23E05

Establishment of Plasma Electron Ablation Method
プラズマ電子アブレーション法の開発

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A new ablation technique is being developed from the investigation of the surface wave plasma. Relatively low positive bias voltage beyond a certain threshold value applied to small target materials in the plasma results in a transition to a high electron current flow and in the generation of a steady plume, *i.e.* plasma with the much higher density locally. The target materials are eroded and deposited to substrates, as in the case of Laser ablation method. The dependence of the transition bias voltage on the argon gas pressure shows a minimum as seen in Paschen curve shifted to a lower pressure and lower voltage range.

1. Introduction

In previous studies on the surface wave plasma (SWP), its features relevant to the application to material processing have been revealed [1,2]: the low electron temperature but the high plasma density homogeneously distributed due to the ambipolar diffusion. The discreteness of the coupling mode to the surface wave allows the independent control of the bias voltage to target materials from the generation of the SWP: films of FeNi, TiN, AlN were sputter deposited [1] with the negative target bias, whereas $La_{1-x}Sr_xMnO_3$ films were prepared with the positive bias [2].

The latter method seems similar to the pulsed Laser deposition method [3] as far as erosion of the target without melting trace, the plume generation, and deposition are concerned, and therefore has been defined as the plasma electron ablation.

In the present study, it is aimed to find appropriate operation conditions for forming the plume in order to optimize the rate of ablation of target materials, the mechanism of the plume generation, and the role of the plume in the ablation.

2. Experimental Procedure

A cylindrical discharge vessel (340mm in inner diameter, 60cm in height, stainless steel UHV compatible) has been employed with a top plate flange having two quartz windows on which a 4-line-slotted waveguide is attached. In this study, steady-state plasma discharge is maintained with the microwave power (2.45GHz) ranging from 200W to 350W in Ar gas (1-20 Pa).

A graphite disk (AX60) has been chosen as a target material to verify whether it emits carbon without melting. Pellets have been cut out from the disk and set in three ceramic target holders (type A with an aperture hole of 5 mmϕ and 2 mm in depth, type B with an aperture 3 mmϕ and 6 mm in depth type C with an aperture 3 mmϕ and 4 mm in depth) so that small area of the pellet is exposed to the SWP. The target holder is placed near the center axis of the vessel and at 10 cm from the top plate flange. Insulation of the electric feedthroughs and cables to the target has been an important issue to prevent serious damages from the microwave power, electrical shortage in the SWP, and the joule heating of the current. The target bias voltage ranging up to +100V (10A max) can be applied externally.

3. Results and Discussion

Electron saturation current of 0.2 Acm^{-2} results typically when the target is biased positively up to +40 V in SWP in Ar at 1Pa with the MW power of 350W, in good accord with the data obtained with electrostatic probes [1, 2]. But above a certain value V_{tr} around +60 V, the electron current density increased abruptly to the value of 10 Acm^{-2}, and the plume of about 1 cm in length appeared quasi constantly, as shown in Fig.1.

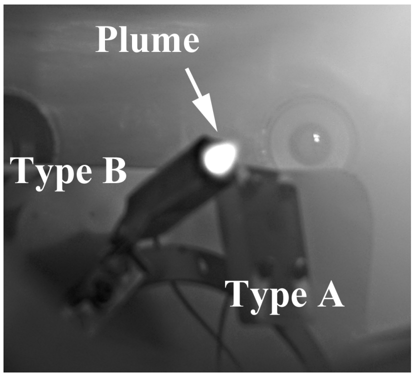

Fig.1 A photograph of the plume from a graphite target in the holder type B.

The plume is not sustained in the low pressure range with the external bias voltage only: it is extinguished just as soon as the MW power is switched off.

The minimum values V_{tr} of the bias for the plume to be generated are plotted in Fig.2 as a function of Ar pressure for the three types of the target holder A, B, and C. Higher values are needed for Type B in the lower pressure range. The dependence seems to obey the Paschen's law [4] well known as a universal phenomenological function of *P*x*d* product, where *P* is the gas pressure and *d* is the gap length between an anode and a cathode. Two Paschen curves in Fig.2 roughly reduced by a factor 3 along the ordinate are overlaid with 2 parameters: an *effective* electrode gap *d* of 5cm with a secondary electron emission coefficient γ of 1.2 (green), and *d* 3cm with γ 1.5 (Blue). The value of *d* is much longer than the length of the aperture of the holder

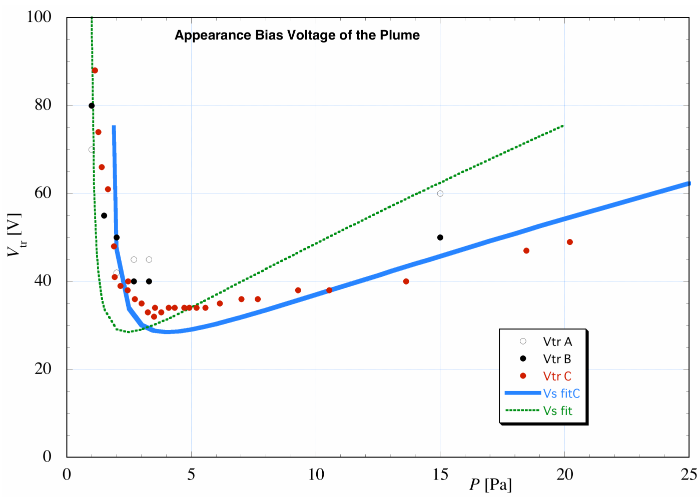

Fig.2 Minimum threshold bias voltage V_{tr}, to induce the plume in Ar plasma as a function of Ar gas pressure for 3 types of target holders. Two Paschen curves are shifted and overlaid.

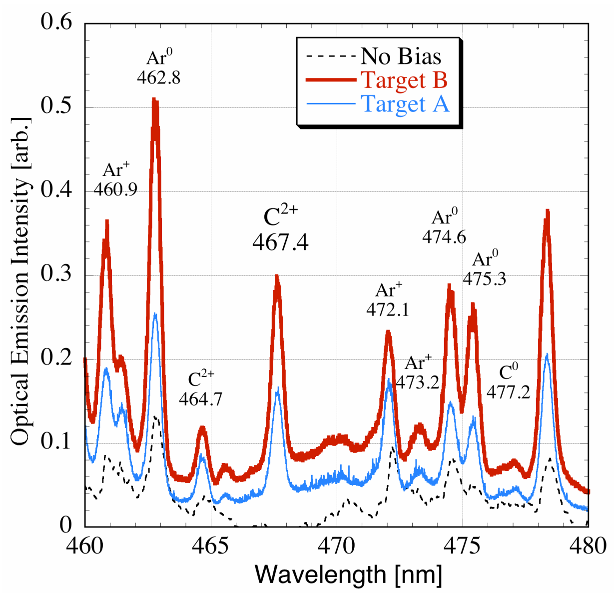

Fig. 3. Optical emission spectra obtained from the plasma without target biasing (broken line) and with the target bias using the target holder type A (thinner line) and type B (thicker line), as seen in Fig.2(a) and (b), respectively.

and seems to be related to the current density, which depends on various experimental parameters. Thus the plume is regarded as a DC discharge with an effective cathode of the SWP, as solution plasmas in pre-ionized fluids.

The temperature of the target remains well below its melting point even with a maximum heating power of 150 W (60V x 2.5A), but carbon atoms (ions) are detected in the plasma with optical emission spectroscopy and identified as shown in Fig.3. Atoms in the surface layers within the electron projectile length of the order of a nanometer may be excited and ejected, *e.g.* as in the case of electron stimulated desorption since the electron energy exceeds some threshold value of 50 eV. A significant line peak appeared at the wavelength 467.4nm for C^{2+} whereas a small hump was seen for neutral carbon atoms *e.g.* at 477.2 nm in contrast the low electron temperature plasmas. In the present spectra any lines from C^{+} ions were not identified yet. The high degree of ionization (exceeding unity) was also reported [5] for the cases of the Laser ablation and of the channel spark in terms of the interaction of intense photons and of electrons with released atoms. Likewise ejected carbon atoms collide with electrons having the maximum energy of 60 eV while they fly or are confined in the plume. This electron energy value is greater enough than the second ionization energy of carbon. A simple computation yields an average value of the order 10^4 incident electrons for a surface carbon atom per one second.

4. Concluding Remarks

The pressure lower than 5 Pa is preferable for the ablation method taking the mean free path of the released atoms outside the plume into account, and also taking the applicable higher electron energy leading to a higher ablation rate into account. The plume offers the possibility of higher ionization degree of the target atoms and therefore may influence the deposition process.

References

[1] T.Banno, H.Kutsuna and S.Minami: Vacuum **80** (2006) 667.

[2] T.Banno: *Proc. 10th Intern. Symp. Sputtering and Plasma Processes, Kanazawa, 2009*, P.79.

[3] M.Izumi, Y.Konishi, T.Nishihara, S.Hayashi, M.Shinohara, M.Kawasaki, and Y.Tokura: Appl. Phys. Lett. **73** (1998) 2497..

[4] M. A. Lieberman and A. J. Lichtenberg: *Principles of Plasma Discharges and Materials Processing* (Wiley, NewYork, 2005) 2nd ed., Chap. 14, p.546.

[5] Th.Witke, A.Lenk, B.Schultrich, C.Schultheiss: Surface and Coatings Technol. 74-75 (1995) 580.