Structure and Microtribological Mechanism of Teflon Deposited Film

Jihui WANG†, *Xinchun LU*, *Shizhu WEN and Hengde LI*
State Key Laboratory of Tribology, Tsinghua University, Beijing 100084, China
Liduo WANG
Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Hong Kong
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Teflon film was prepared by ion beam enhanced deposition method. The structure and microtribological properties were studied by PHI-5300, FT-IR, XRD and atomic force and friction force microscope (AFM/ FFM). The results show that the deposited Teflon is in crystalline state, and its structure is the same as the bulk Teflon. There are two periods in the friction and wear tests for Teflon film. When the load is less than 70 nN, the micro friction force is linear with the load, and the Teflon does not have the lubricity. But when the load is greater than 70 nN, the friction force of Teflon film will stay nearly constant, and worn marks will be created in the friction and wear process. The worn depth of Teflon film increases linearly with the load.

1. Introduction

Polytetrafluoroethylene (PTFE) is widely used as solid lubricant and the component of composite plating or multilayer film in the low friction materials designing. In the composite plating[1] and multilayer film[2], Teflon is in the form of ultra-fine particles or thin layer. Because the properties of these low dimensional materials are different from their bulk states, it is very urgent to reveal the properties of these low dimensional materials, and then develop new materials with high specific performance.

In 1995, the friction force microscope (AFM/ FFM) was developed based on the atomic force microscope by State Key Laboratory of Tribology cooperated with the Institute of Chemistry, Chinese Academy of Sciences, and then the analysis and measurement for the AFM/FFM image were made[3]. So the microtribological properties of materials in nano scale can be investigated[4]. With the development of microtribology, it is possible to reveal the microtribological mechanism and build up the relationship between the micro tribology and macro tribology. In this paper, the Teflon film was prepared by the ion beam assisted deposition method, and the structure, microtribological properties were measured by AFM/FFM. The relationship between the microtribological mechanism and the structure was discussed.

2. Experimental Procedures

Sample preparation: The sample preparation process was carried out by ion beam assisted deposition system. The Teflon film was prepared by Ar^+ ion beam sputtering pure Teflon target. Si (100) wafer was used as the substrate. In the sputtering process, the base pressure was 1.3×10^{-3} Pa, sputtering energy was 1.5 keV, sputtering ion current was 30~40 mA, pressure of Ar^+ was 5.3×10^{-3} Pa, pressure for deposition was $1.3\times10^{-3}\sim1.7\times10^{-3}$ Pa, deposition temperature is 25°C, the sputtering time was 60 min. The thickness of Teflon film was about 820 nm.

Structure analysis: The chemical bonding structure and phase composition were determined by PHI-5300 X-rays photoelectron spectrum, FT-IR2000 infrared absorption spectrum and X-ray diffraction apparatus.

Micro friction and micro wear: The microtribological behavior was carried out in CSPM-930A atomic force and friction force microscope (AFM/FFM), the normal spring constant of Si_3N_4 cantilever (scanning tip) was 0.38 N/m. During the micro friction test, the Si_3N_4 tip moved back and forth on the sample surface in the Y direction at a given load (normal force), *i.e.* the counterpart of the Teflon sample in the friction and wear process was Si_3N_4 tip. The silicon nitride cantilever was square pyramidal with a tip radius of about 50 nm produced by plasma-enhanced chemical vapor deposition method (PECVD), and the detail schematics of the cantilever can be found in literature [5]. The normal force and friction signals were respectively recorded by upper and lower halves, left and right halves of the quadrant photo diode. The friction force signal value was the half of the difference between the average $+Y$ (scanning in positive Y di-

† To whom correspondence should be addressed

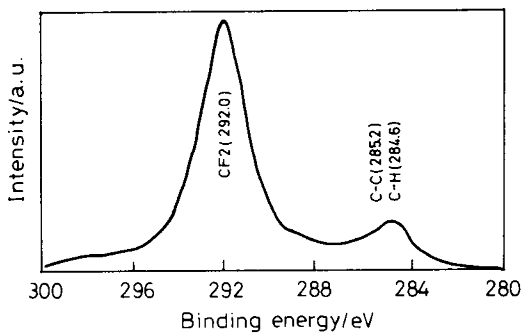

Fig.1 Cls spectrum of the deposited Teflon film

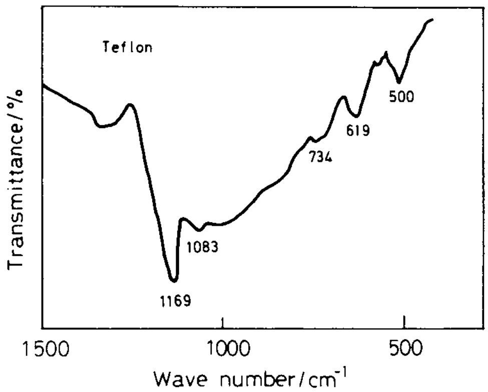

Fig.2 Infrared absorption spectrum of Teflon film

rection) and -Y (scanning in negative Y direction) friction signals. For wear, the cantilever scanned for 50 times in the area 1 μm$\times$1 μm along the X direction at a given load, and then measured the worn surface morphology in the area 2 μm$\times$2 μm. The worn depth can be calculated through measuring the difference between the worn area and initial area which was not worn.

3. Results

3.1 Structure

Figure 1 is the X-ray photoelectron spectrum of Teflon film. It can be seen that there is a high crest in 292.0 eV, and a low crest near 285.0 eV. Quaranta[6] and d'Agostino[7] have measured the binding energy of six components in fluorinated environment: CF_3 (294.0±0.1 eV), CF_2 (292.0±0.1 eV), CF (289.7±0.2 eV), C-CF (287.4±0.2 eV), C-C (285.0±0.2 eV), C-H (284.6 eV). By comparing these results, it can be concluded that Teflon film consists of CF_2 (292.0±0.1 eV) and a small amount of C-C (285.0±0.2 eV) and C-H (284.6±0.20 eV).

Figure 2 is the infrared absorption spectrum of Teflon film. It is seen that there are not only the strongest C-F absorption peaks near 1169 cm^{-1} and 1083 cm^{-1} but also characteristic peaks near

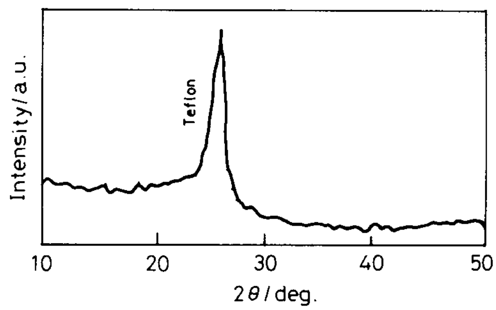

Fig.3 X-ray diffraction pattern of Teflon film

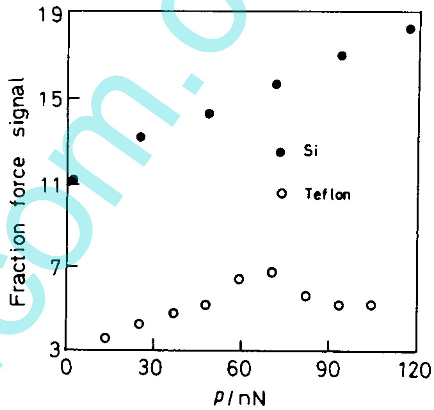

Fig.4 Dependence of friction force of Teflon film and Si(100) on load

734 cm^{-1}, 619 cm^{-1} and 500 cm^{-1}. All these show that Teflon film has the characteristic structure of PTFE.

The X-ray diffraction pattern of Teflon film is shown in Fig.3. From the figure, it is observed that Teflon film is in crystalline state, not in the amorphous state. So it is proved from the above results that Teflon film is in crystalline state, and the structure of Teflon film is the same as the bulk Teflon.

3.2 Micro friction behavior

In order to quantify the micro friction behavior of Teflon film, single crystalline Si (100) specimen was used as the reference. Figure 4 is the dependence of micro friction force signal of Teflon film and Si (100) on load. For Si (100), the micro friction force almost increases linearly with load. Through the linear regression, the following relationship can be obtained:

$$f = 0.061p + 11.457 \qquad \text{Si(100)}$$

As for Teflon film, when the load is less than 70nN, the micro friction force signal increases linearly with the load:

$$f = 0.057p + 2.78 \qquad \text{Teflon}$$

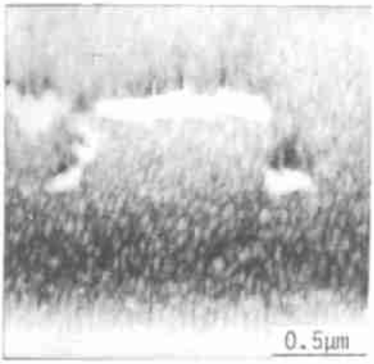

Fig.5 Morphology of Teflon film after the friction at 116 nN load and 10 cycles (2 μm×2 μm)

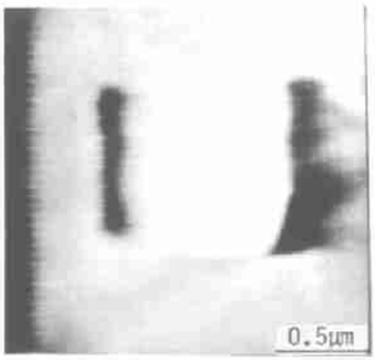

Fig.6 Worn morphology of Teflon under 110 nN load and 50 cycles (2 μm×2 μm)

But when the load is greater than 70 nN, the micro friction force signal does not increase with the load, the friction force almost keeps constant. Through the observation of the surface morphology after micro friction process when the load is above 70 nN, it is found that there is an obvious worn mark and projection in the edge of worn mark in Teflon film (Fig.5). As to Si (100), there is no observed worn mark under the maximum load after the micro friction test.

According to the characteristics of microtribology[8], the slope of micro friction signal with the load can be thought as the representatives of micro friction coefficient[4], and the intercept of micro friction signal with the load can be regarded as the representatives of sample surface adhesion[9]. From the above formula, two periods can be classified for the micro friction process of Teflon film: 1) at the load under 70 nN, micro friction coefficient of Teflon film is almost equal to the friction coefficient of single crystalline silicon, *i.e.* Teflon does not have the lubricity, and there is no micro worn mark after the friction test; 2) at the load above 70 nN, micro friction force of Teflon film almost keeps constant in the friction test, and there is an obvious worn track after micro friction test. From the intercept of micro friction signal with

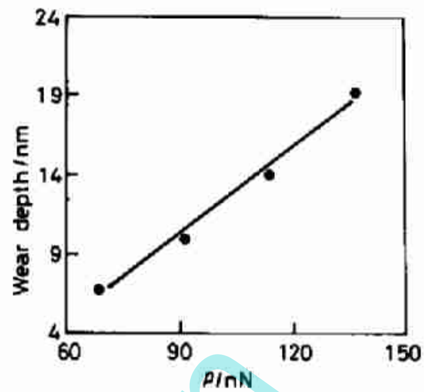

Fig.7 Dependence of worn depth of Teflon film on load

the load, it can be observed that adhesion of Teflon film is less than that of single crystalline silicon, *i.e.* Teflon has high anti-adherence.

3.3 Micro wear

Regarding the fact that wear could occur in the friction process of Teflon film at the load above 70 nN, wear test of Teflon film was carried out. The experimental results show that worn marks can not be found at the load under 70 nN and 50 cycles of scanning, but when the load is higher than 70 nN, there is an obvious worn tracks on the surface of Teflon film. Figure 6 is the surface topography of Teflon film after wear test at 110 nN and 50 cycles of scanning in the area of 1 μm×1 μm. It is seen that there is a deep worn mark on the Teflon film. The dependence of worn depth of Teflon film on the load is shown in Fig.7. The worn depth of Teflon film is also in nano scale, and the worn depth Teflon film increases linearly with the load.

4. Discussion

The molecular structure of Teflon is the zigzag backbone or rod-like of -CF_2-CF_2- groups that gradually twists through 180° over a distance corresponding to 13 CF_2 groups. The Teflon molecule exhibits extremely high cohesion, but the intermolecular strength is not high because there is Van der Waals force between molecules, so the Teflon with rod-like molecules is very easy to slip under the shear stress. In the friction process, the wear resistance of Teflon is very low since the Teflon has low adhesion, high lubricity and low friction coefficient[10].

During the friction and wear tests, two periods can be classified according to the load. One is the load below 70 nN, the friction force created in friction and wear tests is too small to make the Teflon film shear. So in this period the friction force increases linearly with the load, and there are no transfer of atoms and no worn marks. The second period is the load above 70 nN, the friction force created in the friction and wear tests would make the Teflon molecular atom slip. So there would be an obvious worn mark and projection in the film, and the friction force would not increase with the load.

5 Conclusions

(1) The deposited Teflon is in the crystalline state, and the structure of Teflon film is the same as its bulk state.

(2) There are two periods in the friction and wear tests for Teflon film. When the load is less than 70 nN, the micro friction force is linear with the load. the micro friction coefficient of Teflon film is almost equal to the friction coefficient of single crystalline silicon, *i.e.* Teflon does not have the lubricity. But when the load is greater than 70 nN, the friction force of Teflon film stays nearly constant, and worn marks are created in the friction and wear process. The worn depth increases linearly with the load.

Acknowledgement

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