Effect of Filtering Duct Coil Current on the Bonding Structure of Tetrahedral Amorphous Carbon Film

Han Liang, Cui Bin and Yang Wei

ABSTRACT

Tetrahedral amorphous carbon (ta-C) films were deposited at 200 V and 500 V pulse substrate bias by adjusting the filtering duct coil current ranging from 5 A to 13 A in filtered cathodic vacuum arc (FCVA) system. The bonding structure of ta-C films is measured by visible Raman spectroscopy. The ratio of average ion current density to deposition rate decreases with the filtering duct coil current. Meanwhile, the deposition rate increases with the increment of the filtering duct coil current. The intensity ratio ID/IG of the films increases with the increment of the filtering duct coil current, which indicates the graphitization of the films concurrently increase with the filtering duct coil current.

INTRODUCTION

Tetrahedral amorphous carbon (ta-C) films deposited by a filtered cathodic vacuum arc (FCVA) have extensively studied because of its unique properties that are extreme hardness, chemical inertness, thermal stability and so on[1-3]. Meanwhile, the ta-C film is p-type with low electronic affinity as a suitable candidate for emission display applications, these properties are ascribed to the high fraction of tetrahedral hybridization (sp3 bond) in the films.

It is well known that the structure of the ta-C films strongly depend on the substrate bias [4-7]. The carbon ion with optimal energy will form the films with nearly up to 88% sp3 bonding. The carbon ions and carbon groups is selected and transported by a magnetic field which is generated by the current of magnetic filtering duct coil. Hence, the current of filtering duct coil is also an important parameter during depositing ta-C films. In this paper, the influence of the filtering duct coil current on the bonding structure of ta-C films is reported.

EXPERIMENTAL DETAILS

Two groups of 100-nm thick ta-C films with the substrate negative pulse bias of 200 V and 500 V were deposited on silicon substrates using the filtered cathodic...
vacuum arc (FCVA) system at room temperature. The FCVA deposition system employs a magnetic filtering technique to remove unwanted macro particles and neutral atoms. The samples of each group were deposited by adjusting the filtering duct coil current from 5A to 13A. The deposition chamber was evacuated to \( 1 \times 10^{-3} \text{ Pa} \) prior to deposition. The carbon plasma was generated by a dc pulse arc discharge. The arc current is 80 A. The microstructure of ta-C films was measured by visible Raman spectroscopy (514nm Jobin Yvon, France). The input power was 20mW and the sampling duration was sustained 180s. The C ion flux can be measured by Faraday cup.

RESULT AND DISCUSSIONS

Raman spectroscopy is an effective method to study the microstructure of ta-c films. Fig.1 and Fig.2 show the Raman spectra of the films deposited with different filtering duct coil current at the substrate bias of 200V and 500V, respectively. The typical Raman spectrum of ta-C film exhibits one main feature, a broad asymmetric Raman intensity distribution in the range 1100—1800cm-1. This broad peak can fitted to two Gaussian peaks[8], one around 1360cm-1 (D-peak) and the other around 1580 cm-1 (G-peak).

![Figure 1. Raman spectroscopy of ta-C films deposited at bias 200V.](image1)

![Figure 2. Raman spectroscopy of ta-C films deposited at bias 500V.](image2)

Fig.3 and Fig.4 show the Curve fitting for Raman spectroscopy of ta-C films deposited with the filtering duct coil current of 5A and 13A at the substrate bias of 200V and 500V respectively. The G mode at 1580cm-1 with E2g symmetry involves the in-plane bond-stretching vibration of any pair of sp2 sites. The D peak at 1360cm-1 is a breathing mode of A1g symmetry involving those sp2 sites only in
ring [6,9]. According to the fit method, the relative intensity ratio $I_D/I_G$ can be calculated and the results are shown in Fig.5. The relative intensity ratio $I_D/I_G$ can be used as a parameter for estimating the content of sp3. The smaller the value of $I_D/I_G$ is, the higher the sp3 content[8] is.

![Figure 3.](image.png) Curve fitting using two Gaussian line shape for the ta-C films deposited at bias 200V.

As shown in Fig.5, the ta-C films deposited at the substrate bias of 200V have lower intensity ratio $I_D/I_G$ than that of those films deposited at substrate bias of 500V, which can be explained by the sub plantation theory[10]. The intensity ratio $I_D/I_G$ of the ta-C films deposited at the substrate bias 200V increases from 0.18 to 0.39 with the increment of the filtering duct coil current increasing from 5A to 13A. The intensity ratio $I_D/I_G$ of the films deposited at the substrate bias of 500V increases from 1.3 to 2.0 with the increment of the filtering duct coil current. These results indicate that the sp3 fraction decreases gradually with the increment of the filtering duct coil current. In contrast, for the sp2 cluster, the situation is quite the reverse.

![Figure 4.](image.png) Curve fitting using two Gaussian line shape for the ta-C films deposited at bias 500V.

![Figure 5.](image.png) The relation between the intensity ratio $I_D/I_G$ and filtering duct coil current.

In our experiment, the thickness of the films is constantly kept by adjusting the deposition time because the deposition rate is different along with filtering duct coil current. The relation between deposition rate and filtering duct coil current is shown in Fig. 6. The deposition rate of the two group samples increases gradually with the increment of the filtering duct coil current. Specifically, the deposition rate
of the group samples deposited at substrate bias of 200V is less than that of the group deposited at substrate bias of 500V, and this result agrees with the results that are reported by Y.B.Zhang\[11\]. Their study showed that the films deposited at 200V may have higher density because of more sp3 site content included in the films. A film with higher density can exhibit a smaller thickness value, and consequently it indicates a lower deposition rate. The phenomenon of deposition rate increased with the filtering duct coil current can also be observed from the inspection window of the chamber. When filtering duct coil current is increased, the brightness of the ion beam at the filtering duct exit increased. The ion flux can be measured by the Faraday cup linked to an ammeter. The Faraday cup was located at the place away from the exit about 40cm.

![Figure 6. The relation between deposition rate and filtering duct coil current.](image)

![Figure 7. The relation between average ion and filtering duct coil current.](image)

The value of the ampere meter can be recorded when adjusting the filtering duct coil current at 200V and 500V substrate bias. The average value of the ion flux is shown in Fig.7. Meanwhile in our experiment, there is not much difference in the average ion current between 200V and 500V substrate bias when the filtering duct coil current was fixed, this result is also corresponding to the results that are reported by YaWei Hu[12]. The increasing coil current will increase the magnetic field density in the duct, which will reduced plasma losses to the walls due to a reduction diffusion perpendicular to field lines\[13,14\]. Hence, the ion current and deposition rate can be enhanced.

Increasing ion current density will increase the film growth on substrate. According to the stress model presented by Davis\[15\], the stress is proportional to the ratio of the incident flux \( j \) to the deposition rate \( d \) as following

\[
\sigma \propto \frac{Y}{1 - \nu} \frac{jE^{1/2}}{Nd}
\]  

(1)
Where \( E \) is ion energy, \( \dot{j} \) is incidental ion flux, \( d \) is deposition rate, \( N \) is the bulk density, \( Y \) is Yong’s modulus, \( \nu \) is the Poisson ratio. In order to qualitative analysis this results, the average ion current (\( Z \)) is substituted for the incident flux \( j \) because the incident flux \( j \) is proportional to the average ion current \( Z \). As shown in Fig. 8, The ratio of the average ion current \( Z \) to the deposition rate \( d \) decreases with the filtering duct coil current, which indicates that the stress of the films gradually decrease with the filtering duct coil current. The decrease of stress is attributed to the graphitization of the film\[16\]. As shown in Fig.5, the increasing ID/IG with the increment of the filtering duct coil current shows clustering of sp2 bonds will be increased, which release the stress of films. In addition, the higher deposition rate will produce more thermal on the substrate during the deposition\[17,18\], especially on the vacuum environment. It can increase the carbon mobility, and causes carbon atoms diffuse to the surface for graphitization.

![Figure 8](image)

*Figure 8.* The relation between the ratio of the average ion current \( Z \) to the deposition rate \( d \) and filtering duct coil current.

**CONCLUSION**

The structure of ta-C films was found to depend on the filtering duct coil current during the deposition. The ratio of average ion current density to deposition rate decrease with the filtering duct coil current. It induces the increase of sp2 cluster, which can be indentified by the intensity ratio ID/IG of the films. High deposition rate maybe induce the increase of substrate temperature, which causes the increment of sp2 cluster and graphitization of the films. Hence, the filtering duct coil current is an important parameter that should be paid more attention to deposit high quality ta-C film.

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**REFERENCE**