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Formation of Neutral Beam by Low Angle Reflection

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Abstract

In this study, a neutral beam was formed using a low angle forward reflection of the ion beam and its degree of neutralization at different reflection angles was investigated. When the ion beam was reflected by a reflector at the angles lower than 15°, most of the ions reflected were neutralized and the lower reflector angle showed the higher degree of neutralization. Photoresist(PR) and SiO_2 etchings were carried out with the neutralized oxygen and fluorine radical fluxes, respectively, and highly anisotropic etch profiles could be obtained suggesting the formation of highly directional neutral flux.

Keywords : neutral beam, etching, low angle, reflection

1. Introduction

Plasma etching is one of the key technologies in the fabrication of deep submicron silicon-based integrated circuit. However, conventional plasma etching techniques could have serious disadvantages for the future device fabrication due to the energetic charged particles(ions or electrons) and ultraviolet light [1]. Among these, charge-up damage is the most severe as the thickness of the gate-oxide layer becomes thinner with shrinking pattern size [2]. To avoid charge-related damages, several neutral beam etching techniques have been proposed such as hyperthermal atomic beam [3-5], neutral beam by ion-neutral scattering [6-8], neutral beam by ion-electron recombination [9,10], etc.

In this study, as one of the ion-electron recombination methods, a method forming a near parallel neutral beam called "low angle forward reflected neutral beam" has been proposed and the characteristics of neutralization by various surface reflection angles have been studied. The flux, energy, and angle of the neutralized particles after the reflection can be varied depending on the reflection angle of the ions, but these are not easily measured by experiment. Therefore, in this study, a simulation technique was used to estimate the characteristics of neutralization in addition to the experiment.

2. Experiment

As the reflector, parallel reflection plates made of silicon wafers with variable angle to the incident ion beam were used to investigate the effect of reflection angle and also to form a large area neutral flux. The ion beam source used in this experiment was made of a 4-inch diameter inductively coupled plasma source and two graphite grids. These two grids were used to extract and accelerate the ion beam to the reflector.

Small fraction of ions reflected from the reflector can remain un-neutralized after the reflection, therefore, to remove the un-neutralized reflected ions, a retarding grid system was installed after the reflector. Two meshed screens were used with the one grounded and the other

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grid varied from 350 to 750 V. Faraday cup was used to measure the remaining ion flux after the reflector or after the retarding grids. SiO_2 and photoresist with Cr mask were etched to investigate the degree of anisotropy of the reflected flux using SF_6 and O_2, respectively. Simulation of neutral beam was carried out using XOOPIC code and TRIM code [11-13]. Flux and angular distribution of the ions emerging from the ion source grids were calculated using XOOPIC code.

The XOOPIC code makes us to obtain the energy and direction of the each ions passing through the ion gun grids by calculating the force acting on the ions from the electric field formed between the two grids. The final energy and direction of the each ions emerging from the ion gun grids are fed to TRIM code to simulate the behavior of the neutral beam reflected. The flux and energy of the neutral beam have been calculated from Eqs. (1) and (2), respectively [14].

$$R_N(E_{in},\ \theta) = 1.0 + \left(1.0 - \frac{\theta}{90^\circ}\right)\left[R_N^O(E_{in}) - 1.0\right] \tag{1}$$

$$R_E(E_{in},\ \theta) = 1.0 + \left(1.0 - \frac{\theta}{90^\circ}\right)\left[R_E^O(E_{in}) - 1.0\right] \tag{2}$$

where,

$R_N^O(E_{in}) = -0.237\log_{10}^{(E_{in}/E_L)} + 0.19$

$R_E^O(E_{in}) = -0.22\log_{10}^{(E_{in}/E_L)} + 0.06$

R_N^O, R_E^O : reflection coefficients

θ : normal incident angle=(90°-incidet angle)

E_L : energy reduction constnat

E_{in} : incident energy

The angular distribution of the neutrals has been calculated from Eq. (3).

$$\phi = \arctan\left\{\sin\theta / \left[\cos\theta + \left(\frac{M_1}{M_2}\right)\right]\right\} \tag{3}$$

where,

M_1 : incident ion mass

M_2 : reflector mass

3. Results and Discussion

The results on the simulation of the neutralized flux as a function of reflector angle (that is, the angle between the ion beam direction and the reflector surface) are shown in Fig. 1.

As shown in the figure, as the reflector angle was decreased from 20° to 5°, the neutralization ratio was increased. Compared to the neutral flux at 15°, the neutral flux at 5° increased about 5.27%.

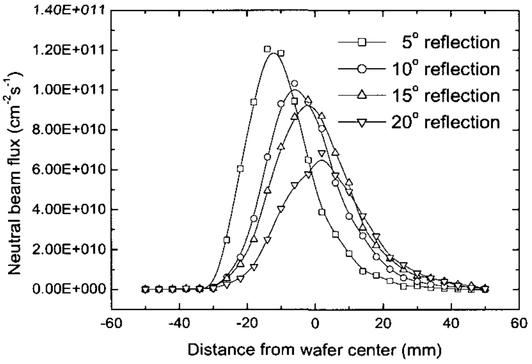

Fig. 1. Neutral beam flux as a function of reflection angle after the reflection of the ion flux calculated by XOOPIC code and TRIM code.

Simulation condition; ion current: 0.56 $\mu A/cm^2$, gas: Ar, pressure: 0.1 mTorr, distance between the ion gun and the sample: 14 cm

Higher neutralization at lower reflection angle was also obtained theoretically by Helmer et al. for the reflection of 50 eV Cl^+ ions on bare silicon [15,16]. Energy and angular distribution of the neutrals were also obtained by the simulation (not shown). The energy of the reflected neutrals showed a cosine distribution, however, most of the neutrals showed the same energy as that of the incident ions. Also, the reflected angle was remained same as the incident angle for most of the neutrals even though some scattering of the reflected neutrals was found.

The compare with the simulation data, the degree of neutralization after the reflection of the ions at the reflector located at various angles was measured experimentally even though the angular and energy distribution

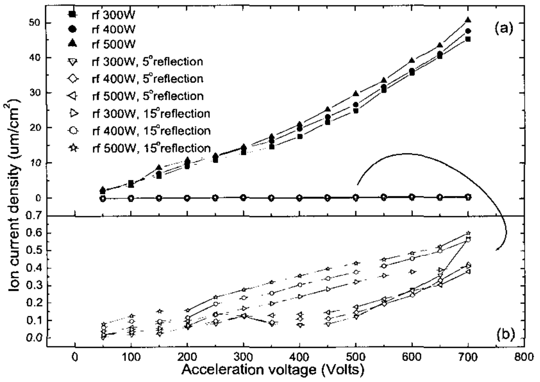

Fig. 2. Ion beam current density measured by a Faraday cup as a function of ion source acceleration voltage, rf power to ion gun, and with/without the reflection (5° and 15°). 7 sccm of SF_6 was used to generate plasmas in the ion gun. The distance between the ion gun to the Faraday cup was 10 cm

of the neutralized flux could not measured. Fig. 2 shows the ion current measured using the Faraday cup as a function of acceleration voltage (50 to 700 V) and rf power (300 to 500 W) to the ion gun for different reflector angles (5° and 15°) and with/without the reflector. As shown in Fig. 2(a), the measured ion current after the reflection decreased drastically compared to the ion current measured before the reflection. The ion current decreased to 99.2% after the reflection at 5° while that decreased to 98.9% after the reflection at 15°. Even though the increase of neutralization was small by changing the reflector angle from 15° to 5°, the increase of neutralization was consistent and was believed to be from the increase of increased neutralization at the lower reflector angle as shown in Fig. 2(a). The increase of remaining ion current after the reflection for higher rf power and acceleration voltage is from the increase of incident ion flux. The remaining ion current which is from the non-neutralized ions after the reflection could be also removed almost 100% by using a retarding grid and by applying the voltage to the grid close to the acceleration voltage. Similar experiments were also conducted using O_2 ion gun and similar results were obtained (not shown).

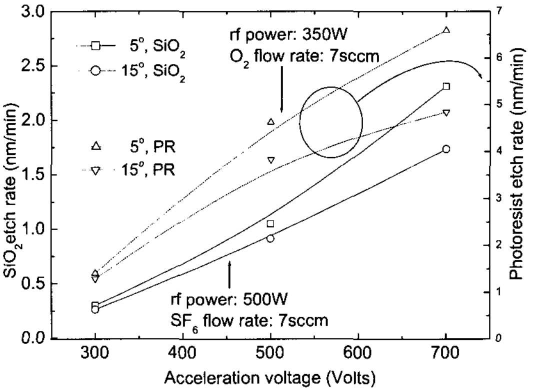

Fig. 3. SiO_2 and photoresist etch rates as a function of acceleration voltage with SF_6 and O_2 ion guns, respectively.

Using the neutralized fluxes generated from SF_6 and O_2 ion guns, SiO_2 and photoresist were etched, respectively. Fig. 3 shows SiO_2 etch rates and photoresist etch rates as a function of acceleration voltage. During the etching, all of the ions were removed by using the retarding grid system. As shown in the figure, the increase of SiO_2 and photoresist etch rates of about 26% could be obtained by decreasing the reflector angle from 15° to 5° possibly due to the more neutral flux at 5° as shown in Fig. 1.

SiO_2 etch condition ; the distance between the ion gun and the sample : 10 cm, rf power to ion source : 500 W, and gas flow : 7 sccm of SF_6. Photoresist etch condition ; the distance : 21 cm, the rf power : 350 W, and gas flow : 7 sccm of O_2 To find out the directionality of the neutrals obtained in our method, the etch profiles were observed and one of the results is also shown in Fig. 3 for SiO_2 etching by SF_6. Vertical profiles could be obtained suggesting the directionality of the neutrals obtained in the experiment.

4. Conclusions

In this study, using a low angle reflection of the ions extracted from the ion gun, highly directional neutral beams were obtained that could be applicable to the etching without charging damage. The lower reflection angle showed the higher degree of neutralization, therefore, the etch rates were higher for the lower reflection angle when only neutral beam reflected from the reflector was used for the etching

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