DEVELOPMENT OF RIBBON ION BEAM SOURCE AND TRANSPORT SYSTEM FOR INDUSTRIAL APPLICATIONS

E.S. Masunov[1], S.M. Polozov[1], T.V. Kulevoy[2], R.P. Kuibeda[2], V.I. Pershin[2], S.V. Petrenko[2], D.N. Seleznev[2], I.M. Shamailov[1], A.L. Sitnikov[1]
[1]Moscow Engineering Physics Institute, Kashirskoe shosse, 31, 115409, Moscow, Russia;
[2]Institute of Theoretical and Experimental Physics
Bolshaya Cheremushkinskaya, 25, 117218, Moscow, Russia
E-mail: smpolozov@mephi.ru

The design of ribbon ion source and transport system is discussed in this paper. This system is created at ITEP for ion beam implantation in semiconductor technology. The Bernas type ion sources are used for ribbon ion beam production. The periodic system of electrostatic lenses is proposed for intensive ion beam transport. The results of implanter component development are observing.

PACS: 29.25.Ni, 61.72.Tt.

1. 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 result in lower beam currents that in turn adversely affects the process throughput. At the beginning, the cold cathode ion sources with "low currents" were used for mushiness for early MOS (Metal-Oxide-Semiconductor) circuit fabrication, which requires doses of $10^{11}…10^{12}$ ions cm^{-2}. The use of hot filament ion source (IS) technology with currents of tens of milliamperes followed some years later, when ion implantation was applied to MOS transistor source-drain formation (which required doses $10^{15}…10^{16}$ ions cm^{-2}).

The research and development efforts of new ion beam source and other implanter components provide in ITEP in collaboration with MEPhI, HCEI (Tomsk) and other. The ultimate goal is to develop steady state intense ion sources to meet needs of hundreds of electron-volt ion implanters has been in progress. The schematic view of implanter developing is presented in Fig.1 where ion source, extraction system and transport are shown. Here 1 is the schematic view of Bernas magnet, 2 – cathode and anticathode, 3 – plasma, 4 – extraction system, 5 – electrostatical deflector, 6 – anode, 7 – electrodes of electrostatical undulator. The Bernas (see Fig.2) and Freeman ion sources are proposed for ribbon ion beam production in common R&D project. The beam transport choice is one of main problems of implanter design. The periodical system of electrostatics lenses (electrostatical undulator) was proposed for this goal (see Fig.3). The common results of development implanter components are discussed in this paper as ion source, extraction system and transport line.

2. BERNAS ION SOURCE

The Bernas ion source is under investigation as a most perspective in framework of ITEP program of implanter ion source development for extreme regimes [1]. The photo of ITEP Bernas ion source is shown in Fig.2,a. The construction of it is shown in Fig.2,b. Here 1 is filament, 2 – cathode, 3 – anticathode, 4 – anode, 5 – extraction system, 6 – oven for solid materials, 7 – HV insulator. The electrical lay-out is shown in Fig.2,c. This IS can be used for both gases and solids ion beams generation. For solid ion beam generation depending on the temperature needed, the oven can be installed both inside and outside the IS. The discharge region consists of the cathode, the anticathode and the anode. Both cathodes are made from tungsten. The anode can be either from the molybdenum or from the graphite. To start and control discharge, the cathode is heated by electron beam from filament. The e-beam is accelerated by 1.5 kV between filament and the cathode. The control of discharge current is provided by the variation of filament heating current. This IS originally can provide the dc ion beams of boron, phosphorus, arsenic and antimony with ion beams with current up to a few tens mA, accelerated by 4…12 kV.

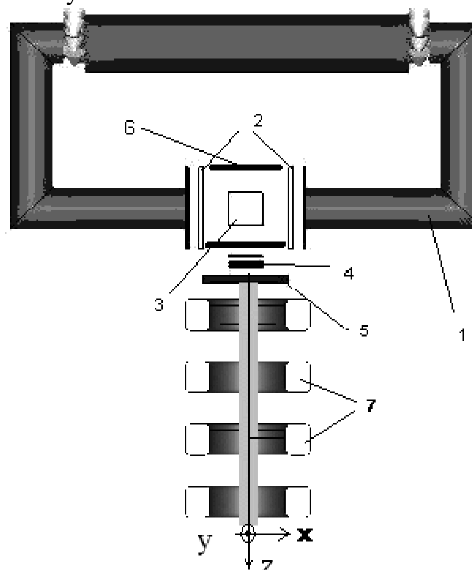
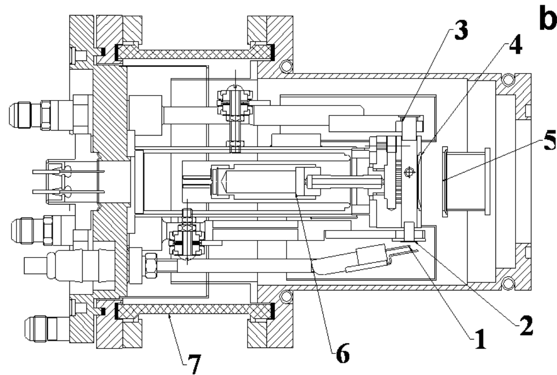


Fig.1. Schematic view of ion implanter

The extraction slit has dimension – 2×20 mm. The cathode life time of the ion source is not exceeds 100 h. For high energy implantation, the significant increasing of generated ions charge states was achieved by injection additional electron beam into the discharge region [2]. The typical beam spectra are given in Figs.4,5.



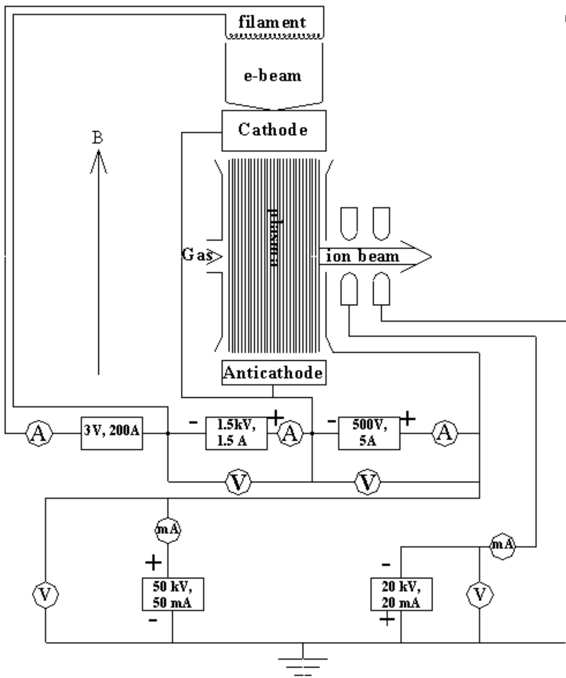


Fig.2. The general view (a), construction (b) and electrical scheme (c) of the IHC Bernas ion source

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. The current density limitation associated with extracting and transporting low energy ion beams result in lower beam currents that in turn adversely affects the process throughput.

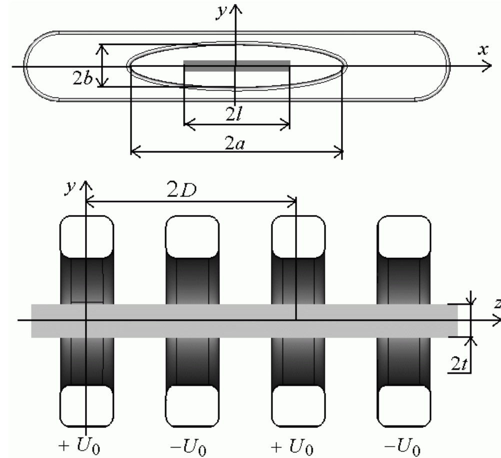


Fig.3. The general view of electrostatic undulator

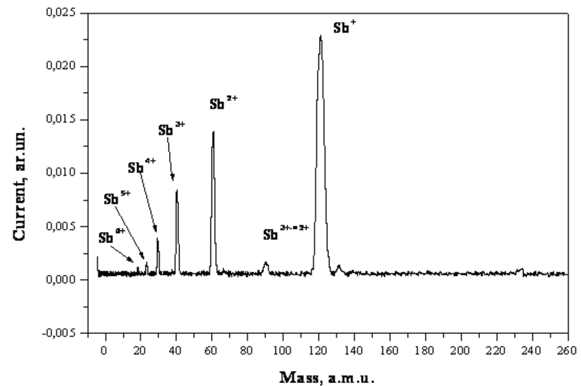


Fig.4. Spectrum of antimony beam from ITEP Bernas ion source

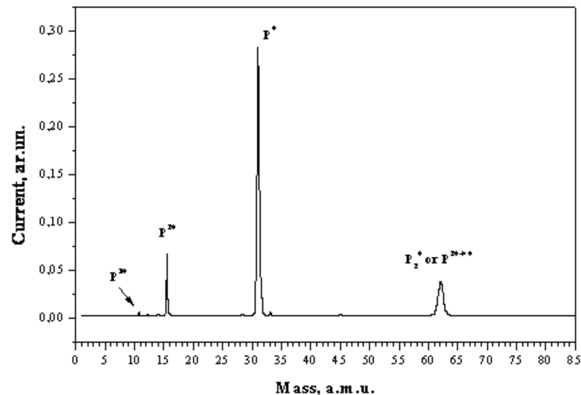


Fig.5. Spectrum of phosphorus beam from ITEP Bernas ion source

It has been proposed [3] 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 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 ($B_{10}H_{14}$). The boron atoms in

ion beam of molecule decaborane have energy less of approximately 1/11 of the molecule's energy. The implanted dose is ten times larger for integrated beam current [4]. For low energy implantation program, the ITEP Bernas ion source was modified for decaborane ion beam generation [5]. The stable decaborane beam with total current of 1 mA under 4 keV energy (boron equivalent – ~380 eV) was obtained. The charge state distribution measured is shown in Fig.6.

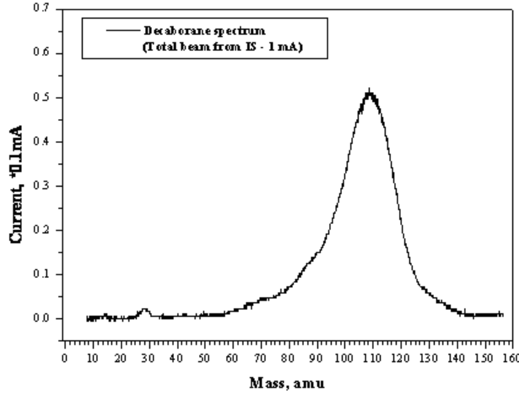


Fig.6. Decaborane spectrum from ITEP Bernas IS

3. EXTRACTION SYSTEM

The standard three electrodes acceleration – deceleration system is used

The magnetic field of Bernas source can negative influence to beam quality. This influence, at first, provides to the beam transverse emittance enlarging and, at second, can turn the beam from axis. The beam can propagate to the back side with any conditions.

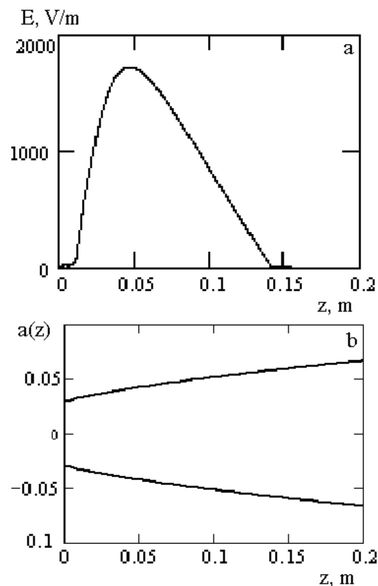


Fig.7. Electrostatic deflector

Two ways was proposed for this negative influence compensation. The transport can be shielded by means of soft magnetic steel case. But this method can not be useful in drift. In such gap the magnetic field has the maximal value also (up to 0.1 T). The magnet field can be compensated by means of especially designed electrostatical deflector here. Fig.7 shows the field distribution of the deflector axis that is necessary for compensation (a) and the form of electrodes realize this distribution (b). This form can not be easily realized but the beam dynamics investigation shows that electrodes of simple trapezoidal form are useful. The field distribution will close to showed in Fig.7 this case.

4. BEAM TRANSPORT

The electrostatical undulator was proposed for beam transport [6] as it was noted above. It was shown using BEAMDULAC-Tr code that low velocity beams of boron, phosphorus, antimony, decaboran and other ions (β=0.001) with current I=1…10 mA can be transported to the some meters using electrostatic undulator. The amplitude of undulator field E_0 must be equal to 12…14 kV/cm for ions with charge to mass ratio range A/Z=10…120. The current transmission coefficient is 100 % in this case and high output beam quality can be derived [7].

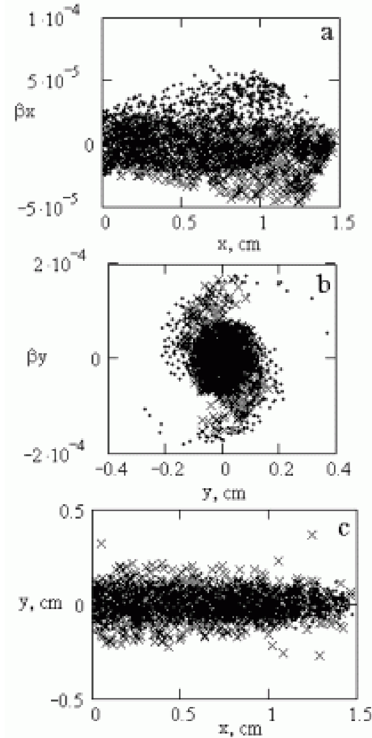


Fig.8. The results of beam dynamics simulation with Z/A=1/117 and Z/A=1/100

The ions with different charge to mass ratio Z/A are producing by Bernas source. It is interesting problem to simulate the dynamics of beam including different ions. It was shown that the electrostatical undulator can transport multi ion beam. It is possible when the charge to mass ratio of different ions is not very differs and the ion velocities are close. As an example (see Fig.8) the decaboran ($B_{10}H_{14}$) beam has ions with Z/A=1/100…1/124. Figure shows the output transverse emittance in (β_y, y) (a) and (β_x, x) (b) planes and beam cross-section (c). The ions with Z/A=1/100 are plotted by "×" and for Z/A=1/117 by points. Figure is plotted with ion energy 10 keV ($\beta=4.27\cdot10^{-4}$ for A=117 and $\beta=4.62\cdot10^{-4}$ for A=100), the channel has 25 periods, total beam current is 1 mA. It is clear that both ion types are transported simultaneously. But the ions with different Z/A as B_{10}^{+} and B_{10}^{2+} can not be transported simultaneously because the ion velocities were differ appreciably. For example,

if the B_{10}^+ ion energy is equal 10 keV ($\beta=1.46\cdot10^{-3}$) for B_{10}^{2+} W=20 keV ($\beta=2.07\cdot10^{-3}$).

The transport channel construction and tuning errors can influence to the beam dynamics. The correct treatment of this influence is one of difficult problem in accelerator design. New method was proposed for this goal [8]. Note that several construction errors can be observed in undulator based transport: the shifts of electrodes along three axes, rotation around one of axis, the errors in electrode aperture and thickness sizes, etc. The investigation method includes two stages: the calculation of electrostatical field in channel with construction errors and the simulation of beam dynamics in this channel. The especial version of BEAMDULAC code was used for beam dynamics study.

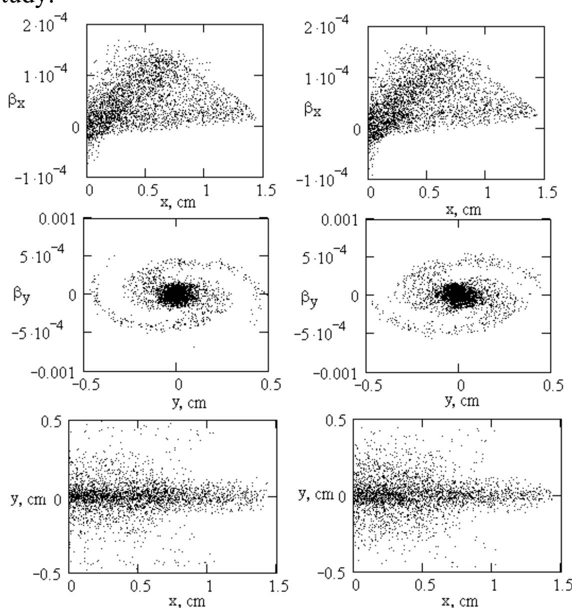


Fig.9. The results of construction errors influence study

An example illustrating this method is presented in [8]. Such example shows that the maximal shift of electrodes along longitudinal axis z can not be larger 300 μ. The second example is shown in Fig.9. The ribbon boron ion beam dynamics was studied in transport channel with the next parameters: the beam current 10 mA, ion energy 10 keV, the channel has 25 periods. The output transverse emittance in (β_y, y) and (β_x, x) planes and beam cross-section are shown for "ideal" channel (no constriction errors, left figures) and with treatment of electrodes rotation around longitudinal axis (right figures). The maximal rotation is equal 0.5° in this example. It is clear from figures that such error is not critical for ion beam transport.

At last the errors of electrodes manufacturing and tuning must be not larger than 300 μ along longitudinal axis z, 200 μ along transverse axis and 0.5…1° for rotation angles as it was shown by means of the numerical simulation. All this tolerances can be easily realized.

CONCLUSIONS

The common ITEP ion implanter R&D activities were observed. The results of Bernas ion source, extraction system and transport design are presented. The results of multi ion beam dynamics study and the influence of construction errors to the beam dynamics are discussed.

REFERENCES

1. T.V. Kulevoy, et al. Highly stripped ion sources for MeV ion implantation // *Rev. Sci. Instrum.* 2004, v.75, N 5, p.1900.
2. T.V. Kulevoy, et al. ITEP Berna IS with additional e-beam // *Rev. Sci. Instrum.* 2006, v.77, N 3, 03C110.
3. I. Yamada, W.L. Brown, J.A. Northby, M. Sosnowski // *NIM*. 1993, v.B79. p.223.
4. A.S. Perel, W.K. Loizides, W.E.Reynolds // *Rev. Sci. Instrum.* 2003, v.73, N 2, p.877.
5. T.V. Kulevoy, et al. Decaborane beam from ITEP Berna ion source // *Rev. Sci. Instrum.* 2006, v.77, N 3, 03C102.
6. E.S. Masunov, S.M. Polozov. Low energy beam transport for heavy ions in electrostatic undulator // *Proc. of RuPAC*. 2004, p.225-227.
7. E.S. Masunov, S.M. Polozov, T.V. Kulevoy, V.I. Pershin. The low energy ribbon ion beam source and transport system // *Problems of Atomic Science and Technology, Series "Nuclear Physics Investigations" (46)*. 2006, N 2, p.123-125.
8. E.S. Masunov, S.M. Polozov. Using BEAMDULAC code for multi beam dynamics investigation in ion linac // *Problems of Atomic Science and Technology, Series "Nuclear Physics Investigations" (50)*. 2008, N 5, p.136-139.

Статья поступила в редакцию 05.09.2007 г.

РАЗРАБОТКА ИСТОЧНИКА И СИСТЕМЫ ТРАНСПОРТИРОВКИ ЛЕНТОЧНЫХ ИОННЫХ ПУЧКОВ ДЛЯ ПРОМЫШЛЕННЫХ ЦЕЛЕЙ

Э.С. Масунов, С.М. Полозов, Т.В. Кулевой, Р.П. Куйбида, В.И. Першин, С.В. Петренко, Д.Н. Селезнев, И.М. Шамаилов, А.Л. Ситников

Рассматриваются вопросы, связанные с разработкой ленточного ионного пучка и системы транспортировки. Система имплантации разрабатывается в ИТЭФ для имплантации ионного пучка в полупроводники. Для получения ленточного ионного пучка используется источник типа «Бернас». Для транспортировки пучка предложено использовать периодическую систему электростатических линз. Рассматриваются результаты разработки отдельных частей имплантора.

РОЗРОБКА ДЖЕРЕЛА І СИСТЕМИ ТРАНСПОРТУВАННЯ СТРІЧКОВИХ ІОННИХ ПУЧКІВ ДЛЯ ПРОМИСЛОВИХ ЦІЛЕЙ

Е.С. Масунов, С.М. Полозов, Т.В. Кулевой, Р.П. Куйбіда, В.І. Першин, С.В. Петренко, Д.Н. Селезнев, І.М. Шамаілов, А.Л. Сітников

Розглядаються питання, пов'язані з розробкою стрічкового іонного пучка і системи транспортування. Система імплантації розробляється в ІТЕФ для імплантації іонного пучку у напівпровідники. Для одержання стрічкового іонного пучка використається джерело типу "Бернас". Для транспортування пучку запропоновано використати періодичну систему електростатичних лінз. Розглядаються результати розробки окремих частин імплантору.