EFFECTS OF SILICON PARTICLES ON DC AND/OR AC DISCHARGE CHARACTERISTICS IN MAGNETIZED SILANE PLASMAS

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Abstract

Temporal Evolution of two-dimensional profiles of silicon particles in DC silane-argon plasmas has been observed in the presence of the crossed magnetic field perpendicular to the discharge electric field. These experimental data were obtained by Mie scattering method using a dye laser(wavelength 488nm) excited by excimer laser and a He-Ne laser(632.8nm).

In DC plasma, silicon particles were transported in the direction opposite to ExB drift of plasmas, and the spatially integrated Mie scattering intensity (SIMSI) was decreased with increasing applied magnetic flux density. On the other hand, in AC plasma, the SIMSI was rapidly increased after the discharge-on and was also decreased over the critical magnetic flux density. From the calculation of equations of motion for negative electrons, positive ions and negatively charged particles, it is suggested that the particles drift in the direction opposite to ExB drift of plasmas by the space charge effect. When the particle radius is increased and the electron density is decreased, the drift velocity of particles is decreased by the decrease of space charge electric field.

1. Introduction

Since the work of Spears et. al., [1] particle generation has been observed in situations as different as etching plasmas[2], sputtering plasmas[3] and deposition plasmas.[4, 5] The formation mechanism and dynamics of these particles (or dust) depend on each system, and are not well understood. They may be introduced in the discharge by plasma surface interaction or produced in the volume by polymerization of the gas and/or its dissociation products. The presence of dust particles in the plasma is a serious problem in etching, sputtering and deposition processes because of the contamination of the substrates being processed.

Recently studies on generation of silicon particles and their behavior are increasing interest both from a scientific and technologic point of view, in the plasma enhanced chemical vapor deposition (PECVD) process for the deposition of a hydrogenated amorphous silicon(a-Si:H) thin film. In order to control the particle's contamination in device fabrication, a thorough understanding of the forces that control particle motion in plasmas is required. Generally, it is considered that an electrostatic force, an ion drag force, a neutral drag force, a force of gravity and a thermophoretic force are acting on the spatial distribution of silicon particles in processing plasmas. However, little is known about the effects of a magnetic field perpendicular to the discharge electric field on particle dynamics in silane plasmas.[5] The authors have investigated dynamics of silicon particles when a modulated magnetic field was applied to the DC silane plasmas. In the research, it was observed the particles were moved in the direction opposite to **ExB** drift of plasmas.

In the present paper, we report the experimental results on both the behaviors of silicon particles in the presence of a magnetic field perpendicular to discharge electric field by observing two-dimensional profiles of Mie scattering intensity (MSI) and the temporal variation of discharge characteristics for various applied discharge voltages and gas pressures in DC and/or AC silane plasmas. Furthermore, the mechanism of particle drift motion will be discussed on the basis of theoretical calculation of the simple model.

2. Experimental

The experiments were performed in a cylindrical vacuum vessel, as shown in Fig.1.Four solenoid coils were attached outside the vessel to produce homogeneous magnetic fields of 0-76gauss in the axial direction of the vessel. Inside the vessel, a pair of approximate Rogowski-shaped electrode made of SUS304 of 90mm in diameter and 20mm in thickness were set perpendicular to the magnetic field line with 30mm in spacing. This geometry enabled to investigate the behaviors of the particles in the presence of **ExB** drift of plasmas. Mixture gases of 10% SiH_4 diluted with Ar were used in the experiment. The gas pressures and gas flow rates were controlled by a mass flow controller and a capacitance manometer. The gas pressure was varied in the range of 0.2--0.5Torr in the experiment. Glow discharges were generated by a DC or an AC(60Hz) power supply. In the experiment, the discharge voltages were varied in the range of 350-650V and 250-750V for DC and AC discharges, respectively. In most of the experimental conditions, silicon particles were generated. Mie scattering method was used to observe the spatial distributions and behaviors of the particles in the discharge space. A pulsed dye laser pumped by XeCl excimer laser and a He-Ne laser was alternatively used as laser sources for Mie scattering. The former operated at 488nm with a pulse energy of 1mJ in 20ns duration, the latter operated at 633nm with 0.5mW. Both laser beams were expanded by a factor of 10 by telescope lenses, then incident to the discharge space from a horizontal view port. Thus the entire gap space of the discharge was irradiated by the laser beam, of which axis was perpendicular to both **B** and **E**. Cross-sectional images of the spatial distributions of Mie scattering intensity were detected by an image-intensified charge coupled device camera(ICCD) viewed along magnetic field lines. To reject the background plasma line emission, proper band-pass optical filters were attached to the front side of ICCD according to the difference in the laser wavelength. A number of sequential image data of Mie scattering was first recorded on a video tape. Then some of the frame image data was digitized on a pc by 8bit image data acquisition board. All the data taken on the pc was further transferred to a workstation and processed on it. Strictly speaking, Mie scattering intensity is a complicated function of the number and of the size of particles. We can only see the overall feature of particles.

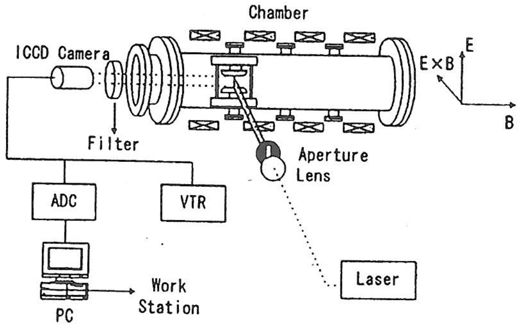

Fig.1 Experimental apparatus.

3. Experimental Results and Discussion

3. 1 Temporal variations of discharge current and particle growth

In silane plasmas, it is generally agreed that the formation of negatively charged particles by an electron attachment leads to decrease of electron density. The deposition of a-Si:H thin films on the electrode leads to decrease of secondary electron emission coefficient of the electrode.[6] Thus the particle growth should be related discharge current.

Figure 2 shows the temporal variation of discharge current under the condition of the pressure P=0.3Torr, the magnetic field B=0 and discharge voltage V=600V in DC glow discharge plasmas. They are normalized by the initial value at t=0. From the figures, it is found that discharge current increases to the maximum value, afterward discharge current decreases dramatically, and shows the tendency to saturation with an increase in discharge time. In other words, the plasma resistance decreases to the minimum value, after that the resistance increases dramatically, and it shows the tendency to saturation with an increase in discharge time. It was also shown in the experiments that the discharge time to reach the minimum value of plasma resistance decreases with increasing the discharge voltage or the pressure. The temporal variation of emission intensities from SiH^* (414.2nm) and H_α(656.3nm) qualitatively agreed with that of discharge currents.

The temporal variation of spatially integrated Mie scattering intensity (SIMSI) is also shown in the same figure. The values of SIMSI are normalized by the maximum one at t=60min. The SIMSI is rapidly increased after about 20min and have the peak value, and after that decreased slowly. These results may be explained by the following. The plasma resistance is decreased because of the input power loss during the generation and the growth of silicon particles, and it is increased because of the reduction of discharge current by the saturation of silicon particle growth and the fall of heavy particles from the discharge space and a-Si:H thin film deposition on cathode surface, with the increase in a deposition time. Finally, plasma resistance is saturated, since the secondary electron emission coefficients of a-Si:H electrode become constant.

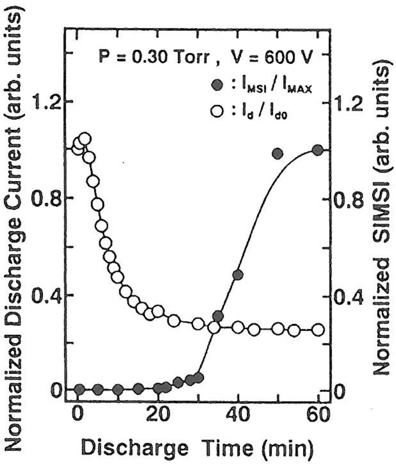

Fig.2 Temporal variations of discharge current and SIMSI under the condition of the pressure P=0.3 Torr, B=0 and discharge voltage V=600V in DC glow discharge plasmas.

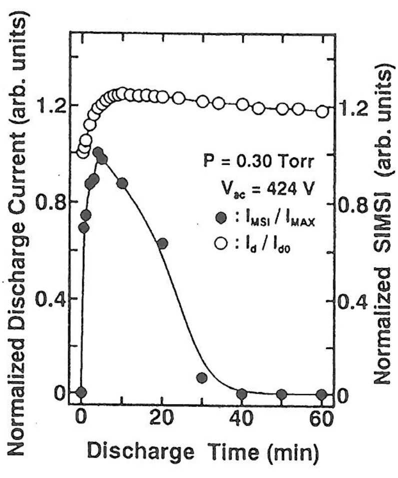

Fig.3 Temporal variations of discharge current and SIMSI under the condition of the pressure P=0.3 Torr, B=0 and discharge voltage V=424V in AC glow discharge plasmas.

In AC discharge plasmas, both the temporal variations of discharge current and SIMSI show the different characteristics as compared with the above mentioned DC discharge, as shown in Fig.3. Here the pressure and effective value of discharge voltage were 0.3 Torr and 424V, respectively. The SIMSI is rapidly increased just after discharge-on. On the other hand the discharge current does not decreased rapidly after it has the maximum value. These differences may be caused by the particle loss during discharge-off time in an AC discharge. It was observed that the particle radius was smaller than that in DC discharge plasmas.

These experimental results depend on both the discharge voltage and the gas pressure. In Fig.4,the dependence of SIMSI on discharge voltage in AC plasmas as a parameter of gas pressure is shown. These results clearly show the discharge conditions of particle formation.

However, the relationship between particle formation and discharge characteristics is not clear for the moment because of the complex charge-up process of particles in the silane plasmas.

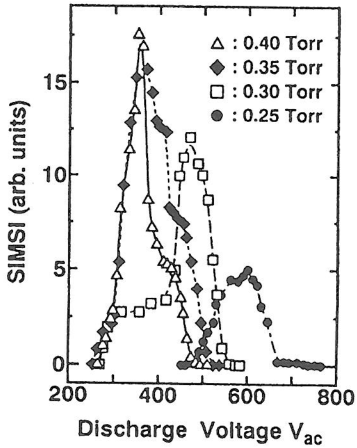

Fig.4 Dependence of SIMSI on discharge voltage in AC plasmas as a parameter of gas pressure.

3. 2 Silicon particles transported by a crossed magnetic field

Figure 5 shows typical two-dimensional profiles of Mie scattering intensity from silicon particles in the presence of crossed magnetic field **B** perpendicular to the discharge electric field **E**. The data were measured at the discharge time t=60min. From the figure, it is found that silicon particles are transported in the opposite direction of **E**x**B** drift. In Fig.6, dependence of SIMSI data on electron Hall parameter h_e is shown This figure shows silicon particle density is decreased with increasing applied magnetic flux density. This particle motion in the field can be explained as follows. As the authors have already reported, in the crossed magnetic and electric fields, plasmas are transported in the **E**x**B** drift direction.[7, 8] At that time, only electrons are magnetized for the present magnetic field range of several tens of gauss, they drift with non magnetized heavy ions at the modified ambipolar **E**x**B** drift velocity. As the result, the ion current density has an unbalanced profile on the cathode surface.[9] Since ion drag

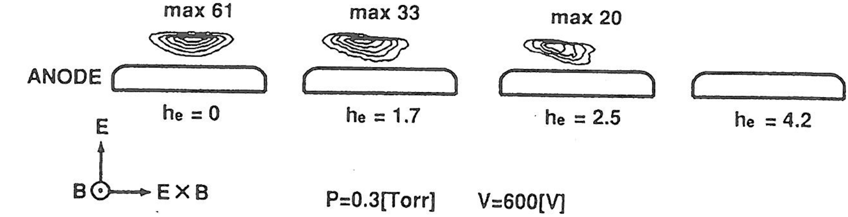

Fig.5 Two-dimensional profiles of Mie scattering intensity from silicon particles in the presence of crossed magnetic field **B** perpendicular to the discharge electric field **E**.

force strongly depends on ion current density, the particle transport parallel to thecathode surface may occur by the unbalances among electrostatic force, ion drag force and force of gravity.[10]

In order to study the mechanism of particle drift motion, theoretical calculation has been performed with use of three equations of motion for electrons, positive ions and negatively charged heavy particles. The drift velocity perpendicular to the electric filed **E** in the cathode sheath region was calculated for three species on the basis of simple model, which was assumed that only Lorentz force plays an important role in perpendicular motion to **E**. Here the electric charge, radius and mass of particles and various plasma parameters were assumed as those in Ref.11.

In Fig.7, it is shown typical calculation results on drift velocity of particles, v_{py}, in the **ExB** direction, for various particle radius r_p and electron Hall parameter h_e. In the figure, particles have negative velocity, which means particles are transported in the direction opposite to **ExB** drift. With increase of particle radius, velocity both of particles and ions are decreased and electron velocity is increased. It can be explained by the decrease of total ambipolar electric field among three species. With increasing h_e, i.e., crossed magnetic field B, the v_{py} is increased for weak B and is decreased for strong B. The dependencies of both velocities of electrons and ions on h_e are resemble to v_{py}. When the electron density is quite low for the conditions of high h_e or large r_p, both negative particles and positive ions drift with same velocity in the **ExB** direction, as if ambipolar **ExB** drift for negative and positive ions occurred. These calculations qualitatively agree with the above mentioned experimental results.

These experimental results on profiles of SiH* radicals, plasmas and the MSI in a cross magnetic field supports the hypothesis that useful radicals for deposition process can be separated from harmful silicon particles by a crossed magnetic field.

When the applied magnetic field was modulated by a low frequency signal, interesting particle dynamics were observed. The particles moved in the direction opposite to **ExB** drift of plasmas, more slowly as compared with the plasma motion. In this case, more drastic decrease of SIMSI was observed. It suggests that the particles are slowly transported by the unbalance between an electrostatic force and an ion drag force to the particle, caused by the **ExB** drift.

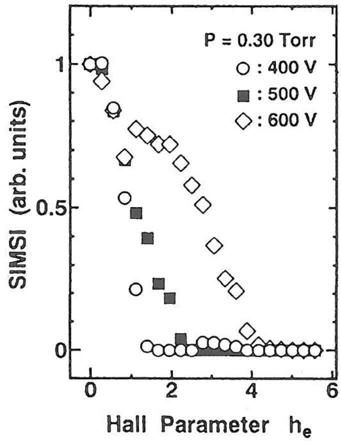

Fig.6 Dependence of SIMSI data on electron Hall parameter h_e.

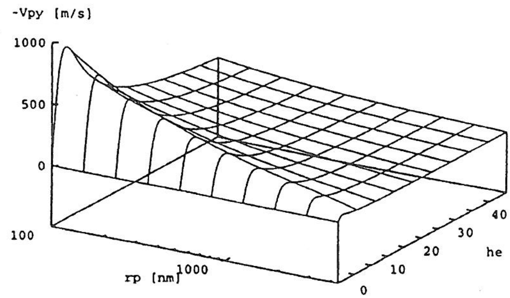

Fig.7 Typical calculation results on drift velocity of particle, v_{py}, in the **ExB** direction, for various particle radius, r_p, and electron Hall parameter h_e.

From the above result, we propose a new particle-free CVD process with same frequency and phase of $\mathbb{E}$ and $\mathbb{B}$, modifying the scanning plasma method [7] for the preparation of large-area uniform a-Si:H thin films.

4. Conclusions

In DC silane plasma, silicon particles were generated and transported in the direction opposite to ExB drift of plasmas, and the spatially integrated Mie scattering intensity (SIMSI) was decreased with increasing applied magnetic flux density. On the other hand, in AC plasma, the SIMSI was rapidly increased after the discharge-on and was also decreased over the critical magnetic flux density. From the calculation, positive ions and negatively charged particles, it is suggested that the particles drift in the direction opposite to ExB drift of plasmas by the space charge effect. When the radius of particle is increased and the electron density is decreased, the drift velocity of particles is decreased by the decrease of space charge electric field.

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