ATLANTIS PRESS
Advances in Intelligent Systems Research, volume 154
6th International Conference on Measurement, Instrumentation and Automation (ICMIA 2017)

The effect of the substrate bias on structure and friction coefficient of tetrahedral amorphous carbon films deposited by filtered cathodic vacuum arc

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Keywords: Tetrahedral amorphous carbon film; substrate bias; friction coefficient

Abstract. Tetrahedral amorphous carbon (ta-C) films were deposited with filtered cathodic vacuum arc by changing the substrate bias from 0V to 500V. The fraction of the sp^3 bonding will be effected by the substrate bias, and the sp^3 fraction is about 85% when the substrate bias is -200V. The RMS of the films decreases with the increment of the substrate bias,the surface of the film deposited at the substrate bias -200V is smoothest, and the RMS is about 0.18 nm.When the substrate bias is 0V, the friction coefficient is the highest and the antiwear ability is poor; when the substrate bias is increased from 0V, the friction coefficient decreases with the increment of the substrate bias and the antiwear ability of the films is improved because of the lower RMS and the self- Lubrication.

Introduction

Tetrahedral amorphous (ta-C) film has a very high sp^3 bond content, with similar characteristics of natural diamond, it has a wide range of applications [1~3]. ta-C film not only has a very high hardness, but also has a good lubrication characteristics [4], which can be used to decrease the friction of the moving parts in the mechanical and aerospace areas, improve the wear resistance, corrosion resistance and so on. At present, the researches on tribological properties of ta-C films are mainly focused on the influence of friction conditions and friction environment on it. However, the effect of bond structure on the friction coefficient of ta-C film has been reported less.

Therefore, in this paper, ta-C thin films were fabricated by S-bend magnetic filter cathode technology. By analyzing the change of the sp^3 content of ta-C film and the surface morphology with the substrate bias, the effect of substrate bias on the structure and friction coefficient of the film has been studied. It is very important for the preparation of ta-C thin films by optimizing the magnetic filter cathode technology in practical industrial applications, which makes the films have stable and good tribological properties.

Experiment

The ta-C film was prepared by magnetic cathodic vacuum arc arc technique. The cathode was made of graphite with purity of 99.99%. The magnetic filter was s-type with double elbow, and the substrate material was monocrystalline silicon sheet with has been single-sided polished. Before the film deposition, the substrate was washed with absolute ethanol and acetone for 15 minutes, dried and placed in a vacuum chamber. The background pressure of the vacuum chamber is reduced to the order of 10-3Pa. First, argon ions are used to bombard the surface of the substrate , the flow rate of argon is 20sccm, and the beam is 20mA. The surface treatment is carried out for about 15min. The substrate is pre-sputtered with argon ions in order to remove the oxide layer on the surface of the silicon wafer, increasing the adhesion of the film to the substrate. After the argon ion bombardment, the ta-C film was deposited. Graphite target arc discharge current 90A, and maintain the magnetic filter current unchanged, the substrate applied negative bias 0V, 120V, 200V, 500V respectively during the preparation of ta-C film. The film thickness is 100nm. The structure of the film was analyzed by Jobin Yvon Raman spectrometer, and the wavelength was 514nm and the laser input power was 20mW. The friction coefficient is tested by WTM-2E miniature friction-and-wear tester. The test data includes real-time friction coefficient, average friction coefficient, ball-disc type, dual friction material is GCr15 steel ball with diameter of 4mm, test load of 2N, speed of 800r / Min, the radius of rotation is 4mm. When the antifrction of the film fails, the friction coefficient will be abrupt. The surface morphology of the films was observed by atomic force microscopy.

Result and Disscussion

1 Effect of Substrate Bias on the Structure of ta-C Thin Films

The Raman spectras of the ta-C film samples prepared at different substrate bias are shown in Fig. 1, and the acquisition interval of the Raman spectra is from 700 cm^{-1} to 2000 cm^{-1}. For the ta-C films deposited at 0V, 120V, 200V, the Raman spectra show a narrow peak near 950cm^{-1} and an asymmetry peak in the frequency range of 1100cm^{-1} ~ 1800cm^{-1}. A narrow peak near 950 cm^{-1} is the second-order scattering peak of the Si substrate [5], which is often used to measure the degree of transparency of the ta-C film. Generally for the same thickness, the higher the degree of transparency is, The higher the sp^3 bond is in the film [6]. However, at 500V bias, the second-order scattering peak intensity is zero, which indicates that the film has a lower degree of transparency and sp^3 bond in the film compared with others. The asymmetric broadening in the frequency range of 1100cm^{-1} ~ 1800cm^{-1} is due to the excitation of the sp^2 hybrid carbon atoms in the film. The sp^3 bond can be observed indirectly by detecting the change of sp^2 bond Changes.

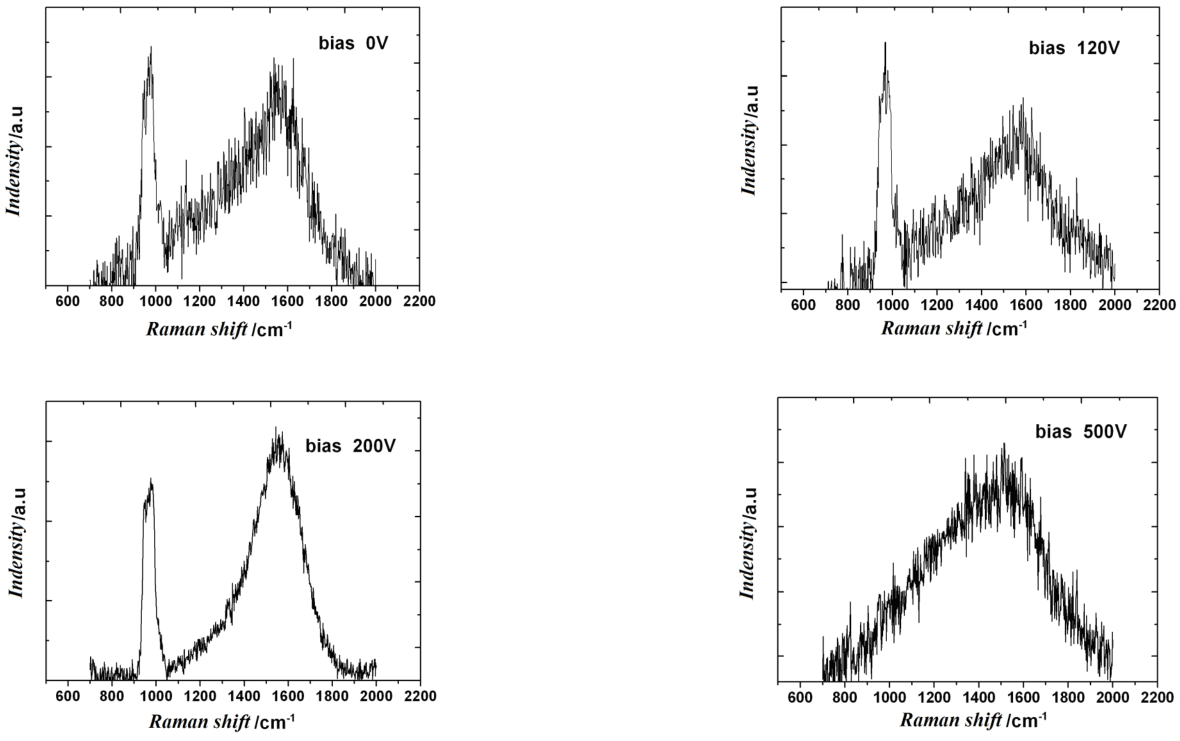

Fig. 1 Raman spectrum analysis for ta-C films deposited at different bias

In order to analyze the Raman spectra, two gaussian peaks can be used to fit the asymmetric broad spectrum in the frequency range of 1100 cm^{-1} to 1800 cm^{-1} [7]. One of the peaks is located at 1360 cm^{-1} and is usually defined as the D-peak [8], which is generated by the respiratory vibration pattern of the sp^2 bond in the ring-like nanocrystalline graphite clusters in the film. The other peak is at 1580 cm^{-1}, which is generated by the stretching vibration mode of all sp^2 bonds of the film, defined as G-peak [8]. The relative intensity ratio (I_D / I_G) of the D peak and the G peak can be used to characterize the sp^3 bond content and sp^2 bond content of the film and the size of the cluster size. The correspondence between I_D / I_G and the content of sp^3 bond in Raman spectrum has been obtained by comparing Raman spectrum and low energy electron loss spectroscopy (EELS) of ta-C thin films[7]. If the value of I_D / I_G in the film is smaller, the higher the sp^3 bond content of the film is.

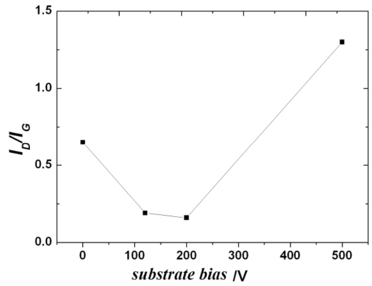

Fig.2 The relation between I_D/I_G and substrate bias

The film I_D / I_G value can be calculated by Gaussian peak fitting and its relationship with the deposition bias is shown in Figure 2. It can be seen that the I_D / I_G value of the ta-C film is about 0.65 at the deposition bias of 0 V; when the deposition bias is increased to 120 V, the I_D / I_G value of the ta-C film About 0.19, which shows that sp^3 bond content is increasing with the increase of deposition bias. When the deposition bias continues to increase to 200V, the I_D / I_G value is about 0.15, the sp3 bond content of the ta-C film is about 85% according to the reference [7]; when the deposition bias is 500V, the I_D / I_G value of the ta-C film increases to 1.3, indicating that the film in the sp3 bond content greatly is reduced. It is clear that the substrate bias is an extremely important deposition process parameter for ta-C film with high sp^3 bond content. This mechnism of deposition has been explained well by The sub implantation model [9]. The results show that the optimum deposition bias window should be around 200V.

2 Effect of Substrate Bias on Surface Morphology of ta-C Films

Atomic force microscopy was used to observe the surface morphology of ta-C films prepared under different substrate bias conditions. The observation area of atomic force microscopy was 1 μm × 1 μm. The RMS value of the surface roughness varies with the substrate bias as shown in Fig. 3. The results show that when the substrate bias voltage is within the optimum deposition window bias (around 200V), the film has a small surface roughness of about 0.18; when the substrate bias deviates from the optimum deposition window bias, the film surface roughness And the sp^3 bond has a small surface roughness, which is consistent with the results of Lifshize [10] and Shi [11].

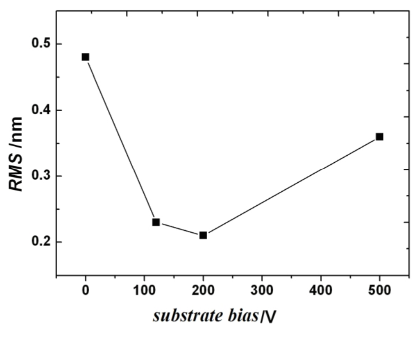

Fig.3 The relation between RMS and substarte bias

3 Effect of Substrate Bias on Friction Coefficient of ta-C Films

The ta-C film prepared under different substrate bias was tested by ball wear test. The test results are shown in Fig 4. When the substrate bias is 0V, the roughness of the film is large, so the coefficient of friction coefficient of the film is large, and at this time the deposition of carbon ion energy is very low, the substrate bombardment effect is weak, so The adhesion between film and substrate is so poor that it reduces the wear resistance of the film. It shows that the film failures when the number of friction cycles is more than 20,000. The substrate has a high sp^3 bond content, the surface of the film is dense, and the surface roughness is small. Therefore, the film has a smallest coefficient of friction when a substrate bias voltage of 200 V has been applied. The average coefficient of friction is about 0.08 or so. Although the film surface roughness at bias 500V is more than that of 120V, 200V, the friction coefficient is not obvious change. That is because the film has more sp^2 bond content when the substrate bias 500V is applied, which will cause the formation of self-lubricating effect in the process of friction test[12]. So the film friction coefficient is also small and wear resistance is also better.

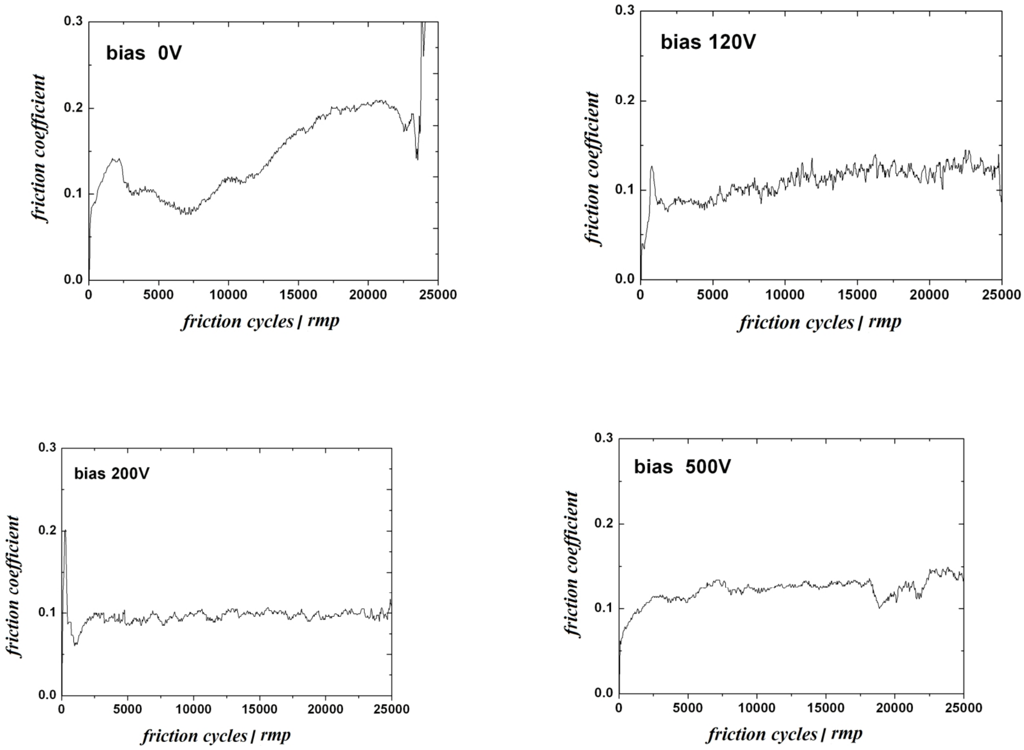

Fig.4 Friction coefficient of ta-C films at different bias

Conclusion

In this paper, ta-C films were prepared by magnetic filter cathode technique under different substrate bias conditions. The effects of substrate bias on the structure and tribological properties of ta-C films were studied. The following conclusions were obtained:

1. Substrate bias has a great influence on the sp^3 bond content of ta-C film. ta-C film with sp^3 bond content of 85% is prepared when the substrate bias is negative 200V.

2. The surface roughness of the film is the largest at 0V bias, and the surface roughness decreases with the increase of the substrate bias. But when the bias voltage is more than the optimum substrate bias, the surface roughness of the film is also increased.

3. When the substrate bias is 0V, the friction coefficient of the film is large and the wear resistance is very poor. When the substrate bias is gradually increased from 0V, friction coefficient of the film will be greatly reduced and the wear resistance is improved due to the decrease of the surface roughness of the film and the self-lubrication of the graphite in the frictionthe.

Acknowledgements

This work was financially supported by the Fundamental Research Funds for the Central Universities（JB160502）.

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