THE LOW ENERGY RIBBON ION BEAM SOURCE AND TRANSPORT SYSTEM*

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The ribbon ion beam can be used in the commercial ion implanters in order to enlarge the beam current. The Bernas type ion source and periodical system of electrostatic lenses (electrostatic undulator) are proposed for high intensity ion implanter design. The ribbon ion source and transport system for such beam are discussed.

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1. INTRODUCTION

Over the past forty years, the breath of applications for ion implantation in semiconductors (usually silicon) has created a commercial equipment market that approaches about two billion dollars per year [1,2]. The ion source, its extraction and transport system are the key components of any ion implanter. As there is no universal ion source, each implanter is built around a source, or sources, to provide the ion species and beam currents required by any particular user of the implanter. 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 $10^{11}\ldots10^{12}$ ions cm^{-2}. The use of hot filament ion source 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 $10^{15}\ldots10^{16}$ ions cm^{-2}). Because they are simple and robust, hot filament ion sources are employed in the majority of all commercial ion implanters.

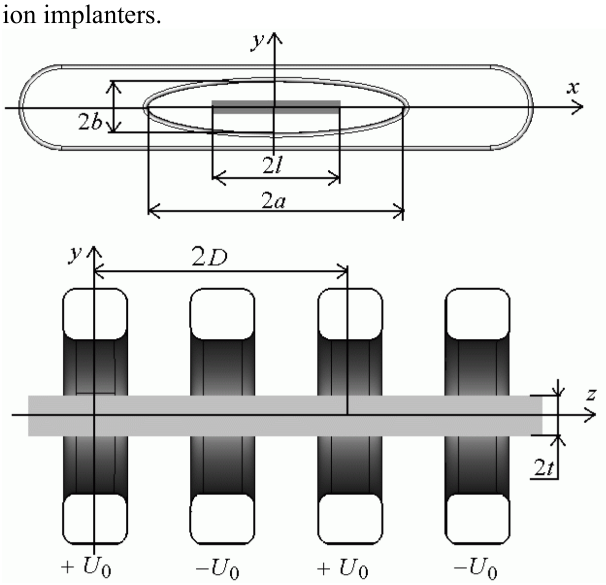

Fig.1. The general view of electrostatic undulator

The transport of the low energy multicharge heavy ions is problem. The choice of effective beam transport system design depends on main beam parameters: an initial transverse emittance, an ion energy, a charge to mass ratio, beam current. Generally, the magnetic and electrostatic lenses are used for axi-symmetrical beam focusing. The magnetic lenses for low energy ion must to have the high magnetic fields. For transport of intensive ribbon ion beams special beam line is needed. In this paper a periodic system of the plane electrostatic lenses (electrostatic undulator) (see Fig.1) is suggested for this goal. This system has simple design and low value of electrostatic potential is necessary for beam transport.

2. ION SOURCE TYPE CHOISE

Two basic designs for the hot filament source comprise the majority of ion sources in semiconductor production environments now: the Freeman source [3] and the Bernas ion source [4]. These sources have very similar operating and maintenance requirements. The indirectly heated cathode (IHC) source representing an improvement over the Bernas ion source operates on similar principals; however the filament has been removed from the chemical environment of the plasma chamber leading to longer lifetime. In Table, taken from [1], one can see that IHC Bernas has serious advantage for the same current beam production.

Ion sources in semiconductor production environments

Source type	Primary species	Beam current, mA	Operating hours
Bernas	B^+	5	80
	B^+	10	40
	As^+, P^+	5	140
	As^+, P^+	10	100
	Sb^+	5…10	40…50
Freeman	B^+	5	30…40
	B^+	10	15…25
	As^+, P^+	5	40…60
	As^+, P^+	10	30…40
	Sb^+	5…10	20…40
IHC Bernas	B^+	5	150
	B^+	10	100
	As^+, P^+	5	250
	As^+, P^+	10	200
	Sb^+	5…10	80…100

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3. PARTICLE MOTION IN ELECTROSTATIC UNDULATOR

The potential of electrostatic field in periodic undulator can be represented as a sum of the spatial harmonics. The interaction of the particles with the every harmonics of the undulator field does not change the average energy of the beam but causes the fast oscillations in the longitudinal and transverse directions. A momentum and a coordinate of particles can be represented as a sum of slow varying and rapid oscillating components. The ion limit current for any value of charge to mass ratio can be appreciated by smooth approximation when the slow varying component is taken to account only [5]. As it was shown in [5] the condition of the transverse focusing for ribbon beam is taken place if

$$\left(\frac{eV}{4mc^2}\right)^2 \ge \frac{A\beta}{Z\pi}\frac{ID^2}{I_\alpha S}. \qquad (1)$$

Here, eZ and mA are charge and mass of ion, V is the electrode voltage which is applied to the neighboring electrodes of the undulator, β is ion velocity, $I_\alpha = 4\pi\varepsilon_0 mc^3/e = 3.1\cdot10^7$ A, I is the beam current and S is the beam cross-section.

Note that limit beam current can be increased using of ribbon beam because its cross-section is larger than for axisymmetric one. For example, if the ribbon beam current is equal to I=10 mA for β=0.001 and beam cross-section is $2a\times2b$=0.3×3.0 cm, the amplitude of electrostatic field at undulator axis $E_0 = \pi V/2D$ must be equal to 10 kV/cm. The limit beam current is 0.75 mA for axisymmetric beam for the same E_0 value and r_b=0.15 cm, comparatively.

The limit beam current and transmission coefficient can be accurate calculated by means of a numerical simulation only. Early the BEAMDULAC code was computed for beam dynamics simulations in linacs. Now the special version of this code has been adapted for beam lines using electrostatic undulator. This code utilizes the well-known Cloud-in-Cell (CIC) method for accurate treat of space charge effects.

It was shown using BEAMDULAC code that low velocity beams (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.

The beam dynamics simulation results are shown in Fig.2. The input (small points) and output (large points) beam transverse cross-section (a) and transverse emittances (x,β_x) and (y,β_y) are presented. The beam dynamics was calculated for boron ions energy 3 keV and beam current 10 mA.

4. PRELIMINARY RESULTS OF RESEARCH

In ITEP the common ITEP-MEPhI research program of ion beam generation for ion implanters is carried on. The IHC Bernas is the main ion source for this research

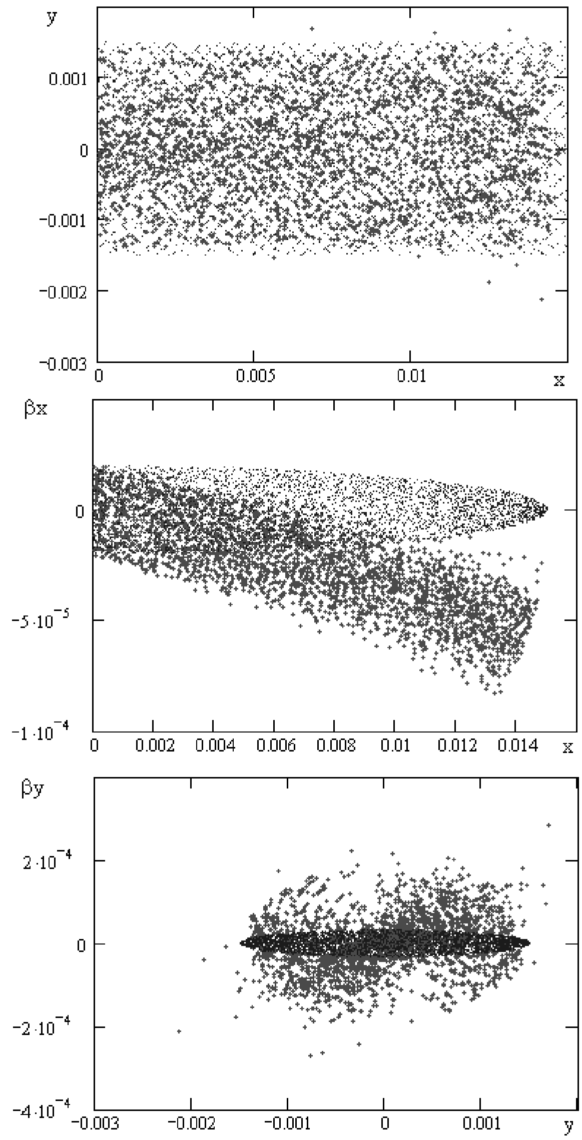

Fig.2. Ion beam dynamics simulation results

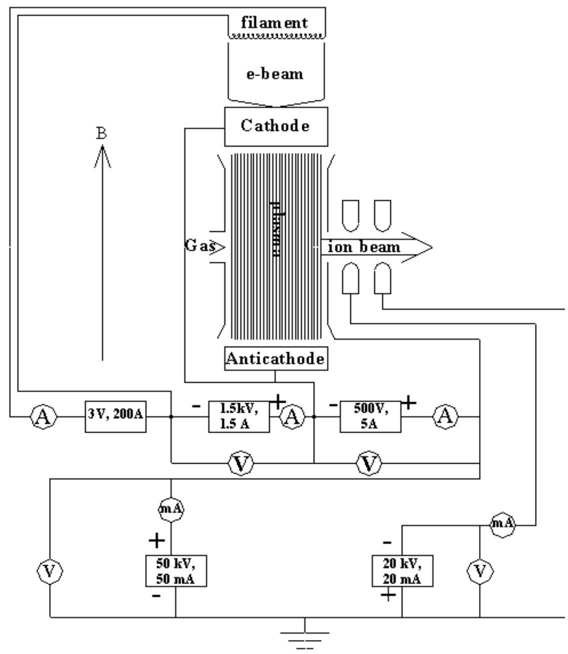

Fig.3. The general view and electrical scheme of the IHC Bernas ion source

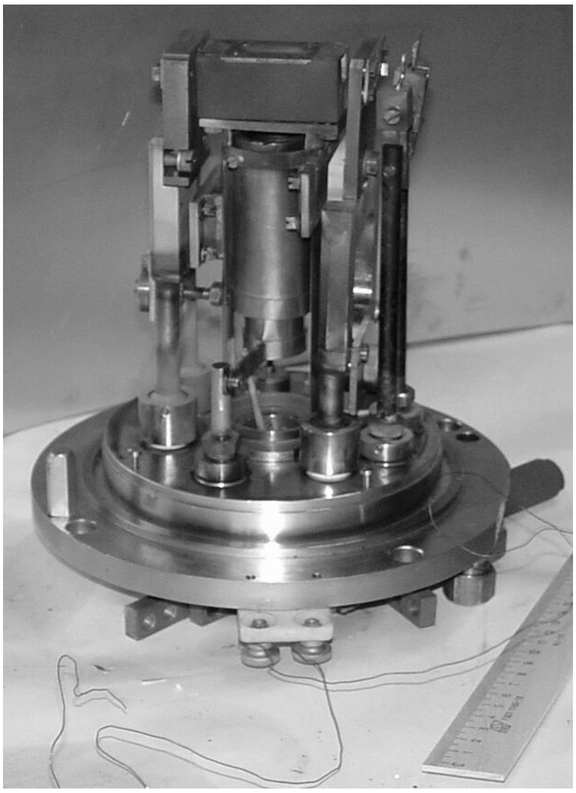

Fig.4. ITEP IHC Bernas ion sour

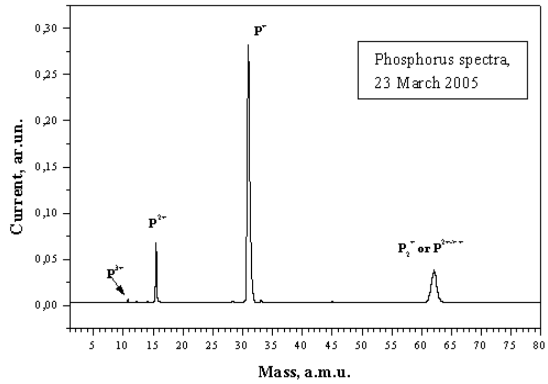

Fig.5. Spectrum of phosphorus ion beam

program. The general view and electrical scheme of the ion source and its photo are shown in Figs.3 and 4. The spectrum of phosphorus and antimony beams generated by ITEP IHC Bernas is shown in Fig.5.

The ion source generates beams of antimony, phosphorus, boron and decaborane ($B_{10}H_{14}$). The antimony, phosphorus, and boron beams are investigated for multicharge state ions generation, which are interested for "high energy" implantation. However, last time 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 designer of advanced implanters. Current density limitations associated with extracting and transporting of low energy ion beams results in lower beam currents that adversely affects on the process throughput.

The ITEP-MEPhI research program includes two directions of overcoming the low energy beam transportation problem. One is to use the boron cluster beams (like decaborane). The second is to construct the low energy transport undulator for monomer boron and phosphorus beams.

5. CONCLUSION

The new concent of ion beam source and beam transport was discussed. It was shown that using of Bernas ion source and electrostatic undulator allows designing the low beta ($\beta=10^{-4}$-10^{-3}) high intensity ion implanter.

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ИСТОЧНИК И СИСТЕМА ТРАНСПОРТИРОВКИ НИЗКОЭНЕРГЕТИЧЕСКОГО ЛЕНТОЧНОГО ИОННОГО ПУЧКА

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Ленточные ионные пучки могут быть применены в коммерческих ионных имплантерах для увеличения тока пучка. Для создания сильноточного имплантора предлагается использовать ионный источник Берна и периодическую систему электростатических линз (электростатический ондулятор). Обсуждаются выбор источника ленточного ионного пучка и система его транспортировки.

ДЖЕРЕЛО Й СИСТЕМА ТРАНСПОРТУВАННЯ НИЗЬКОЕНЕРГЕТИЧНОГО СТРІЧКОВОГО ІОННОГО ПУЧКА

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Стрічкові іонні пучки можуть бути застосовані в комерційних іонних імплантерах для збільшення струму пучка. Для створення потужнострумового імплантора пропонується використати іонне джерело Берна й періодичну систему електростатичних лінз (електростатичний ондулятор). Обговорюються вибір джерела стрічкового іонного пучка й система його транспортування.