TRANSPORT SYSTEM FOR ION IMPLANTATION

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Abstract

ITEP in collaboration with MEPHI and HCEI (Tomsk) develops the high intensity ion beam generation and transport systems for low energy (1 – 50 keV) ion implantation. Such facilities are used for semiconductor technology. The Bernas type ion source is used for the ribbon ion beam production. The periodical system of electrostatic lenses (electrostatic undulator) was proposed for ribbon beam transport line. The design of transport system and the results of the beam dynamics investigation are presented. The influence of the electrodes construction errors on the beam dynamics is discussed.

INTRODUCTION

Progressive semiconductor device scaling in each technology node requires the formation of shallower junctions, and thus lower energy implants. The continuing need to reduce implantation energies creates significant challenges for the designers of advanced implanters. Current density limitation associated with extracting and transporting low energy ion beams results in lower beam currents that in turn adversely affects the process throughput. It has been proposed [1] that by implanting clusters of boron atoms, the implanted dose rate will be larger and the problems associated with low energy beam transport will be less significant. The individual atoms on a singly charged cluster of *n* identical atoms accelerated with voltage *V*, have an energy of *eV/n*. The extracted energy would have to be *n* times greater to get the same velocity as the monomer. In addition, the dose rate would be *n* times larger then the electric current. That is why BF_2 is used extensively in the industry – a 10 keV BF_2 implant, for example, is equivalent to a 2 keV boron implant. A much more dramatic example of this energy partitioning is decaborane ($B_{10}H_{14}$) and even octodecoborane ($B_{18}H_{22}$). The boron atoms in an ion beam of molecule decaborane have energy less of approximately 1/11 of the molecule’s energy. The implanted dose is ten times the integrated beam current [2].

In ITEP and MEPhI in collaboration with HCEI, Russia, and BNL, USA a joint research and development efforts whose ultimate goal is to develop steady state intense ion sources to meet needs of 100’s of electron-volt ion implanters has been in progress. The Bernas ion sources with directly heated cathodes are the main ion sources for this research. The decaborane ion beam generation and transportation up to target are the main goals of the experiments with these ion sources. The results of decaborane beam generation are presented. As well the periodical system of electrostatic lenses (electrostatic undulator) was proposed for ribbon beam low energy transport line. The required tolerance for electrostatic undulator electrodes installation was investigated and results are presented as well.

BESRNAS ION SOURCE WITH DIRECTLY HEATED CATHODE

As we wrote previously [3], [4], [5], first experiments with decaborane beam we carried out at Bernas ion source with indirectly heated cathode (IHC). The extracted beam current was significantly less then 1 mA. To increase the discharge current, it is necessary to increase the temperature of the working surface of indirectly heated cathode. The decaborane is fragmentized at the temperature of ~ 350ºC [2]. To provide the discharge chamber temperature less than 300ºC, we constructed the water-cooled discharge chamber from copper. From other hand, to prevent the decaborane crystallization at the vapor channel walls, decaborane vapor channel should be kept at high enough temperature to prevent decaborane condensation into the vapor channel. To avoid the condensation, the additional heating up to 60 – 80°C along vapor channel was provided. During operation the temperature of the cupper discharge chamber riches the temperature of 60 – 80ºC. To provide the decaborane vapor pressure needed in the discharge chamber region, the oven was heated up to 60 – 100ºC. Therefore the quasi-uniform temperature distribution along all decaborane vapor channel was established.

We found that for water-cooled discharge chamber it is about impossible to start the discharge. The working surface of IHC is overcooled due to heat transmission from working surface of IHC to cooled part of discharge chamber. Even if the opposite surface of IHC reaches the temperature of melting point for tungsten the emission current from the working surface is less than 1 mA.

The IHC was taken out and we carried out experiments with Bernas ion source with the filament as a directly heated cathode. The stable decoborane beam of 1 mA total current under 4 kV was extracted. At the target the decaborane peak current was 60 μA that was limited by the mass-analyzer throughput efficiency. The spectrum is given in Figure 1. Such result is process equivalent to a 0.37 keV, 10 mA for total current and 600 μA at the target implant for pure B^+ beam, a condition not allowed by the Child–Langmuir law. Nevertheless one can see that the beam transmission throughout the implanter channel is very small.

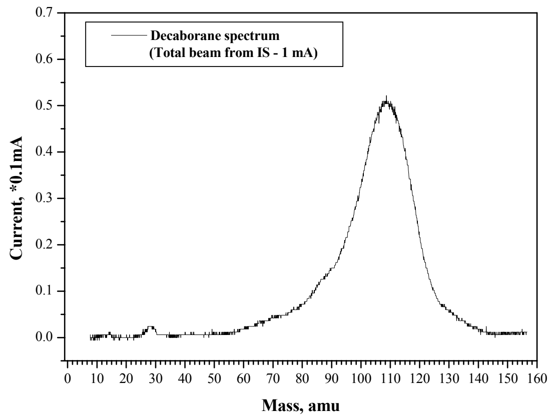

Figure 1: Mass spectrum from ITEP Bernas ion source.

At the last December the decaborane beam spectrum with high resolution was measured. To increase the resolution, the ion beam energy was increased up to 12 kV. Also two vertical slits of 0.8 mm were installed in front of the magnet separator entrance. The distance between the slits was 100 mm. Another slit of 3 mm was installed in front of Faraday cup at the magnet separator output. To minimize the influence of the ion source magnetic field on the beam transportation, the magnetic shields was used. The one shield is a tube from still with diameter 4 cm and length exactly equal to the distance between two slits. The second one is a tube with the same diameter but length is equal to the distance between ground electrode of extraction system to the first slit. The thickness of tubes is 2 mm. It was found experimentally and confirmed by simulation that such shield completely protect the ion beam from ion source magnetic field. The spectrum of decaborane beam is shown in Figure 2. As one can see the reasonable resolution of $B_{10}H_n^+$ peaks as well as peaks of decaborane fragments were achieved.

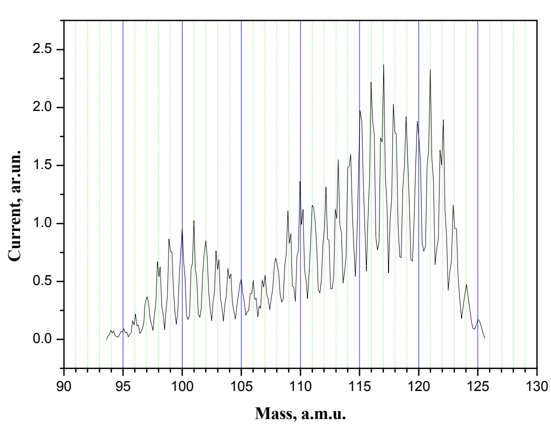

Figure 2: The decaborane beam spectrum with high resolution.

ELECTROSTATIC UNDULATOR

The beam transport line is one of the main problems for low energy ion implanter design. The periodical system of electrostatics lenses (electrostatic undulator EU [6]) was proposed for this goal. However the first simulation of the EU transport line developed for transportation of ion beam generated by Bernas ion source demonstrated the strong beam instability [7]. The instability is resulted by ion source magnetic field penetrated into transport line. As it was mentioned above, the experiments with magnetic shields demonstrated very efficient protection of transport line against the ion source magnetic field. As the result the EU transport line can be used for low energy beam transportation and, as example the EU line for 4 keV decaborane beam was developed. The EU layout is shown in Figure 3. The parameters of EU for 4 kV decaborane ion beam transportation are the following: structure period $D = 1$ cm, field amplitude on axe $E = 2.5$ kV/cm (potential on electrodes is equal to ± 2.5 kV), maximal aperture size $a \times b = 3 \times 0.6$ cm.

The results for the decaboran beam transportation throughout the EU line are presented in Figure 4. The BEAMDULAC code was used for beam dynamics study [8]. The ion energy is 4 keV ($\beta = 2.7 \cdot 10^{-4}$). The channel has 100 periods; the beam current is 1 mA. Figure shows the initial (red points) and output (blue points) beam cross-section (a). As well the transverse emittances in (β_x, x) (b) and (β_y, y) (c) planes are shown. The particle distributions on x (d) and y (e) axes are presented also. The current transmission coefficient is equal to 98 %.

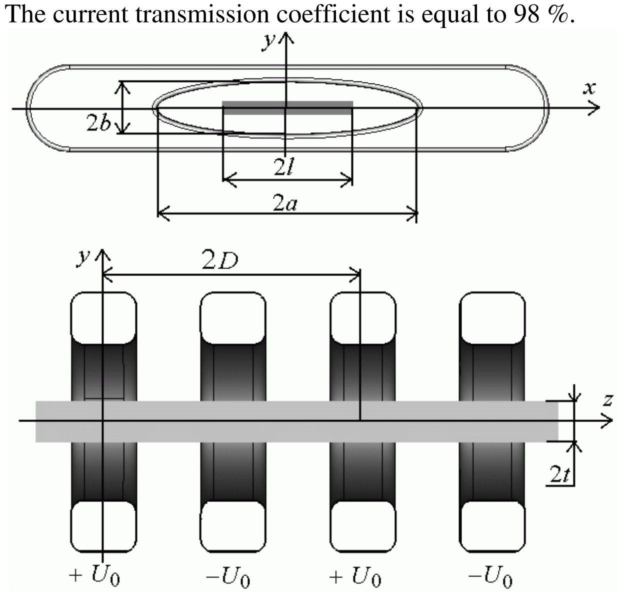

Figure 3: The general view of electrostatic undulator.

The transport channel construction and tuning errors can influence to the beam dynamics. The correct treatment of this influence is one of the most difficult problem in transport line design. New method was proposed for this goal. Several construction errors can be

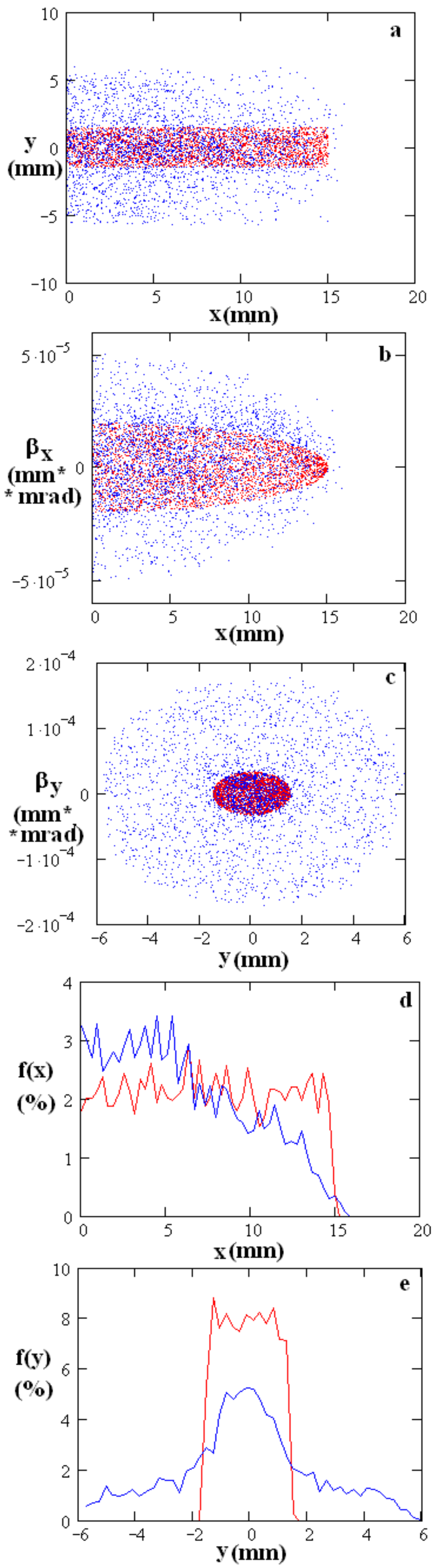

Figure 4: Initial and output beam parameters in EU beam transport.

observed in EU transport line: the shifts of electrodes along three axes, rotation around axis, the errors of electrode aperture and thickness dimensions, etc.

The investigation method includes two stages: the calculation of electrostatic field in channel with construction errors and the simulation of beam dynamics in this field. The special version of BEAMDULAC code was used for beam dynamics study. It was found that tolerances of the EU electrodes installation should be better than 200 μ for all three coordinates and better than 0.3° for rotation angles. One can see that such tolerances can be easily realized.

The output beam energy dispersion is not increased along the EU transport line and the beam halo includes only 5 % of particles. It is necessary to emphasize that the energy spread is within 150 eV. It is process equivalent to less than 15 eV energy dispersion at the target implant for pure B^+ beam.

CONCLUSION

The ITEP Bernas ion source provides the stable low energy (4 keV) decaborane beam with current of 1 mA. The beam consists of ions with different number of hydrogen atoms – $B_{10}H_n$ where n can be from 1 to 14. To transport such beam to the magnet separator the Electrostatic Undulator line was developed. The tolerance of EU electrodes installation should be better than 200 μm and 0.3º. The manufacture of the line is planned for the autumn and installation should be done till next summer.

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