Design of EBIS for nanoprocesses using HCI

2004 J. Phys.: Conf. Ser. 2 52

(http://iopscience.iop.org/1742-6596/2/1/007)

Design of EBIS for nanoprocesses using HCI

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Abstract. The design of EBIS for nanoprocess using HCI is presented. The EBIS uses commercial super-conducting magnet cooled by a closed-cycle refrigerator. We have made trajectory simulation of electron beam in 100mA range to determine the configuration of electrodes and magnet coils appropriate to obtain high current density beam at the drift tube region.

INTRODUCTION

It has been reported that bombardment of highly charged ions (HCIs) on various material surfaces produces nanostructures with specific spectroscopic characteristics[1,2]. We have been studied the structural and spectroscopic properties of surfaces irradiated with HCIs using Tokyo-EBIT[3], however, it is essential to have more intense and convenient EBIS to extend our research subjects such as the creation of ordered array of nanostructures using single ion implantation technique[4,5]. On the possible application of HCIs for nanotechnology, it is needed to control the impinging position of HCI on the substrate with the accuracy better than 10 nm. The realistic method to place HCI with required accuracy should be to use a mask with a hole as proposed by Schenkel et al[5], however, this needs an intense ion source which produces more than 10^8 ions for the specific charge state. Among various types of ion sources of HCI, EBIS is the most appropriate one to the application for the fabrication of nanostructures in the light of beam emittance and charge state distribution inherent to each one. In the present paper, we describe the plan of a new EBIS for the application of nanoprocesses using HCI.

SPECIFICATIONS OF NEW EBIS

The main purpose of constructing the new EBIS is to have a convenient ion source of HCI to get much more intense beam for the irradiation experiments related to the applications for nanotechnology. Taking into account that the available intensity which is trimmed off from the ion beam into macroscopic beam size using a small hole is so limited that irradiation procedure takes much time, it is preferable to use an ion source with simple operational procedure and inexpensive running cost. Table 1 summarizes the proposed specifications for the new EBIS compared with those for Tokyo-EBIT. In the present design the magnetic field to compress electron beam of the new EBIS is provided by a commercial superconducting (SC) magnet cooled by a closed-cycle refrigerator so as to be operated with less labor by even an operator not familiar to the detail of the ion source. The magnetic field strength is determined from the efficiency for beam compression, that is, the relation between magnetic field and beam radius[6] suggests us that higher field is not so effective to beam compression.

TABLE 1. Comparison of the specifications of two EBIS/T.

	New EBIS	**Tokyo-EBIT**
Acceleration voltage (kV)	40	300
Electron beam current (mA)	300	300
Magnetic field at DT (T)	3	4.5
Type of cooling of SC coil	Closed-cycle refrigerator	Liquid He tank
Typical size (Height x Width)	0.6x 1 (m)	3 x 2 (m)
Direction of beam axis	Horizontal	Vertical

The vacuum tube system including an electron gun, drift tube electrodes and a collector will be separated from the magnet system as shown in Fig.1, and fully bakable up to 250～300℃ when it is extracted from the bore of the magnet system. The advantage of separation is that the make up inside the vacuum system become simple and it can be made of materials bearable to bake-out temperature. The structure in the vacuum system may also be disassembled and modified much easier than unified system. The demerit of separation is that the size of SC magnet become larger leading to wider spread of magnetic field. The cryo-pumping effect of SC magnet system is not available for the vacuum system, however, this is not a serious drawback because a cryopump is not so effective for a sufficiently baked system with residual gas being mainly composed of hydrogen. Since the device we are planning is only used as ion source unlike the Tokyo-EBIT, the beam axis is set in horizontal direction, which is convenient to connect to an ion beam line.

Taking into account the application of the present device, it is desirable to make the potential of drift tubes within several kV on the ground level, which makes it easier to decelerate the ions hitting on a substrate and reduce the kinetic energy effect. Then electron gun and collector should be on a floating potential. Also the power supply for each electrode and coil is necessarily on a floating potential. It will be controlled via analog DC voltage that is supplied by DA converters communicating with PC through optical fibers. The output current of each power supply is also monitored by PC using a VF converter.

SIMULATION

For the first step of the designing, the trajectories of electron beam have been simulated using the software TriComp 2D (Field Precision). The layout and dimension of each electrode and magnet is set along following guidelines; 1) the diameter of the bore of SC magnet system is 180-200mm, 2) the strength of SC magnetic field is 3T and is uniform within 5% deviation over a region longer than 50mm along the beam axis, 3) the distance between the cathode and collector should be as short as possible, 4) the vacuum tube system can be separated from the SC magnet system keeping the vacuum system pumped, 5) the strength of bucking coil is kept less than 500AT due to the requirement that the coil could be cooled by thermal conduction. The first requirement comes from that the cathode region must be pumped through the drift tube region by vacuum pumps situated only near the collector due to the fourth requirement, then it is required to secure the conductance between the regions of cathode and collector.

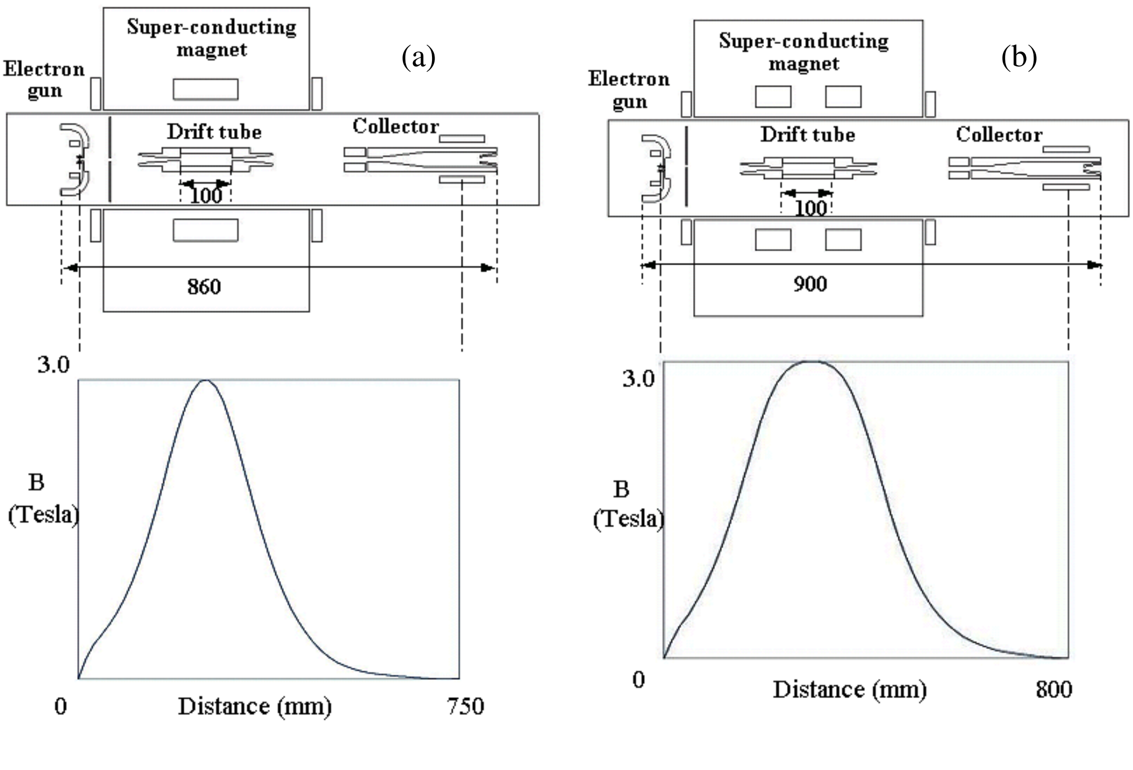

FIGURE 1. Layouts of the electrodes and magnets for two types of SC coil systems: solenoid coil (a) and Helmholz coils (b) with the intensity distributions of magnetic field on the beam axes.

The layouts of the electrodes and magnets are illustrated in Fig. 1 with the intensity distributions of magnetic field on the beam axes for two types of SC coil systems: solenoid coil (Fig.1a) and Helmholz coils (Fig. 1b). The size of SC magnet is settled according to the bore size and the intensity of magnetic field. The Helmholz coils system produces wider flat-region of on-axis magnetic field over 100mm length within 5% deviation with similar coil volume as that of Fig. 1a. Magnetic shields made of soft iron are placed in front of cathode electrodes in the vacuum system and also on both ends of the envelope of SC magnet system in atmosphere.

Examples of trajectory calculation are shown in Fig. 2. Before the trajectory calculation, the strength of the bucking coil and collector coil and the thickness of the magnetic shield covering the cathode assembly were adjusted so that magnetic field at the cathode and around the collector electrode become almost zero. Electrons are assumed to emit from a concave disk with a diameter of 3mm. Trajectories at the center of drift tubes also show that the electrons concentrate in a thin beam with a diameter less than 0.1 mm.

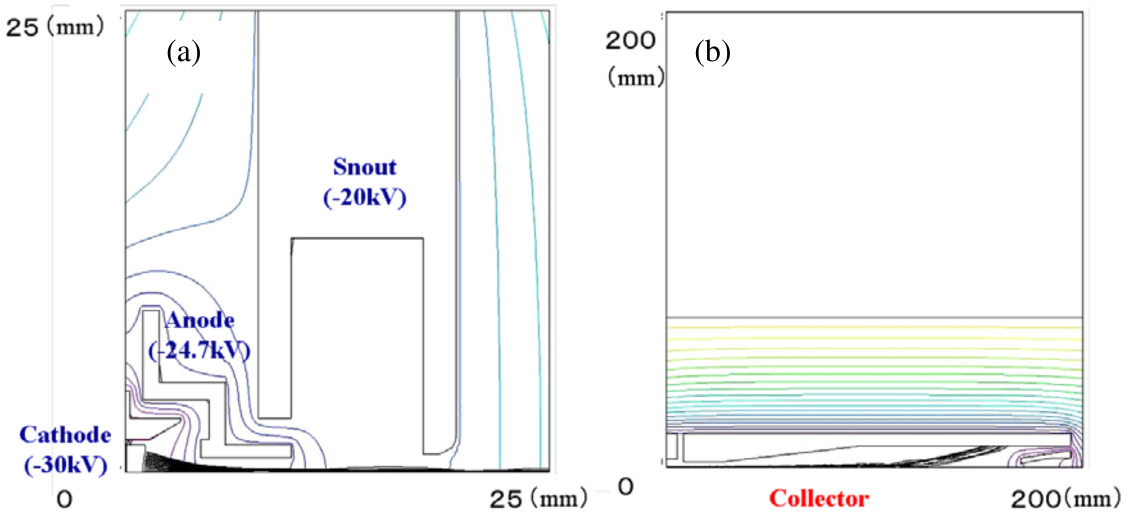

FIGURE 2. Trajectory of electron beam with emission current of 100mA in the new EBIS around the cathode (a) and collector (b) regions.

A simulation experiment was performed to know the possibility of conduction cooling of the heat load from the bucking coil, since the conduction cooling makes the construction much simpler around the electron source which is on high-voltage floating potential. A coil is made of polyimide coated Cu wire (DETAKTA, Isolier- und Messtechnik GmbH & Co KG) wound around a coil bobbin for 300 times. The coil bobbin made of OFHC was supported by a high-voltage resistant feedthrough mounted on a conflat flange via OFHC rods in order to simulate actual condition of thermal conduction for the bucking coil in the presently designed structure of the new EBIS. The atmosphere side of the feedthrough was contacted to a copper plate for heat radiation.

Figure 3 shows the dependence of temperatures of the coil bobbin and copper plate on the magnetic field strength expressed in ampere-turn (AT). The temperature of the coil bobbin was measured by an N-type thermocouple. The figure recommends us that the magnetic strength should be less than 300AT to prevent the degradation of vacuum due to thermal outgassing. It is easily realized to reduce to 300AT from 500AT if the electron gun is retreated from the SC coil for only several centimeters.

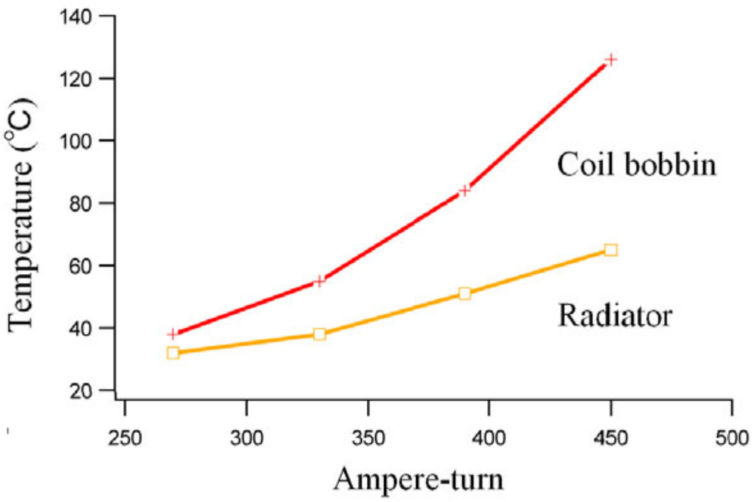

FIGURE 3. Dependence of temperatures of the coil and copper plate on the magnetic field strength expressed in ampere-turn (AT).

In conclusion we have designed an EBIS dedicated for nanoprocess using HCIs. The present design has characteristics that the device uses a commercial superconducting magnet cooled by a closed cycle refrigerator, and the vacuum system that contains such as electron gun is separated from the magnet system and will withstand against ordinary baking procedure. The EBIS will be completed in the end of 2004.

ACKNOWLEDGMENTS

Part of this work was supported by a grant from Japan Science and Technology Agency (JST), and a contract research program from National Institute of Information and Communication Technology (NICT).

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