Discharge Characterization of Photoemission-Assisted Ar Plasma by Langmuir Probe
ラングミュアプローブ法による光電子制御 Ar プラズマの放電特性

Yuki Kotanigawa, Ajia Saijan, Shuichi Ogawa, Yuji Takakuwa
小谷川祐貴, 阿加賽見, 小川修一, 高桑雄二

Institute of Multidisciplinary Research for Advantage Materials, Tohoku University
2-2-1, Katahira, Aoba-ku, Sendai 980-8577, Japan
東北大学多元物質科学研究所　〒980-8577　仙台市青葉区片平 2-1-1

Photoemission-assisted plasma ion source is focused as a new smoothing technique on metal surfaces. To understand the collision process between ions and substrate surfaces, plasma potential of photoemission-assisted plasma must be measured. The pressure dependence of plasma potential profiles were measured by a Langmuir probe. As a result, it was found that that plasma potential profile is proportional to the distance from the surface in photoemission-assisted Townsend discharge, and the kinetic energy of ions that collides to surface is smaller than ~1eV. These proportional profiles indicates that ion sheath is not formed in Townsend discharge because of low ion density in photoemission-assisted plasma. Furthermore, These low energy ions can be used for not only surface planarization but also CVD growth on frangible materials such as graphene.

1. Introduction

We have developed the photoemission-assisted plasma ion source[1-4] as a new surface smoothing technique to achieve the nano-scale flatness by ion bombardment. For surface planarization, kinetic energy of ions are very important parameter, so that measurements of ion energy is necessary. To measure the kinetic energy of ion in plasma, there are mainly two methods. One is the spectroscopic method using energy analyzer. In this method, we can obtain not only kinetic energy but also ion mass or ionic charge. However, extensive space is necessary to attach the ion energy analyzer. In addition, the ion energy at the time when ions collide to surface is difficult. The another method is the calculation based on plasma potential. The plasma potential can be obtained easily by Langmuir probe. In this research, we fabricated a Langmuir probe and equipped to photoemission-assisted apparatus. The line profile of plasma potential is measured in various conditions, and ion energy is calculated by using a classical dynamics of binary collision model.

2. Experimental methods

A schematic illustration of the photoemission-assisted plasma ion source apparatus is shown Fig.1. A UV lump is installed on the chamber. The UV light (λ = 172 nm) pass through a quartz window and is introduced into the chamber. The substrate is irradiated by the UV light and bias voltage is applied between an electrode and the substrate. The substrate is covered by glass to prevent the abnormal discharge between a sample holder and chamber wall. The substrate is Au deposited Si wafer, and thickness of Au films is 200 nm. The Langmuir probe can be moved between the substrate and electrode with 1 mm resolution in vertical direction. The distance between the substrate and electrode is 63 mm.

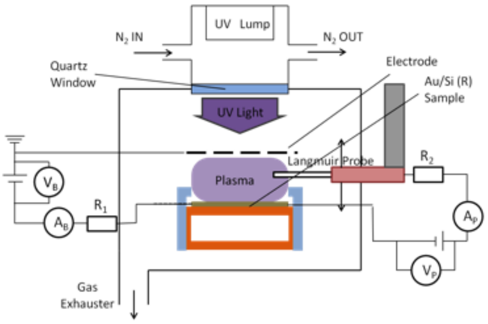

Fig. 1 Schematic illustration of the photoemission-assisted plasma ion source.

We investigated the position dependence of the Ar plasma potential in Townsend discharge. The position dependences were measured by changing the gas pressure and applied DC bias voltage.

3. Experimental results and discussion

The Ar gas pressure dependence of plasma potential profile is shown Fig.2. Among these profiles, the DC voltage was constant at 150 V. In 30 Pa, the plasma potential increases until 15 mm and then becomes constant. This line profile indicates the formation of ion sheath at 0 to 15 mm range. Therefore it is concluded that it is not Townsend discharge but glow discharge. When Ar pressure increases up to 150 Pa, the profile shows

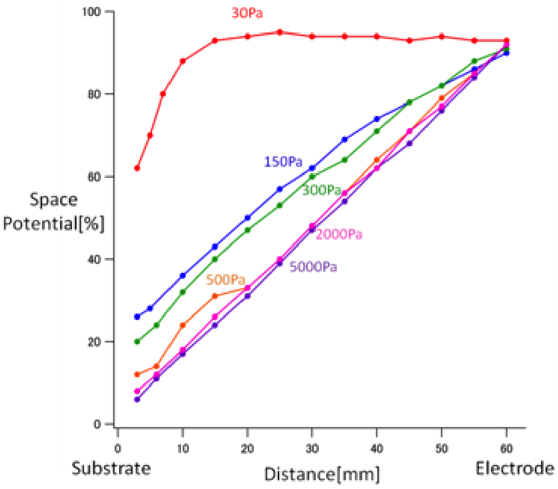

Fig. 2 Ar gas pressure dependence of plasma potential profile in Townsend discharge.

linear shape. Further increase of Ar pressure, the gradient of profiles becomes more steeply. The intercept at 1 mm indicates the ion sheath formation, so that it is found that the voltage depression in ion sheath decreases with increasing Ar pressure. This result indicates that ion density of Townsend discharge decreases with increasing Ar pressure. This is because that electrons in plasma can be obtained enough energy in low pressure so that effective ionization occurs. On the other hand, electrons cannot be accelerated in high pressure because the inelastic collision between electrons and Ar atoms, so that only the small number of ions are formed. In experiment at 30 Pa, a large number of Ar^+ ions are generated and enough Auger electrons are supplied by γ regime, so that glow discharge is generated.

The DC voltage dependence of plasma potential line profile is shown Fig. 3. The gas pressure was 500 Pa among these experiments. The gradient of line profile becomes smaller with increasing the bias voltage. The density of Ar+ ion in plasma increase by increasing bias voltage, so that it is also found from this result that the voltage depression ion at ion sheath is decreased by decreasing Ar+ ion density.

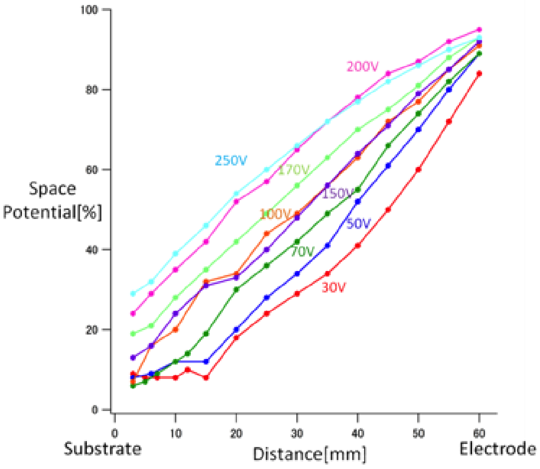

Fig. 3 The bias voltage dependence of the plasma potential profile in Townsend discharge.

In the next step, we calculate the Ar ion energy when ions collide to the substrate using classical dynamics of binary collision model. The Ar ions are accelerated by bias voltage and collide with Ar atoms. When Ar^+ ions and Ar atoms collide, the kinetic energy of Ar^+ ions becomes half. When we assume that plasma potential is linear between the substrate and electrode, the incident ion energy E (eV) on the surface is represented as $E=2.0\times(V\cdot\lambda_{Ar})/d$. Here d shows the distance between the substrate and electrode, V shows potential difference, and λ_{Ar} shows mean free path of Ar ion. Using this equation, the incident ion energy is calculated as 11 eV at 30Pa-150V (glow discharge), 0.095 eV at 500Pa-50V, and 0.16 eV at 500Pa-150V, respectively. In the Townsend discharge, ion potential is linear, so that the number of collision becomes large. On the other hand, the number of collision is small in glow discharge because acceleration area is only near the substrate due to ion sheath. Therefore, ion energy in glow discharge becomes larger.

4. Conclusion

In this study, we investigated the plasma potential of photoemission-assisted plasma ion source using a Langmuir probe to evaluate the incident ion kinetic energy. In the Townsend discharge, the plasma potential profile shows a linear shape, meanwhile ion sheath is formed in the glow discharge. Using classical dynamics of binary collision model, we calculate the Ar ion energy when ions collide to the substrate. In the Townsend discharge, the ion energy is smaller than 1 eV but it is higher than 10 eV in glow discharge. It is found that low energy ion radiation can be obtained by using photoemission-assisted Townsend discharge, and by using low energy beam, the surface planarization on metal surface will be achieved.

Reference

[1]Y. Takakuwa: Japan Patent No. 3932181 (2007).
[2] Y. Takakuwa: M&E, 36 (2009) 116.
[3] T. Takami, S. Ogawa, H. Sumi, T. Kaga, A. Saikubo, E. Ikenaga, M. Sato, M. Nihei and Y. Takakuwa: e-J. Surf. Sci. Nanotech., 7 (2009) 882.
[4] S. Ogawa, M. Sato, H. Sumi, M. Nihei, and Y. Takakuwa: IEICE Technical Report, SDM2010-222 (2011) 26.