ASIATRIB 2002International Conference
JEJU ISLAND, KOREA

Effect of Humidity on Tribological Behavior of Si-DLC/DLC Multi-layer

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To investigate the humidity effect on tribological behaviors of Si-DLC/DLC multi-layers, the samples were prepared using a hybrid system consisted of an ion-gun for deposition DLC films and a balanced magnetron sputter for introducing silicon atoms to Si-DLC films. The Si-DLC/DLC multi-layers were composed of pure DLC films and Si-incorporated DLC films alternatively and had different bilayer numbers. Hardness and residual stress were drastically decreased through the formation of Si-DLC/DLC multi-layers compared to those of the pure and Si-incorporated DLC films. Wear results obtained under the various humidity conditions (<10 %, 40~50 %, and >85 %) showed that the pure DLC film was largely depended on the humidity while the Si-DLC and the Si-DLC/DLC multi-layers were little affected by the environmental humidity. Although friction coefficients of all samples were increased with the relative humidity, the multi-layer films showed relatively lower friction coefficients than those of the single films.

Keywords : Wear, Friction, Diamond-like Carbon, Multi-layer, Humidity

1. Introduction

Diamond-like carbon (DLC) films are of considerable research interests because of their widespread applications as protective coatings in areas such as optical windows, magnetic storage disks, car parts, biomedical coatings and as micro-electromechanical devices (MEMs) [1-5].

Although DLC films have been considered as a strong candidate for low friction wear-resistant coatings, it is well known that some problems, such as high residual stress and fragility on the moisture, are still remained for DLC films to be used as protective coating applications. In order to overcome these drawbacks, some ideas were introduced such as the deposition of metals incorporated DLC films [6,7] and the formation of Me-DLC/DLC multi-layers [8]. Okuri and Arai reported that they could obtain Si incorporated DLC (Si-DLC) films having low friction coefficients around 0.05, which were not affected by the various test environments [7]. But these Si-DLC films showed poor wear resistance. It was also reported that the properties of DLC films could be improved by means of the Si-DLC/DLC multi-layered films showing a low residual stress level and a similar wear resistance to DLC films [8].

In this work, we investigated the tribological behaviors of Si-DLC/DLC multi-layer films having different layer numbers under various environments, especially relative humidity. In the Si-DLC films, a small amount of 0.5 at.% Si was incorporated to the Si-DLC films. It was shown that the hardness and residual stress were quite depended on layer numbers of Si-DLC/DLC multi-layer films while the tribological behaviors showing improved properties for the multi-layer samples were little affected by layer numbers.

2. Experimental details

DLC, Si incorporated Si-DLC, and Si-DLC/DLC multi-layer films were deposited on (100) Si wafers using a Hybrid coating system (Fig.1), which was equipped with an ion-gun for DLC films and a DC magnetron sputtering for incorporating Si atoms to Si-DLC films. The substrates were ultrasonically cleaned in acetone and dried with N_2 gas blowing. After introducing the substrates, the chamber was preheated up to 120 °C and then evacuated up to less than $2x10^{-6}$ Torr. Subsequently, we cleaned the substrates by argon ion bombarding with a substrate bias of –600 V for 30 minutes to remove the surface native oxide. Before Si-DLC/DLC films were deposited, interlayers of Si and Si+C had been pre-deposited with substrate bias of –200V to enhance the adhesion between the Si substrate and the deposited films. Samples were prepared with using C_2H_2 + Ar mixed gases and silicon source of magnetron sputtering. The Si-DLC/DLC multi-layers were deposited with alternative sequences of pure DLC films and Si-incorporated DLC films. And the multi-layers were prepared with the different bilayer numbers (set numbers of DLC and Si-DLC) from one to ten and this process was controlled by varying the each deposition time. The total thickness of the samples was fixed around 500 nm.

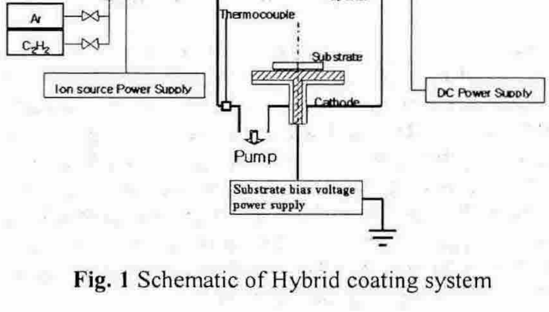

Fig. 1 Schematic of Hybrid coating system

The thickness was measured by atomic force microscope (AFM). The hardness of the films was assessed using a nano indentation method. The stress in the deposited films was measured and calculated from the radii of curvature of the silicon strips of 100 ㎛ in thickness before and after deposition using well known Stoney's equation.

In order to study tribological properties, such as friction coefficient and wear behaviors of the samples, under different relative humidity conditions (<10 %, 40~50 % and >85 %), we used a ball-on-disk type tribometer (2 N and 1 ㎧). A sample was adhered on a plate and rotated against a stationary ruby ball

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(3 ㎜ in diameter). Friction coefficient was automatically obtained using a PC interface system. Wear rates of the samples were calculated after measuring the worn-out volume of the wear track. For every wear track of specimens, laser microscope images were taken.

3. Results and discussion

Rutherford backscattering spectroscopy (RBS) analysis of ten set Si-DLC/DLC showed that coated film was incorporated 0.5 at.% of Si, which is not shown here. Results of other films RBS analysis showed similar content (~ 0.5 at.% Si) of Si in all Si-incorporated samples.

Figure 2 shows (a) the micro-hardness and (b) residual stress of DLC, Si-DLC, and Si-DLC/DLC multi-layer samples were measured by nano-indentation and stress measurement system, respectively. The results show that the hardness value (~30 GPa) of the Si-DLC film decrease a little regarding to that of DLC film (~35 GPa), while the residual stress (~2.5 GPa) of the Si-DLC decrease drastically with respect to that of DLC film (~4.34 GPa). It is thought that the carbon networks are slightly weakened and these networks play a role of stress absorption by means of incorporating Si atoms to DLC film. However, it is quite questionable and required further works why the 10-set multi-layer film has noticeably lower hardness and stress level than those of the Si-DLC.

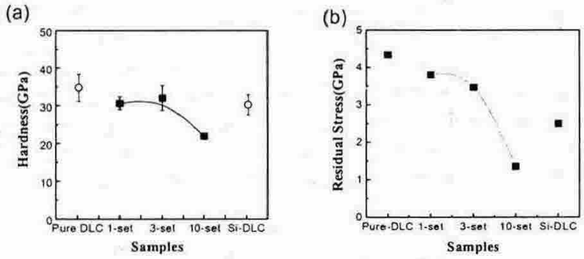

Fig. 2 (a) Hardness and (b) residual stress of DLC, Si-DLC, and Si-DLC/DLC multi-layered films

Figure 3 shows the effects of the humidity on the friction coefficients of the different samples. The friction coefficients of all samples increased drastically at the mild humidity of 40~50 % compared to the low humidity and was saturated at the high humidity. It is also well observed that the single films, such as DLC and Si-DLC, are largely depended on the moisture, while the multi-layer films shows lower friction coefficients and are less affected by the humidity with increase of the layer numbers. It is thought that the formation of silicon oxide during the tribology test acts as a lubricant [9].

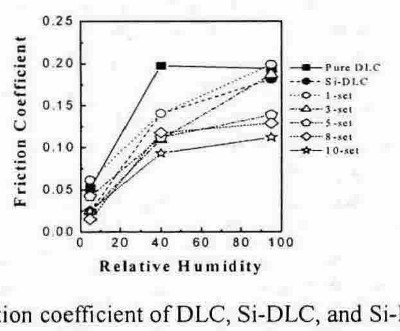

Fig. 3 Friction coefficient of DLC, Si-DLC, and Si-DLC/DLC multi-layered films under various humidity conditions

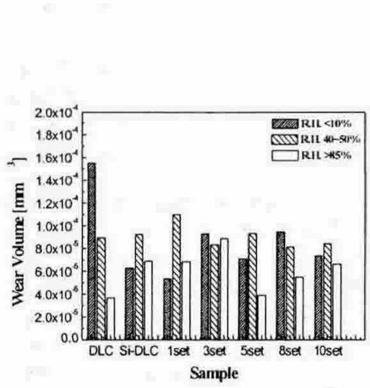

Fig. 4 Wear rates of DLC, Si-DLC, and Si-DLC/DLC multi-layered films under various humidity conditions

The dependency of wear rates on the humidity is also investigated by measuring the worn-out volume of the wear track formed on the specimens after the tribological test, as shown in Fig. 4. This shows that the wear rates of the pure DLC film decrease linearly with increase of the humidity, whereas the Si-contained samples show erratic dependency on the moisture and are less worn out at low humidity than the DLC.

4. Conclusion

We investigated the mechanical properties and tribological behaviors of 0.5 at.% Si incorporated Si-DLC/DLC multi-layer films having different layer numbers under various humidity conditions (<10 %, 40~50 %, and >85 %). The hardness and residual stress were quite depended on layer numbers of Si-DLC/DLC multi-layer films while the tribological behaviors showing improved properties for the multi-layer samples were little affected by layer numbers. Although friction coefficients of all samples were increased with the relative humidity, the multi-layer films showed relatively lower friction coefficients than those of the single films. Wear results showed that the pure DLC film was largely depended on the humidity while the Si-DLC and the Si-DLC/DLC multi-layers were little affected by the environmental humidity.

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