High Deposition Rate of Diamond-like Carbon on Trench Bottom for Acetylene Gas at Plasma Immersion and Deposition Process

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A bright optical emission inside a trench in a solid object was observed during a diamond-like carbon (DLC) deposition process, with the DLC deposition rate being more than two-times faster on the trench's bottom than that on the top of the trench. We found that the secondary electrons inside the trench played an important role in the higher DLC deposition rate on the trench's bottom.

Keywords: acetylene plasma, diamond-like carbon (DLC), optical emission, plasma implantation, deposition

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In plasma immersion ion implantation (PIID) [1–3], the object to be ion-implanted is immersed in plasma and biased with a high voltage pulse. A sheath forms around the object and ions are accelerated across the sheath into the surface of the immersed object. The bias is pulsed to allow the plasma to replace depleted ions between the pulses.

In order to gain insight into the plasma processes for C_2H_2 hydrocarbon gas plasma, we have used optical emission spectroscopy as a diagnostic tool.

The apparatus used in this study has been described in detail in earlier publications [4, 5]. Figure 1 shows the experimental setup for the measurement of optical emissions from hydrocarbon gas plasma of acetylene in PIID. A RF pulse of 50 μs duration at a frequency of 13.56 MHz for plasma generation and a negative pulsed voltage delayed 50 μs after the end of the RF pulse for ion implantation were applied to a sample holder via a single electrical feed-through. Emission pulse shapes were measured using a photo-multiplier with band-path filters. Silicon wafer tips were used for measurements of DLC film thickness. The thickness of the DLC film was measured using a stylus surface profiler.

A bright optical emission inside a trench of a solid object was observed during DLC deposition measurement. Figure 2 shows the DLC deposition rate and the CH line emission intensity on the bottom and the top surfaces for acetylene gas at a pressure of 0.5 Pa, a negative pulse voltage of −10 kV, a pulse width of 5 μs, and a repetition rate of 0.5 kHz. The optical emission distribution and DLC film thickness were measured at various points in the trench which had a depth of 20 mm, a bottom width of 10 mm, and a length of 40 mm. The optical emissions were measured from the trench end, and the observed points were 20 mm inside the trench end, and 2 mm on the surface.

The CH emission ($A^2\Delta$-$X^2\Pi$) at 431.4 nm was almost in proportion to DLC deposition rate for acetylene plasma [6]. The DLC deposition rate and the optical intensity showed almost same tendency, and the DLC deposition rate was more than two times faster on the bottom of the trench solid sample than that on the top of the trench, as shown in Fig. 2. This is an unexpected phenomenon in the ion implantation process. The implanted ion density on the bottom surface is expected to be smaller than that on the top surface. However, the measured results were opposite. These experimental results show that another deposition process is required.

The plasma sheath size is an important factor in the study of the deposition process. However, sheath size is difficult to estimate because the PIID process is a transient mode. The optical emission distribution may be regarded

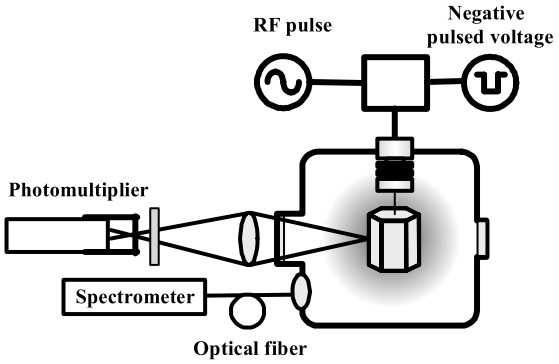

Fig. 1 Plasma immersion implantation and deposition process and experimental setup.

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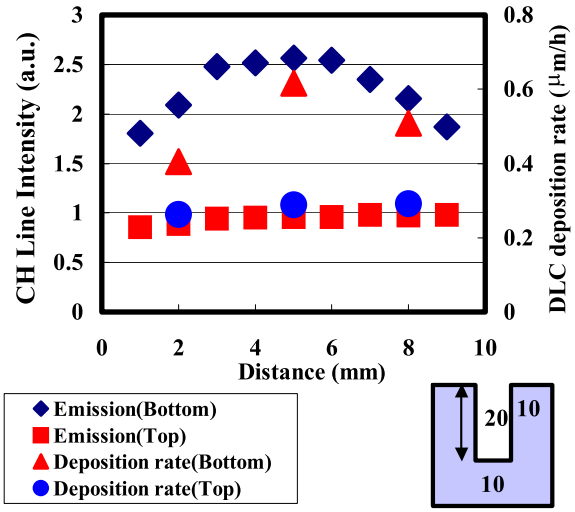

Fig. 2 CH emission and DLC deposition rate for acetylene plasma on trench with 20 mm depth and 10 mm width.

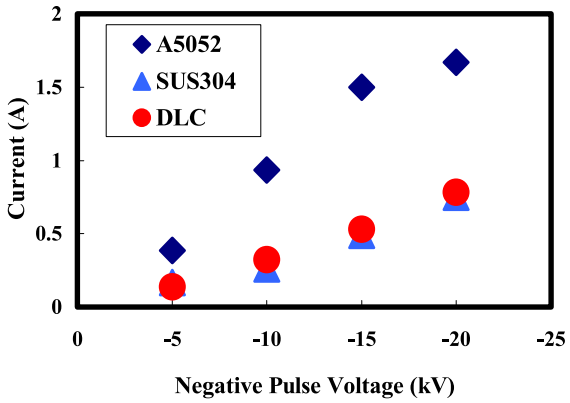

Fig. 3 Pulse currents measured at end of 10 μs pulse width with same diameter and length.

Table 1 Secondary electron emission coefficient of plane target for argon ion [8].

Material	Energy		
	20 keV	30 keV	40 keV
SUS304	4.4	5.3	5.4
Aluminium (oxidized)	14.7	16	15.2
Aluminium (etched)	11.1	11.8	12.8

as a rich plasma area. The time-integrated optical thickness was about 2 cm in this process, which is larger than the trench width.

The plasma production and ion implantation process are coupled at high pressure [7]. The negative pulse voltage sustains plasma production, as well as implanting ions into the solid materials. It seems most probable that secondary electrons generated by spattering on the surfaces inside the trench play a role in the higher DLC deposition rate on the bottom of the trench. To discuss the role of secondary electrons, the pulse currents flowing in three different column samples of SUS304 stainless steel, aluminum (A5052), and DLC, each 140 mm in diameter and 100 mm in length, were respectively measured in argon gas plasma at a pressure of 0.2 Pa, a pulse width of 10 μs, and a repetition rate of 100 Hz. Unfortunately, acetylene gas cannot be used for this test because of DLC surface deposition. An argon gas was used since it leaves no deposition on a surface and it is an inactive gas. Figure 3 shows the currents measured at the end of a 10 μs pulse width, when the current was almost constant. The aluminum column samples showed approximately twice the current than the SUS304 and DLC surfaces at a negative pulse voltage range of −5 kV to −20 kV. The measured current can be given by combining of the ion flux J_i and the secondary electron flux J_{se}. These results seem to be self-consistent with secondary electron emission coefficient shown in Table 1 [8]. The secondary electron emission coefficient for DLC could not be found, but it seems as close as that of the SUS304 in Fig. 3.

This large difference between the pulse currents indicates that many secondary electrons are generated on the surface. The rich ion and electron induced by secondary electrons in the gas may be the dominant DLC deposition process inside the trench compared to that induced by the primary implanted ion. The electron multiplication process in the manner of a hollow cathode discharge may be most probable reason for the rich plasma produced inside the trench.

In conclusion, a bright optical emission inside a trench in a solid object was observed in the DLC deposition process, with the DLC deposition rate being more than two-times faster on the bottom of the trench than that on the top of the trench. We found that the secondary electrons inside the trench played an important role in the higher DLC deposition rate on the bottom.

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