanghai. In this paper we describe the design and the features of this apparatus. Finally the current status of Shanghai-EBIT is shown.

OVERVIEW

The basic concepts of the Shanghai-EBIT is similar to the super-EBITs installed in the other laboratories.1-6 Figure 1 is a scale sketch of the Shanghai-EBIT. The central part of the Shanghai-EBIT is shown in Figure 2. The device will be installed in an existed building in Fudan University. The building consists of three layers. The high voltage system and a tank containing the power supplies are placed at the ground floor. The central part of the EBIT and eight observation ports are put at the first floor. The ion injection and extraction system are mounted at the second floor. Table 1 shows the main parameters of the EBIT.

| Items                                   | Value   |
|-----------------------------------------|---------|
| Vertical Length of the Trap             | 2 cm    |
| Electron Beam Energy                    | 200 keV |
| Beam Current Density                    | 5000 A/cm² |
| Beam Radius                             | 30-50 µm |
| Magnetic Field at the Trap Region       | 5 T     |
| Liquid Helium Consumption               | < 0.5L/hr |
| Vacuum at Room Temperature              | 10⁻⁹⁻¹⁰ torr |
| Number of Observation Ports             | 8       |
| Primary Ion Source                      | MEVVA   |

THE ELECTRON GUN AND ELECTRON BEAM

In this EBIT the electron gun is Pierce-type, which was designed to produce a maximum electron beam current up to 200mA. We used the EGUN program7 to design the gun. A simulation of the electron trajectories in the electron gun is
illustrated in figure 3. A number of experiments have been done to investigate the properties of the gun. It was shown that the permeance is about $0.39 \times 10^{-6} \text{ A/V}^{3/2}$. Furthermore, we simulated the electron beam trajectories from the gun to the collector region using EGUN program. Figure 4 is an example of the simulation. The electric and magnetic field distribution of the whole EBIT was calculated by using the POISSON Superfish program. In case of beam current 200 mA, energy 200keV, it was shown that the electron beam radius in the trap region is around 32 $\mu$m. This result accords with the prediction of Herrman theory. In this case the current density is about 5000A/cm$^2$. This is the value we expected. EGUN program has been used to optimize the design of the collector. The simulation not only gives us useful information for the design of the device, but also gives us the starting conditions for the operation of the EBIT.

**THE SUPERCONDUCTING MAGNET AND THE CRYOSTAT**

At the central part of the EBIT a series of three drift tubes are mounted which are used to trap highly charged ions by applying appropriate voltage. Eight slits are designed around the central drift tube for spectroscopy measurement and gas injection. Surrounding the drift tubes region there are a pair of superconducting Helmholtz coils which produce a magnetic field of 5 Tesla at the central trap region. A measured magnetic field inhomogeneity of less than $2 \times 10^{-4}$ along the trap length of 20mm has been obtained. The superconducting coils and the drift tubes are put inside a cryostat.

The structure of the cryostat used for the EBIT is illustrated in figure 2. The liquid helium container consists of two parts. One of it is small whose volume is only 5 liters. Inside the small container the superconducting magnet coils are kept and dipped in liquid helium. Another bigger container is used to store liquid helium, with the volume of 86 liters. These two parts are connected by four stainless steel bellows. Outside the liquid helium containers there are two layers of cryo screen cooled by utilizing a cryorefrigerator. The inner screen is at 20K, and the outer screen is at 80K.

We have calculated the thermal losses of the whole cryostat, which are given in Table 2. A two stages cryorefrigerator are used to cool the cryo screens. The power of the cryorefrigerator is also shown in Table 2. The values include all the possibilities of thermal loss. The refrigeration power is big enough to serve this cryostat system. By using this cryostat the consumption of liquid helium is very small, less than 0.5 liters per hour. In addition, the cold surfaces of these cryo screens absorb residual gas inside vacuum chamber, just like a very strong cryopump.

| TABLE 2. Thermal losses of the cryostat and the power of the cryorefrigerator |
|-------------------------------|-----------|
| Items                         | Power     |
| LHe tank                      | 220.86 mW |
| 20 K cryo screen              | 3.953W    |
| 80 k cryo screen              | 52.4W     |
| First stage of the cryorefriger (80K) | 100W     |
| Second stage of the cryorefriger (20K) | 10W       |
ION INJECTION AND EXTRACTION SYSTEM

Neutral gas injection and a MEVVA ion source are used to supply EBIT with atoms and primary ions. A differential pumping system has been designed to inject gaseous atoms. A MEVVA ion source was designed to produce lowly chaged ions. The design strategy makes it conveniently to change the cathod.

THE HIGH VOLTAGE SYSTEM

It is intended that the Shanghai-EBIT will be operated at a maximum electron beam energy of 200keV. In this case, the drift tubes will be floated at +30kV from earth, insulated from the vacuum chamber wall (earth) with sapphire rings, at the same time the electron gun and the collector assembly will be floated at −170kV from earth. All the power supplies for the gun and collector assembly are put inside a metal tank filled with 0.3 MPa SF6 insulation gas in order to to achieve higher breakdown voltage. Two coaxal steel tubes filled with SF6 gas are used to transport high voltage cables of the power supplies. Two accelerator tubes made in our institute are used as high voltage insulator. In order to get a higher voltage without breakdown we have optimized the surface structure of the accelerator tubes and the inner electrodes in several ways. The structure of the accelerator tubes is illustrated in Figure 5. The POISSON Superfish program is used to calculate electric field distribution. Figure 6 shows the electric field distribution along the surfaces of the electron gun and high voltage feed components. The extreme values of the electric field inside vacuum and SF6 gas are evaluated. It was shown that the maximum field is on the surface of electron gun shield head and the ground potential end of the accelerator tube. Inside vacuum surface the maximum field value is 60.5 kV/cm, and inside SF6 the maximum value is 45 kV/cm. Both of the values are safe enough as we expected.

THE CONTROL SYSTEM

A computer based control system allows all the power supplies to be set and monitored by the user conveniently. We adopted a commercial product from Group3 Technology Ltd. to constuct the contol system. This is a fiber optically linked distributed control system, which has been successfully used for other high voltage decives such as high voltage particle accelerators and ion implanters.

CURRENT STATUS OF THE SHANGHAI EBIT

We have finished the design and manufacture of the EBIT. The device will be installed in Fudan University, and will be operated in the near future.
ACKNOWLEDGMENTS

The authors gratefully acknowledge Prof. Zou Yaming for many usefull suggestions and help on the design of the device. We are grateful to Prof. Ohtani, Dr. Nakamura and all the members in Tokyo-EBIT group for help in the design of this EBIT. We thank Prof. J. Ullrich and Dr. J. R. Crespo López-Urrutia for giving us chance to visit Heidelberg-EBIT Lab and giving us usefull information. We thank Prof. Leif Liljeby for useful discussion on the design of the device.

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FIGURE 1. A scale sketch of the Shanghai-EBIT.
FIGURE 2. A scaling diagram of the central part of the Shanghai-EBIT
FIGURE 3. A simulation of the electron trajectories in the electron gun.
FIGURE 4. An example of the simulation of the electron beam trajectories from the gun to the collector. In this case, the electron beam trajectories are calculated at energy 200keV, current 200mA, and magnetic field 5T at trap region. The current density at the central trap region including 80% of the beam is about 4773A/cm².
FIGURE 5. The structure of the accelerator tube used as the insulator.
FIGURE 6. The electric field distribution along the surfaces of the electron gun and high voltage feed components.