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Effects of Substrate Bias Voltage on Plasma Anisotropic CVD of Carbon Using H-assisted Plasma CVD Reactor

水素原子源付プラズマ CVD 装置を用いた炭素薄膜の異方性製膜に対する基板バイアス電圧の影響

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To study effects of substrate bias voltage (V_b) on $Ar+H_2+C_7H_8$ discharges and carbon films deposited by H-assisted plasma CVD reactor under anisotropic deposition condition, we have measured V_b dependence of optical emission intensities and mass density of carbon films. With increasing absolute value of V_b, all emission intensities increase and $I_{H\beta}/I_{H\alpha}$ slightly increases. The latter results indicate V_b has a slight influence on electron temperature in $Ar+H_2+C_7H_8$ discharges. The mass density of carbon films reaches a maximum of 2.3 g /cm^3 at V_b = 75 V, corresponding to an ion energy of 100 eV.

1. Introduction

Diamond like carbon (DLC) is a dense, metastable form of amorphous carbon (a-C) or hydrogenated amorphous carbon (a-C:H) containing a high fraction of carbon sp^3 sites, but also sp^2 sites and hydrogen [1,2]. The sp^3 bonding confers valuable properties such as mechanical hardness, low friction, optical transparency, chemical inertness, and chemical inertness and biological compatibility [3]. Deposition profile of the films on nano-patterned substrates is one of the concerns to realize coatings on such substrates. We have succeeded in controlling deposition profile of Cu on trench substrates, and have realized sub-conformal, conformal profiles as well as anisotropic deposition profile, for which Cu is deposited in trenches without sidewall deposition, using a H-assisted plasma CVD method [4-6]. We are applying the method to realize deposition profile control of carbon films [7]. Here we report dependence of optical emission intensities and mass density of carbon films on substrate bias voltage.

2. Experimental setup

Experiments were performed using the H-assisted plasma CVD reactor, in which a capacitively-coupled main discharge and an inductively-coupled discharge for an H atom source were sustained as shown in Fig. 1. This reactor provided independent control of generation rates of carbon containing radicals and H atoms. For the main discharge, a mesh powered electrode of 85 mm in diameter and a plane substrate electrode of 85 mm in diameter were placed at a distance of 33 mm. The discharge of H atom source was sustained with a radio frequency (rf) induction coil of 100 mm in diameter placed at 65 mm above the substrate electrode of the main discharge. The excitation frequency was 13.56 MHz and the supplied power (P_H) was 500 W. The excitation frequency of the main discharge was 28 MHz and the supplied power (P_m) was below 45 W. A bias voltage of 400 kHz was applied to the substrate for

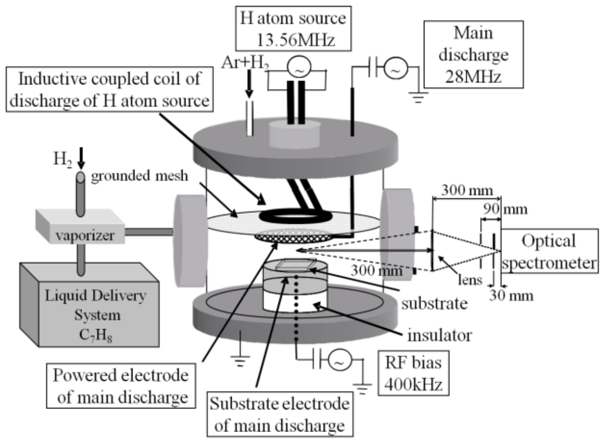

Fig. 1. Schematic of H-assisted plasma CVD reactor.

controlling kinetic energy of ions incident on it. Toluene (C_7H_8) was vaporized at 150°C, and supplied to the reactor with H_2. C_7H_8, H_2 and Ar were supplied at flow rate of 0.63 sccm, 30 or 60 sccm, respectively. The total pressure was 13 Pa. The substrate temperature was kept at 100°C.

Optical emission intensities were measured at 15 mm above the substrate electrode with an optical multichannel analyzer (Hamamatsu Photonics PMA-11-C7473).

3. Results and discussion

First, we have measured dependence of optical emission intensities of $Ar+H_2+C_7H_8$ plasmas. Figure 2 shows dependence of optical emission intensities of H_β (486nm), H_α (656.3nm), and Ar (811.5nm) on the bias voltage. All emission intensities in Fig. 2 increase with increasing absolute value of bias voltage, indicating that generation rates of radicals increase.

Figure 3 shows dependence of emission intensity ratio of Hβ to Hα for $Ar+H_2+C_7H_8$ plasmas on bias voltage. The ratio of Hβ to Hα for $Ar+H_2+C_7H_8$ plasmas is slightly increases with increasing absolute value of bias voltage. Therefore electron temperature slightly increases with increasing absolute value of bias voltage, which partly leads to the increase in the emission intensities in Fig. 2.

Finally, we have measured dependence of mass density of carbon films on the bias voltage. Figure 4 shows the results. The mass density of carbon films reaches a maximum at 75 V corresponding to an ion energy of 100 eV, probably because there is an appropriate ion energy to obtain carbon films of a high mass density.

4. Conclusions

We studied dependence of optical emission intensities of $Ar+H_2+C_7H_8$ plasmas and mass density of carbon films on the substrate bias voltage. The following conclusions are obtained in this study.

1) Substrate bias voltage has slight influence on plasma parameters in the main discharge.

2) Carbon films of a high mass density of 2.3 g /cm^3 are obtained at an ion energy of 100 eV.

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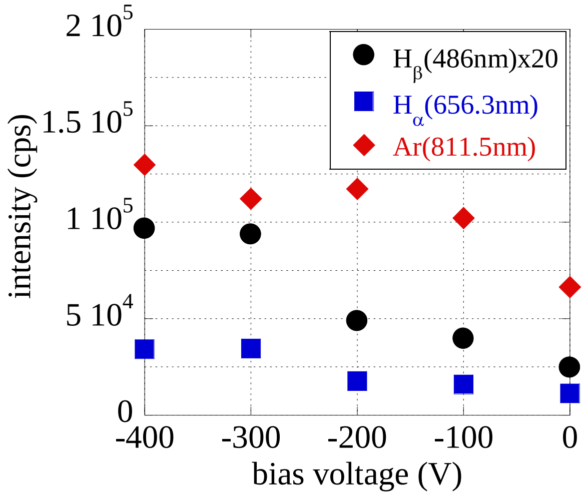

Fig. 2. Bias voltage dependence of optical emission intensities of Hβ (486nm), Hα (656.3nm), and Ar (811.5nm).
Conditions: P_H=500W, $P_m \leq$45W, C_7H_8 0.63 sccm

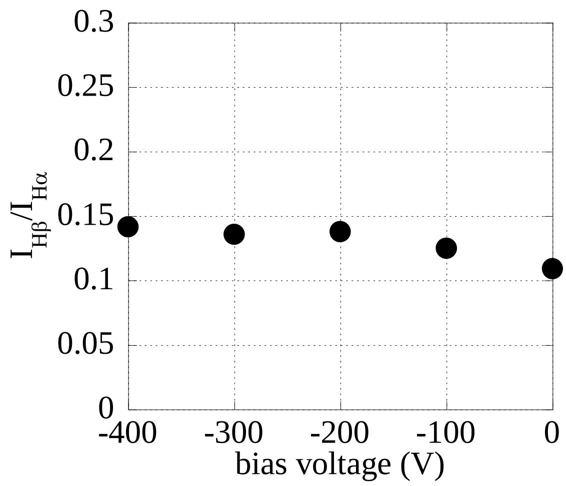

Fig. 3. Bias voltage dependence of emission intensity ratio of Hβ to Hα for $Ar+H_2+C_7H_8$ plasmas.
Conditions: P_H=500W, $P_m \leq$45W, C_7H_8 0.63 sccm

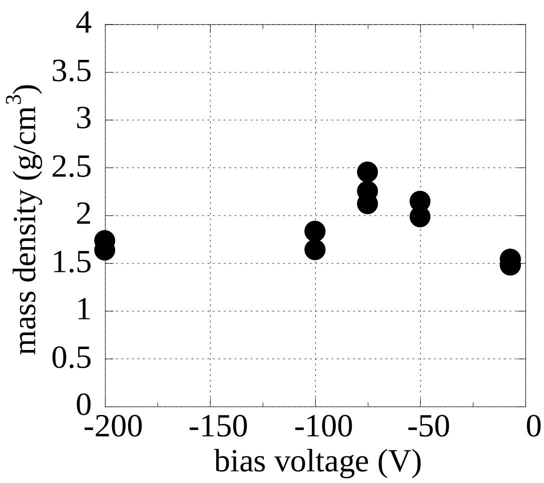

Fig. 4. Bias voltage dependence of mass density of carbon films.
Conditions: P_H=500W, $P_m \leq$45W, C_7H_8 0.63 sccm.