SIMPLIFIED BEAM LINE WITH SPACE CHARGE COMPENSATION OF LOW ENERGY ION BEAM

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Abstract

Simplified beam line for low energy Ion implantation is considered. Compensation of the space charge of high perveance, low energy ion beam in beam lines for ion implantation and isotope separation has been investigated. Different mechanisms of the compensating particle formation such as ionization by the beam, secondary emission of electrons and negative ions, electronegative gas admixture, and external plasma sources are discussed. Advanced space charge compensation increases an intensity of low energy ion beam after analyzer magnet up to 3–4 times. Space charge compensation of positive ion beam by admixture of electronegative gases and damping of the beam instability are discussed. Up to 6 mA of $^{11}B^{+}$ ions with energy 3 keV, 11 mA with 5 keV, and 18 mA with 10 keV have been transported through an analyzer magnet of a high current implanter with space charge compensation by electronegative gases

INTRODUCTION

Ion implantation is the largest commercial application for particle accelerators. Several thousand ion implanters are used for semiconductor circuits fabrication. Most difficult task of ion implantation is high dose implantation of ion with lowest energy. Now for the high-current implanters are used the beam-line (BL) shown in Fig. 1 [1]. Implanters energy is up to 40 or 80 kV, but they have been optimized for sub-1 keV implants, where space charge forces have a dominant effect. The beam line uses a couple of deceleration stages that allow the beam to be transported mainly at higher energies. It is also designed to produce a broad beam at the wafer to maximize the cross section and to minimize the space charge forces at the final implant energy. The wafer is scanned across the ribbon beam in one direction. This beam line is very long, complex and expansive. Due to the complex interactions between the ion beam and the magnetic field applied for beam expansion, this approach creates severe technical, practical, and process related problems that increase the total production cost of such equipment and lead to more complicated operation procedures for carrying out the ion implantation. In particular, the beam path through this system is relatively long, and at low energies and high beam currents it becomes increasingly difficult to control the uniformity of the ion beam and the angular variation within the beam with the precision required by certain commercial processes. Recently were proposed some simplified beam lines for production the same broad ribbon beam as in [1] directly after analyzing magnet [2-4].

Schematic of these BL is shown in Fig. 2. Main feature of this BL is very large magnet aperture along magnetic field for production of ribbon beam with width up to 300 mm .

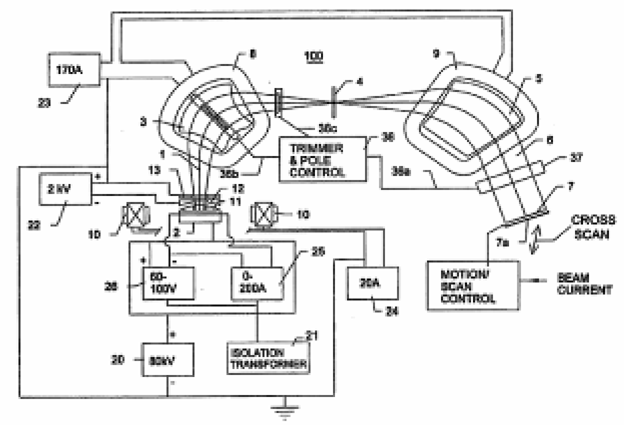

Figure 1: Schematic of high current low energy implanter from [1].

For transportation of low energy heavy ion beam through analyzer magnet is important to have a very good space charge neutralization (SCN) to avoid a beam divergency and particle loss. The space charge compensation energy of low energy ion beam was tested in the simplified beam lines described below.

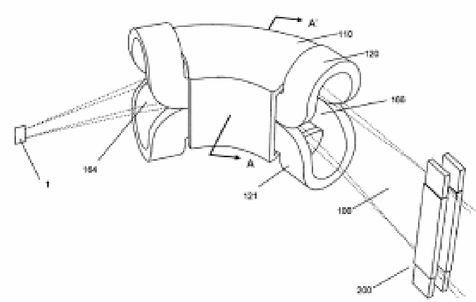

Figure 2: Beam line of implanter with a large vertical aperture. 1-ion source; 100-extended robbon iom beam; 110 magnet; 12, 1210-saddle type coils; 200-multipole beam corrector.

EXPERIMENTAL IMPLANTERS

In first experiments was used the high current ion implanted VESUVII-8M with modified Bernars type ion sources adopted for separation of Rubidium isotopes from RbCl salt. Schematic of the experimental device is shown in Fig. 3. A gas delivery systems (9-14) and plasma sources (16) were used for improved space charge compensation of ion beam generated by ion source (2) and analyzed by magnet (1) with uniform field and vertical edge field focusing.

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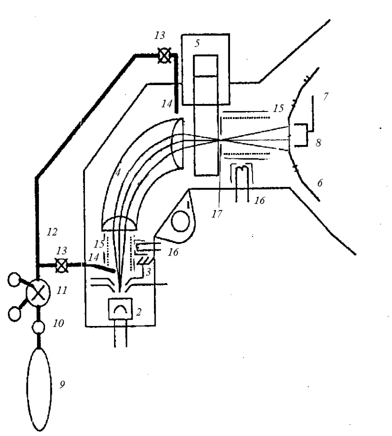

Figure 3: Diagram of implanter VESUVII-8 with improved space charge compensation [4].

With emission slit 2x40 mm an Rb+ ion beam intensity was higher than estimated space charge limit of beam line (40 cm Lamoure radius, 90^{o} bending magnet). But with Ar gas injection the ion beam signal on collector (8) was very noisy, when with admixture of BF_3 gas the beam become stable and mass resolution was improved. It was hypotheses that generation of negative ion can be important for stable space charge compensation.

Further testing of space charge compensation with electronegative gases were conducted in the experimental implanter shown in Fig. 4.

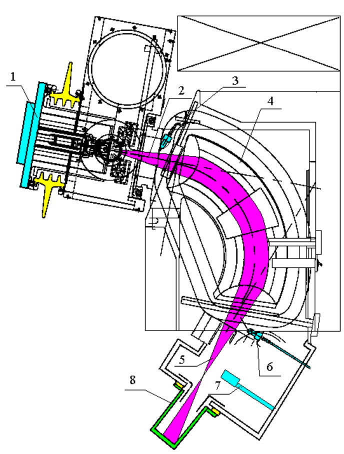

Figure 4: Schematic of implanter with large aperture and enhanced space charge compensation. Ion beams from discharge in BF3 gas.

In almost all previous investigations of SCN of positive ion beams it has been assumed that the compensating particles are electrons [1-5]. However, in the environment of isotope separation and ion implantation where the complex halide and hydride molecules with high electron affinity are often used as working gases, there is a high probability of negative ion formation. In this situation SCN by negative ions could be significant. Indeed, the SCN by negative ion could be the determining factor for productive operation of large scale ion beam industry, but so far this circumference has not been investigated. Before, this possibility has been discussed in [4-7] and some new results will be presented.

A possibility to improve SCN by negative ions was tested in beam line shown in Figs. 3 and 4 with a magnetic scanner and magnetic suppression of secondary electrons in the beam collector after mass analyzer. For production of high perveance ion beams modified Bernas source with two filaments and small anode made from W wire has been used [8-9]. In this configuration drift of ions in crossed fields to the emission slit is improved. In ion source with two filaments is possible to optimize cathode material recycling for periodic restoring of cathodes and increase of lifetime. The high temperature of small anode and ion bombardment of chamber wall prevents from the flakes formation. Three electrode extractors with precise moving electrodes have been used for beam formation. For low energy beam extraction a high voltage on the suppression electrode (up to -20 kV for 3 keV) was used. Production of high energy neutrals and negative ions in the extractor gap and on the suppressor surface is important for enhance of residual gas ionization and improved space charge neutralization. In a "standard" mode of operation with a strong acceleration- deceleration, low gas density and low noise of discharge in ion source are typically a strong instability of ion beam after analyzer as shown in Fig.5.

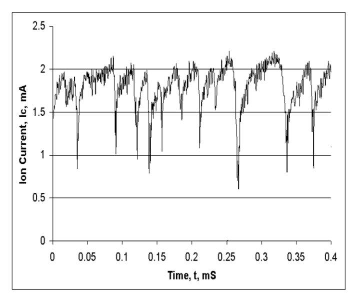

Figure 5: Oscilloscope track of ion beam after analyzer magnet with instability.

It is typically a relaxation type of oscillation. Beam intensity increases up to critical level, this drives instability, loss of SCN, drop of intensity and then this cycle repeats. It was observed, that with electronegative gases in ion sources, such as BF_3, RbCl, CF_4 it is possible to suppress beam instability by increasing gas injection into the source. This instability was not damped by increase of noble gas density such as Ar, or Kr.

Improved SCN and damping of instabilities could be related to adding of negative ions into the beam instead of free electrons.

For enhance negative ion formation in ion beams an injection of electronegative heavy molecules with high electron affinity into the ion beam is proposed. Negative ions in ion beam are formed by collision of electrons with molecules and by bombardment of electrodes surfaces by beam and plasma particles. With the use of negative ion for positive ion beam SCN it is possible to create

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overneutralization, as in the negative ion beam with SCN by positive ions. For low energy ion beam overneutralization discharge plasma and electronegative heavy gas molecules are injected into the beam. For minimization of electric field influence on the beam SCN is used the shielding of beam through grid.

A typical beam line for ion beam production, formation, transportation, separation, scanning, collimation and utilizing consist of the ion source, extraction system, analyzer magnet with mass resolving system, scanner magnet, collimator magnet and end station for the material processing by ion beam. Very good space charge neutralization is necessary in the all parts of ion beam transportation. The strongest space charge forces defocused beam directly after extractor because of multicomponent, high perveance beam is extracted from ion source plasma. The intensity of one component ion beam after analyzer could be considerably lower, but the space charge neutralization of this beam is also important for prevention of the loss of beam intensity and quality. For the prevention of the compensation particles extraction from the beam to the ion source by the electric field of extraction voltage is used a suppression electrode with negative voltage between ion source and grounded extraction electrode reflecting compensating particles into the ion beam.

For improved space charge neutralization electronegative gas is injected into the beam after extraction. A tunnel- shielding around the beam is used to increase electronegative gas utilization and for beam-plasma shielding from electric field. Reflectors made from transparent mesh and negatively biased electrodes can be used for increase of the neutralizing particles lifetime. Gas control systems is used for optimization of the electronegative gas flux.

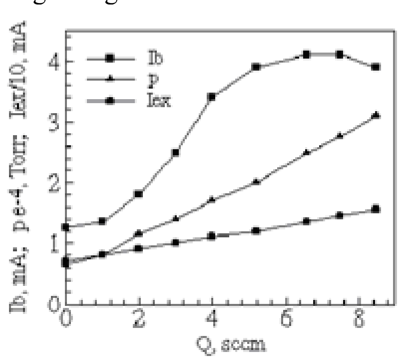

Figure 6: Ion beam current of 3 kV $^{11}B^+$ beam after analyzer magnet versus neutralizing electronegative gas CF_4 flux.

Ion beam neutralization by negative ions is the most important for low energy beams because the cross section of electron production during gas ionization by low energy heavy ions is very low, really zero. An effect of electronegative gas admixture to the 3 keV beam of B^+ demonstrated in Fig.6. Ions of $^{10}B^+$, $^{11}B^+$, F^+, BF^+, BF_2^+,.. was extracted from the 2x90 mm^2 slit of ion source with discharge in the BF_3 gas. Separated beam of $^{11}B^+$ was registered after 14x80 mass- slit of analyzer magnet by magnetically suppressed collector. Optimized fluxes of electronegative CF_4 gas was injected into the tunnel around the beam after extractor and after analyzer. Ion beam current of 3 keV $^{11}B^+$ versus full flux of electronegative gas presented in Fig. 6.

With increase of gas flux the beam intensity increases from 1.3 mA up to 4.2 mA. With increase of gas density an improvement of focusing by neutralizing the repulsing space charge force and attenuation of beam by charge exchange loss of ions is observed. For real improvement a beam transportation- separation electronegative gas should have a high probability of negative ion formation but low cross section for charge exchange for ions of beam

Ion beam instability was dumped by admixture of optimized (Q.>3 sccm) electronegative gas density as shown on Fig.7.

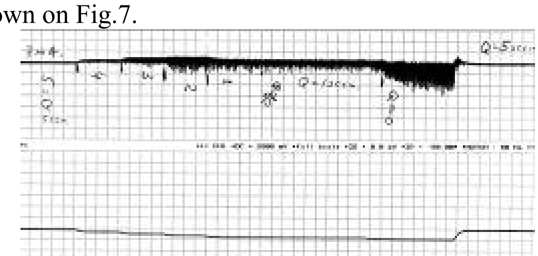

Figure 7: Ion beam current after analyzer with dumping of the beam instability by injection of electronegative gases.

SUMMARY

Space charge neutralization with different plasma sources has been tested: a hollow cathode discharge, RF discharge in the magnetic basket, combination of RF and DC discharge in magnetic field. With all discharges a deep SCN and a low potential of insulated bombarded surface have been reached.

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