아르곤 직류방전의 충돌쉬스 구조해석

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Analysis of Collisional Sheath in an Argon dc Discharge

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Abstract - The electric fields of the sheath region in an argon dc discharge were measured using a laser optogalvanic spectroscopy in a pressure range from 0.88 to 10 Torr, where collisions are significant in the sheath region. The sheath width is estimated as the position where the electric field becomes zero, and the pressure dependence of the measured sheath width was obtained to be $(\text{pressure})^{-1/3}$. The measured electric fields agree well with one-dimensional simulation results but are slightly different from collisional sheath theory in the mobility limited region.

1. 서 론

The sheath has been the main focus of low temperature plasma applications because it is commonly used for etching of semiconductor materials and sputter deposition of thin films. Lieberman reported self-consistent solutions of the high voltage capacitive rf sheaths for both collisional and collisionless ion motions[1,2]. Wang and Wendt evaluated the sheath width using a time-dependent one-dimensional plasma fluid model[3]. Simulation[4] and experimental[5,6] studies were also performed for rf discharges by many researchers, and the sheath electric field was measured using a laser induced fluorescence (LIF) spectroscopy for high pressure helium rf discharge [7,8].

In this work, we carried out the analysis of the collisional sheath structure of the argon dc discharge using laser optogalvanic spectroscopy. For this, we measured the sheath electric fields on the basis of the previously developed method[9]and estimated the sheath width directly. Direct measurements of the sheath electric fields in argon dc discharges also have been compared with a collisional sheath theory[12] and particle-in-cell simulations, and these comparisons explain the suitability of collisional sheath models. The obtained sheath width compares well with the result of simulation. Additionally, the collisional sheath theory assuming constant ion current density was compared with simulation results including the self-constant change of ion current density. The theory and the simulation give different electric field profiles especially near the sheath-bulk boundary.

2. 본 론

2.1 Experiment setup

The spectroscopic scheme used for these measurements is shown in Fig. 1. Argon atoms are excited from the 4s[3/2](J=2) metastable level to the *7f* and *8f* levels. For the optogalvanic measurements, the plasma impedance was measured as the laser was tuned through these transition wavelengths.

The experimental apparatus is shown in Fig. 2. The laser source was a tunable dye laser pumped by a xenon chloride excimer laser. The laser was operated at ~620 nm, and the laser output was frequency doubled to generate the radiation at ~310 nm which was used for the excitation. The output of the dye laser had pulse duration of 25 ns and a spectral width of 0.2 cm1. A cylindrical lens was used to focus the laser beam into a sheet beam with a width of 0.1 mm and a height of 5 mm. The beam was directed through the plasma parallel to the electrode surfaces. Measurements were performed by scanning the dye laser wavelength and measured the absorption spectrum by laser optogalvanic spectroscopy. The optogalvanic signal was averaged by a boxcar integrator before being transferred to a personal computer.

A parallel plate dc discharge was used for these measurements. The discharge was maintained between planar stainless steel electrodes which had a diameter of 40 mm and were separated at 5 mm.

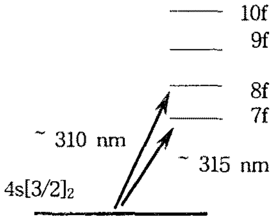

Fig. 1 Excitation transitions for the measurement of electric field in the neutral argon atom.

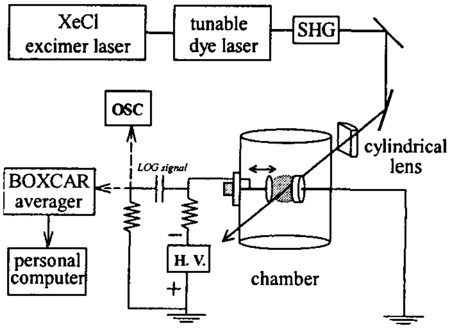

Fig. 2 Experimental setup used for laser optogalvanic measurements in an argon dc glow discharge.

2.2 Result and discussions

Figure 3 shows an example of optogalvanic spectra measured for the transitions from the lower level $4s[3/2]_2$ to Rydberg levels with a principal quantum number n=8. These spectra were obtained from an argon discharge plasmas with pressure of 6.4 Torr. Each optogalvanic signal was measured for different distances from the cathode surface. The distance *d* shown in Fig. 3. is the distance from the cathode surface, the position of which corresponds to d = 0 mm. Although many peaks were detected in Fig. 3, only two peaks can be identified in Ref. [10], corresponding to the transitions from the level $4s[3/2]_2$ to the levels $8f[5/2]_2$ and $8f[3/2]_2$. These optogalvanic spectra forthe measurement of electric fields in argon discharge were already developed[9]. The theoretical calculation of the electric field was performed using the separations marked by letters A and B in Fig. 3[11]. The separation between letters A and B in Fig. 3 decreases with increasing the distance from the electrode. From Fig. 3, the separation between letters A and B becomes zero at the distance of d=1.2 mm, which means that the electric field is zero at d=1.2 mm. On the basis of this method, the sheath width can be estimated as the position where the electric field becomes zero. Figure 4 shows the obtained sheath width in the pressure regime from 0.88 to 10 Torr. The sheath width depends on gas pressure. The voltage differences across parallel electrodes were measured as 438 V, 392 V, 350 V, 267 V, and 250 V when the pressures were 0.88 Torr, 1.2 Torr, 1.6 Torr, 6.4 Torr, and 10 Torr, respectively. The pressure dependence of the measured sheath width is about $p^{-1/3}$. From the collisional sheath theory, the sheath width is proportional to $p^{-1/5}$ for constant potential and ion current density. However, the potential difference and the ion current density vary for different pressures in this experiment.

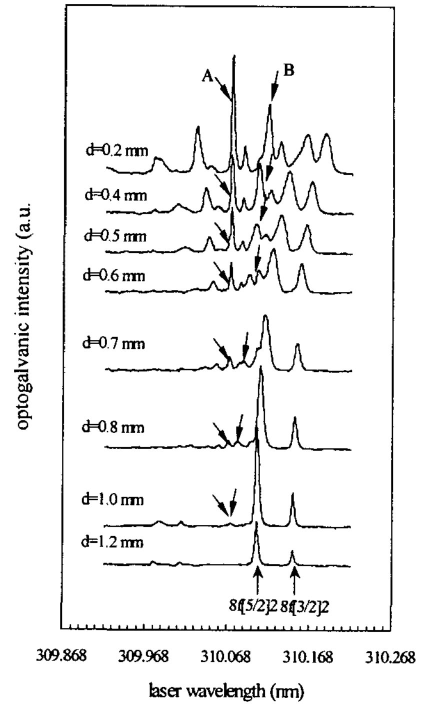

Fig. 3 Laser optogalvanic spectra obtained at different distances from the cathode in an argon dc discharge at 6.4 Torr.

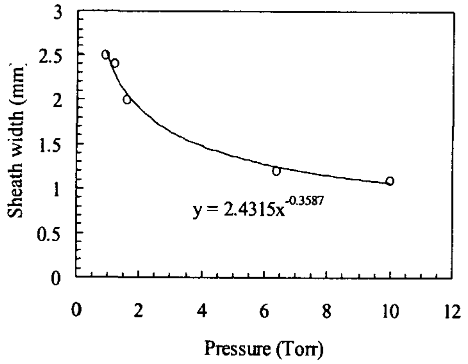

Fig. 4 Sheath widths obtained by experiment at the pressure of 0.88 10 Torr.

Figure 5 shows the comparison of the electric field profile obtained from experiment, simulation, and theory. The gas pressure is 6.4 Torr, and the applied dc voltage is 267 V. For the comparison with experiment, we included the radial loss effect by having 10 % of the generated plasma lost artificially. The simulation result agrees very well with that of experiment.

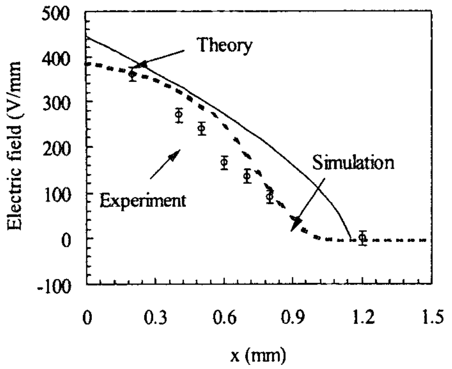

Fig. 5 Comparison of the electric field profile obtained by experiment (circle), simulation (dashed), and theory (solid) for 6.4 Torr and 267 V case with a gap distance of 5 mm. The plasma density and ion current density used in the simulation and the theory are assumed to have 10 % of loss in radial direction. The sign of the electric field is negative.

3. 결 론

The electric field distributions in an argon dc discharge were directly measured by laser optogalvanic spectroscopy. From these measurements, the sheath width can be determined where the electric field becomes zero. The measured electric fields agree very well with one-dimensional simulation results. The result of the experiment in an argon dc discharge was compared with the result of the simulation and theory. The results of experiment agree well with the simulation results rather than the collisional sheath theory. The results of the simulation and the theory show discrepancy near the bulk-sheath boundary and the cathode because of the change of the ion current density due to the ion collisions in the sheath, since the collisional sheath theory assumes uniform ion current density.

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