Simulation of Ion Beam Transport in an Ion Gun for Materials Processing

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***Abstract*—Ion guns with several grids, which control ion energy from a plasma source, are widely used in semiconductor manufacturing process. We report on particle-in-cell simulations of the ion gun to which an electron beam and a magnetic field are applied in order to obtain higher ion fluxes. The electron beam in the energy range from 100 to 1000 eV is emitted in axial direction and the uniform magnetic field of 100 G perpendicular to the electron beam is used. It is revealed from the simulations that an ion flux in the ion gun with the electron beam and the magnetic field is twice larger than that in the conventional ion guns.**

***Index Terms*—Electron beam, ion gun, magnetized plasma, particle-in-cell simulation.**

LOW-ENERGY ion beam sources from a few electronvolts to hundreds of electronvolts are widely used in semiconductor manufacturing process such as deposition, implantation, and plasma etching. Especially, ion beams are applied to the systems for neutral beam etching, in order to reduce a charge-up damage [1]. In a neutral beam source, the ion beam is neutralized by collisions with reflectors. Plasma is created by an inductively coupled plasma (ICP) source. The ion gun is composed of several grids controlled by an external voltage. In the ion gun with two grids, the first grid is applied to positive voltage and the second grid is grounded. Only positive ions are ejected by electric field between grids. A potential inside an aperture determines the sheath structure around the aperture, which is closely connected to the ion flux and the angle distribution [2]. The ion flux and the ion angle distribution, which depend on the ion gun parameters such as grid voltage, grid width, grid interval, and aperture size, are important factors for high performance processing.

Although the ion energy is easily controlled and estimated in the ion gun with two grids, the ion flux decreases with a low-energy ion beam because the ion flux is proportional to electric field between grids. An ion gun with three grids is used for a low-energy and a high-flux ion beam [3]. In the three-grid ion gun, the ion flux depends on the potential difference between the first grid and the second grid. The potential difference between the first grid and the third grid has influence upon the ion energy. The three-grid ion gun allows independent control of ion flux and ion energy, preventing a reduction of ion flux for low energy ions. If a positive voltage is applied to the third grid, it prevents ions from dispersing toward the grid. This improves the directionality of ions, making it easy to control the incident ion angle.

We have performed ion-gun simulations by the two-dimensional object oriented particle-in-cell (OOPIC) code for the optimization of ion beam source [4]. The ion flux, the energy and the angle distribution are calculated in our simulations. In our three-grid ion gun, 300, 0, and 200 V are applied to the grids. The aperture size, the grid width, and the interval between the grids are 4, 1.2, and 0.9 mm, respectively. A low pressure of 0.1 mtorr is used in order to obtain a narrow ion angle distribution. Ar gas is used for obtaining the fundamental characteristics of positive ion beam. Since the ion flux is proportional to a plasma density, an electron beam is utilized in order to increase the plasma density. The current density of the electron beam injected toward the aperture is 66.7 mA/cm^{-2}. The uniform magnetic field of 100 G, which is perpendicular to the electron beam, is applied. This magnetic field cannot affect ion angle distributions, because a gyro-radius of ion is larger than an aperture size. The electron beam and the magnetic field perpendicular to the electron beam result in the increase of the plasma density and the ion flux.

Fig. 1 is a snapshot of a particle distribution. We obtain data from OOPIC and postprocessing the data has been done by a commercial graphic package, SURFER. Density distributions of ions and electrons in the ion gun without an electron beam and a magnetic field are shown in Fig. 1(a) and (b). Fig. 1(c) and (d) are density distributions of ions and electrons in the ion gun with the electron beam and the magnetic field. The energy of the electron beam is 1000 eV in Fig. 1(c) and (d). We have changed the energy of the electron beam from 100 to 1000 eV. The increase of the energy of the electron beam raises the propagation of the electron beam. This propagation depends on the intensity of the magnetic field and the energy of the electron beam. The magnetic field perpendicular to the electron beam prevents high-energy electrons from being ejected between grids. While, in the ion gun with low pressure of 0.1 mtorr and small aperture of 4 mm, an ion flux is 4.8×10^{15} cm^{-2}s^{-1}, it is 1.48×10^{16} cm^{-2}s^{-1} in the ion gun with the electron beam of 400 eV and the uniform magnetic field of 100 G and 1.03×10^{16} cm^{-2}s^{-1} in the ion gun with the electron beam of 1000 eV. The ion flux

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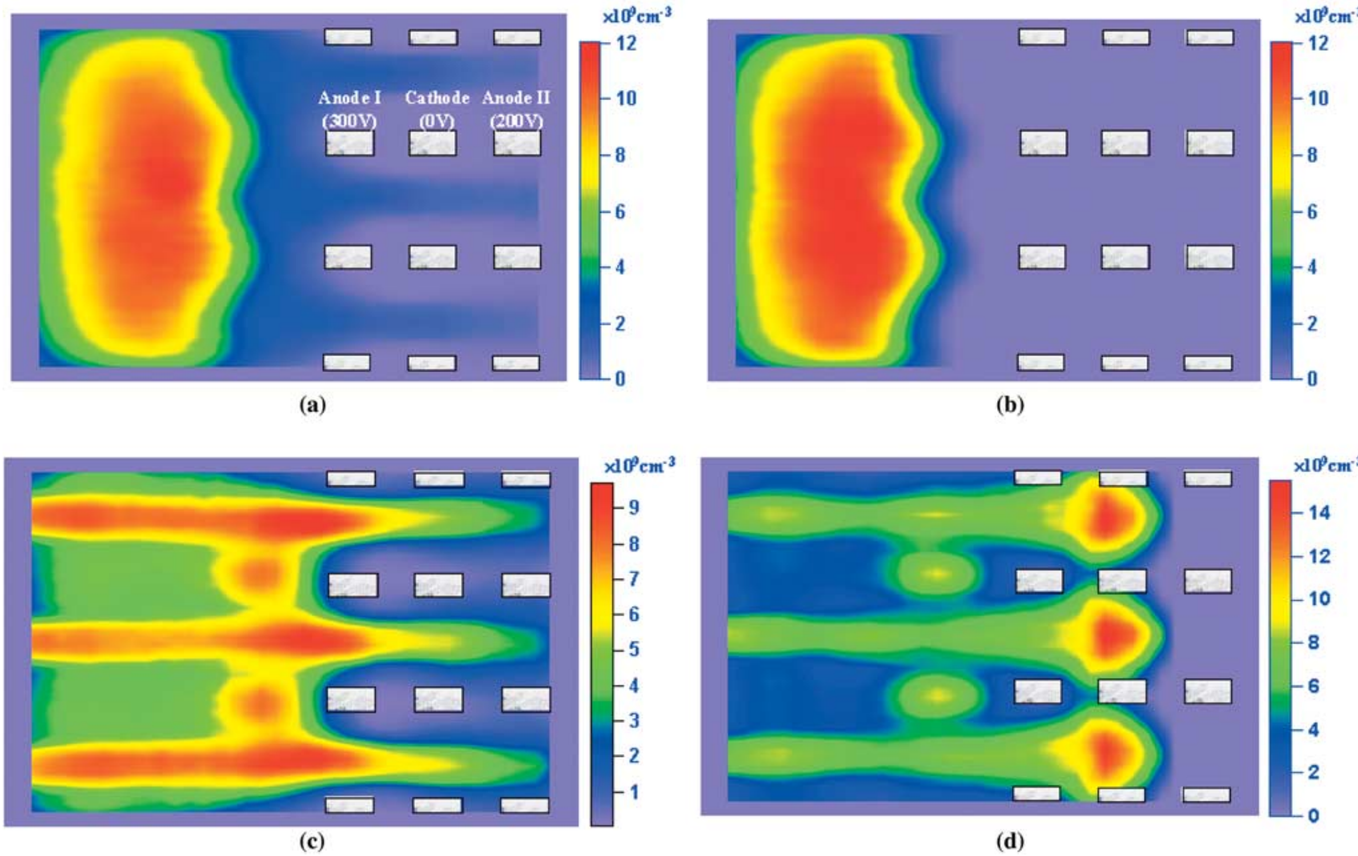

Fig. 1.Snapshot of a particle density distribution by PIC simulation. (a) Ion and (b) electron density distributions in the conventional ion gun. (c) Ion and (d) electron density distributions in the ion gun with the electron beam of 1000 eV and the magnetic field of 100 G. Magnetic field is perpendicular to the electron beam.

in the ion gun with the electron beam and the magnetic field is twice as large as that in the conventional ion gun. The shape and the size of the plasma sheath are important to decide on the ion flux. A high-energy electron beam causes the sheath size to decrease. The reduction of sheath size results in the increase of the ion flux. At low pressure, the electron beam, higher than a few kiloelectronvolts, reduces the ion flux because of the loss of high-energy electrons ejected fast between grids.

In conclusion, we have simulated the ion gun, which is applied to an electron beam and a magnetic field in order to obtain a high ion flux by PIC code. The plasma density and the sheath with ion gun parameters have decisive influence on the ion flux. The electron beam and the magnetic field result in higher ion flux.

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