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플라즈마와 표면굴곡과의 상호작용

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Interaction of a Plasma with Surface Topography

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Introduction

Understanding the interaction of a plasma with a surface containing topographical features is critical to coating of curved objects, etching of surfaces of complex form (e.g., for MEMS), plasma immersion ion implantation, and ion extraction from a plasma by electrically biased grids (for use in neutron generators, ion beam assisted growth and etching of thin films, neutral beam etching, ion thrusters, neutron generators, *etc*) [1, 2]. The flux, energy and angular distributions of ions incident on the target are of primary importance. These quantities depend critically on the shape of the meniscus (plasma-sheath boundary) formed over the topography.

For plasma-grid interaction, for example, the important length scales that control behavior (assuming a thin grid) are the plasma sheath thickness, l, and the diameter of the grid holes, d [3, 4]. Figure 1 shows three cases of plasma molding over holes. In Figure 1 (a), l is much larger than d so that the presence of holes does not disturb the plasma. The plasma-sheath boundary remains nearly planar as if the hole were a solid wall. In Figure 1 (b), l is much smaller than d so that the plasma-sheath interface follows the surface contour. Plasma leaks through and under the holes. Figure 1 (c) is the intermediate situation where l is comparable to d and there is significant disturbance of the plasma-sheath boundary due to the presence of the holes.

In this work, the interaction of an argon plasma with a grid hole was investigated. A single hole was thought to be a well-defined experiment to study plasma-grid interaction. Holes were selected to represent the three possible cases of plasma-sheath meniscus depicted in Figure 1: hole diameter is less than, larger than, and comparable to the sheath thickness. Experimental results will be discussed in terms of energy and angular distributions of ions effusing from a hole.

Experiment

An argon plasma was generated in an inductively coupled plasma reactor. A pinhole electrode (grounded) was attached to the bottom of the plasma source to sample ions incident on the pinhole. Gas pressure and power ranged from 5 to 50 motrr and from 200 to 600 W, respectively.

To measure flux, energy and angular distributions of ions, a gridded retarding field ion analyzer was used. The analyzer was located behind the hole of the grounded electrode. This type of ion analyzer has been widely used to analyze energy distributions of ions in plasma [5, 6]. The analyzer consists of three screens and 11 annular current collecting electrodes. All screens and collecting electrodes are shaped as part of concentric hemispheres centered at the hole. The top screen was maintained at the same potential as the hole (ground) to create a field-free region between the hole and the ion analyzer. The bottom screen was biased at -90 V to repel electrons.

To obtain the ion energy distribution, the middle screen was swept from zero (ground) to positive voltages at intervals of 1 V until the measured current was zero. Only ions with energies greater than the middle screen potential would pass through the screen and be detected by the collecting electrodes. To measure the ion angular distributions, the middle screen was set to 0 V to allow all ions to reach the collecting electrodes. An ion will hit one of the collecting electrodes according to its angle coming out of the hole. Thus, measurement of the ion current at each collecting electrode gave the ion angular distribution.

Results and Discussion

Figure 2 shows the energy distributions of ions through 10 and 1270 μm diameter holes, respectively, for argon plasmas. For the power and pressure ranges employed in this work, the sheath thickness was estimated from 150 to 400 μm. Thus, the pinhole diameters of 10 and 1270μm represent the cases where the hole diameter is much less than and larger than the sheath thickness, respectively.

The hole diameter affects the shape of the ion energy distributions. When the hole diameter (10 μm) is much smaller than the sheath thickness (Figure 2 (a)), the ion energy distribution have two peaks. The ion energy was modulated in this case, because the ion transit time through the sheath was smaller than or comparable to the rf period.

At the same pressure and power range, however, Figure 2 (b) shows that all ion energy distributions obtained with the 1270 μm-diameter hole have single peaks. This result implies plasma leakage in the case of the 1270 μm-diameter hole. If plasma penetrates the hole, most ions escaping from the plasma will be hardly affected by the sheath between the plasma and the hole, and they will arrive at the detecting electrode experiencing the average plasma potential, because their transit time is correspondingly larger. Thus, the ion energy distributions will have a single peak in that case.

When the hole diameter (508 μm) is comparable to the sheath thickness (not shown), the potential distribution is severely disturbed because the plasma-sheath boundary was located inside the hole. In this case, the ion energy distributions have broader single peaks in argon plasmas, suggesting partial plasma leakage due to the greatly disturbed potential distribution around the hole.

Figure 3 shows the angular distributions of ions through 10 and 1270 μm diameter holes, respectively, for argon plasmas. When the hole diameter (10 μm) is much less than the sheath thickness (Figure 3 (a)), the ion angular distribution have a Gaussian shape peaked at zero angle from surface normal in argon plasmas.

When the hole diameter (1270 μm) is larger than the sheath thickness (Figure 3 (b)), the ion angular distribution in an argon plasma is fairly isotropic up to 30° from the surface normal. The shape of the ion angular distribution is nearly constant with power and pressure, implying that plasma leaked through the hole completely.

The desired angular spread of ions extracted from a plasma depends on the application.

For example, anisotropic etching requires a collimated beam, while coating of the sidewalls of microscopic features is facilitated with divergent beams. Therefore, it is very useful to know the degree of ion beam divergence (cone of ion angles) at a given plasma condition.

Figure 4 shows the angle of the cone into which 50 % of ions are contained as a function of the ratio of the hole diameter to the sheath thickness. The angle defining the cone into which 50 % of ions are contained is saturated when the ratio of the hole diameter to the sheath thickness is much smaller than or much larger than unity. At one extreme, the plasma-sheath meniscus was planar and at the other extreme the plasma leaked completely out of the hole. In-between, the cone of ion angles increased with the ratio of the hole diameter to the sheath thickness. In this regime, the plasma started leaking out of the hole, resulting in progressively higher spread of ion angles.

Conclusions

The interaction of a plasma with surface topography was investigated by measuring the energy and angular distribution of ions extracted from a hole in contact with a high density plasma. The ion energy distribution (IED) showed different behavior according to the ratio of the hole diameter to the sheath thickness. When the hole diameter (10 μm) was much less than the sheath thickness, the IED had two peaks in argon plasmas. When the hole diameter (1270 μm) was larger than the sheath thickness, the IED had single peaks, implying that the plasma leaked through the hole.

The ion angular distribution (IAD) was also greatly affected by the ratio of the hole diameter to the sheath thickness. When the hole diameter (10 μm) was much less than the sheath thickness, the IAD had a Gaussian shape peaked at zero angle from surface normal. When the hole diameter (1270 μm) was larger than the sheath thickness, the IAD was fairly isotropic up to 30° from the surface normal. The shape of the IAD was nearly constant with power and pressure, implying that plasma leaked through the hole completely.

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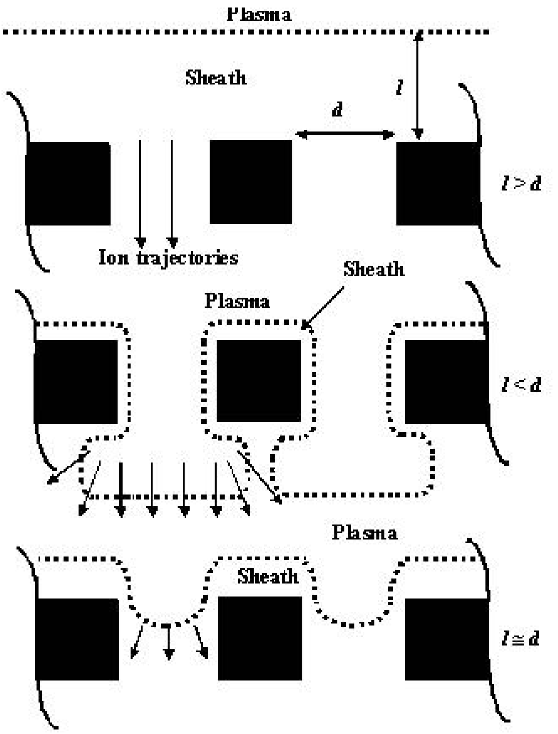

Figure 1. Schematic of plasma molding over holes. (a, top) sheath thickness, l, is larger than hole diameter, d; (b, middle) l is smaller than d; and (c, bottom) l is comparable to d.

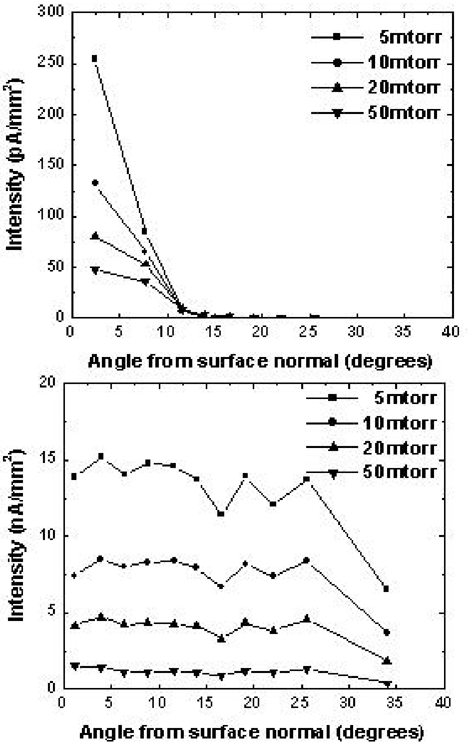

Figure 3. Angular distributions of ions in argon plasmas: (a, top) 10 μm diameter pinhole, 600W and (b, bottom) 1270 μm diameter pinhole, 200W.

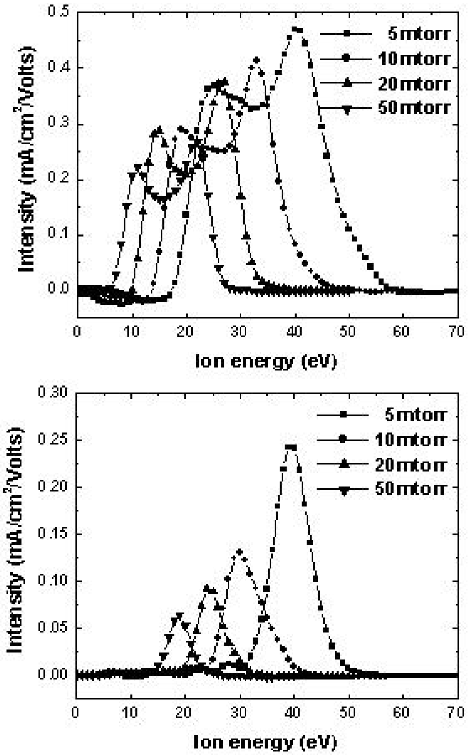

Figure 2. Energy distributions of ions in argon plasmas: (a, top) 10 μm diameter pinhole, 600W and (b, bottom) 1270 μm diameter pinhole, 600W.

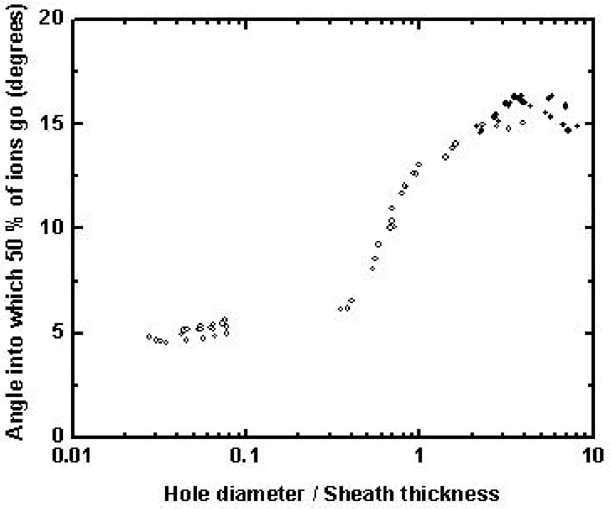

Figure 4. Cone of angles into which 50 % of ions are contained in argon plasmas as a function of the ratio of the hole diameter to the sheath thickness.