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Effect of dielectric barrier discharge treatment on tribological and surface properties of DLC coating with various nitrogen contents

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1. Introduction

Diamond-like carbon (DLC) is a fascinating material as a solid lubricant, and its hybridization of sp^2 and sp^3 provides anti-friction and wear-resistance characteristics due to its bonding structures. Recent studies have reported improved DLC tribological properties, biocompatibility, and mechanical properties through surface modification. Plasma irradiation is widely studied and used. Plasma irradiation modification technology, through plasma treatment, achieves targeted control of material surface properties, offering advantages such as environmental compatibility, high processing efficiency, broad material applicability, and precise controllability. This technique effectively introduces surface functional groups without altering the material's bulk properties, enhancing hydrophilicity, adhesion, and biocompatibility. Kim et al. showed that using oxygen plasma irradiation can reduce the running-in cycles and friction coefficient of *ta*-C coating [1]. In recent years, surface modification by plasma irradiation in atmospheric environments has received more attention. Dielectric barrier discharge (DBD) is one of them. DBD is a non-thermal plasma technique that effectively induces cross-linking on the surface of a material, introducing chemical functional groups and active substances [2,3]. In a previous study, a surface treatment method using DBD for DLC coatings was developed [4]. The results showed that DBD irradiation caused the friction coefficient of nitrogen-doped DLC to decrease from 0.33 to 0.02-0.008. The main purpose of this study is to investigate the effect of DBD irradiation on *ta*-CN_x coatings with various nitrogen contents.

2. Experimental

The tribological properties of the *ta*-CN_x coating under in situ DBD irradiation were evaluated using a ball-on-disk tribometer. A disk coated with *ta*-CN_x and a silicon nitride (Si_3N_4, 8 mm in diameter) ball were used as tribo-pair. Figure 1 shows a schematic of the tribometer. The friction test used a normal load of 0.98 N and a sliding speed of 50 mm/s (rotating diameter of 12 mm). The DBD part is shown in Fig. 1 (b). A high-frequency power supply (PSI-PG1040F, PSI, Japan) was connected to one end of a cylindrical aluminum electrode, and the other end of the electrode was covered with a glass sheet of about 150 μm in thickness to act as a dielectric to prevent arc discharge or spark discharge. Another wire from the high-frequency power supply was connected to the bottom of the rotary table, and the disk coated with *ta*-CN_x was placed on the rotary table. Finally, a high voltage alternating current of 3.5 kV, 4.0 kHz was applied between the aluminum electrode and the disk. The gap between the glass sheet and the disk was 350 μm.

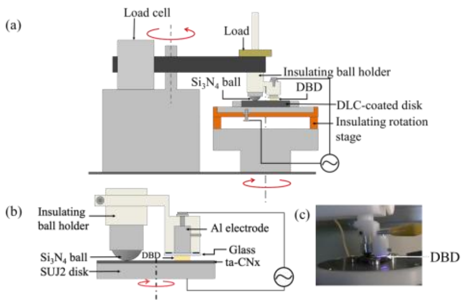

Fig. 1 (a) Schematic diagram of the ball on-disk ball tribometer, (b) Enlarged view of the DBD part of the system, (c) Photographs of the DBD between the DLC-coated and glass plate-covered electrodes

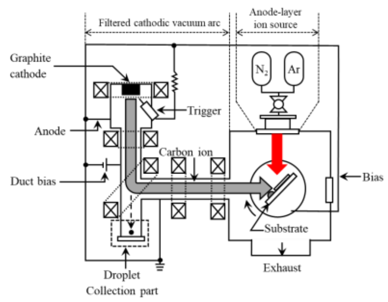

Fig. 2 Schematic of hybrid coating system equipped with an anode-layer ion source and filtered cathodic vacuum arc source

Table 1 Characteristics of *ta*-CN_x coatings with various nitrogen contents

Sample name	N/C atomic ratio	Hardness *H*, GPa	Young's modulus, GPa	Thickness *T*, nm	Roughness *Ra*, nm	I_D/I_G ratio
ta-CN_5	5.10%	53.59 ± 4.09	532.21 ± 38.97	639.50 ± 10.20	5.53 ± 1.18	0.25
ta-CN_{15}	8.90%	33.98 ± 3.98	396.03 ± 55.50	678.80 ± 13.20	5.42 ± 1.09	0.57
ta-CN_{20}	12.50%	17.72 ± 1.17	190.93 ± 6.14	621.50 ± 16.30	5.07 ± 0.46	0.86

The ta-CN_x coating deposition process is as follows, and a hybrid coating system with an anode-layer ion source (ALIS) and filtered cathodic vacuum arc (FCVA) was used (Fig. 2). The carbon target was discharged with an arc current of 50 A, and the carbon ions were accelerated under a substrate bias of -50 V. The nitrogen flow rate was 5, 15, 20 sccm. The characteristics of ta-CN_x coatings with different nitrogen contents are shown in Table 1.

3. Results and Discussion

To elucidate the effect of DBD in-situ irradiation on the friction coefficient of ta-CNx with various nitrogen contents, friction tests were conducted using three coatings with various nitrogen contents, and the results are shown in Fig. 3. where the numbers indicate the amount of nitrogen introduced during deposition. As shown in Fig. 1, the friction coefficient of ta-CN_5 decreases to a minimum of 0.18, the friction coefficient of ta-CN_{15} decreases to 0.12, and the friction coefficient of ta-CN_{20} decreases to 0.01 when in-situ DBD irradiated. The results indicate that the friction coefficient is related to the nitrogen content in the ta-CN_x coating and decreases as the nitrogen content increases. To further analyze the cause of the different friction coefficients, the wear tracks were analyzed using Raman, and the results are shown in Fig. 4. The results show that ta-CN_x coatings with high nitrogen content show obvious D peaks, G peaks as well as 2D peaks and D+D' peaks after DBD irradiation, indicating the appearance of Raman vibrational peaks of graphitic carbon.

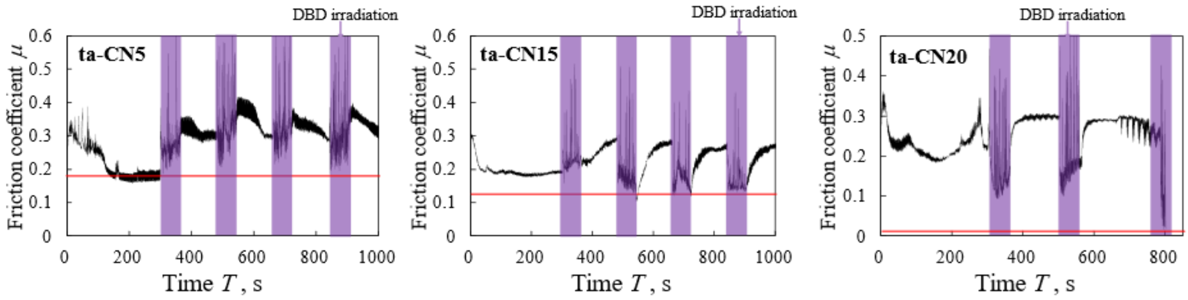

Fig. 3 Friction evolution of ta-CNx coatings with different nitrogen contents during DBD in-situ irradiation

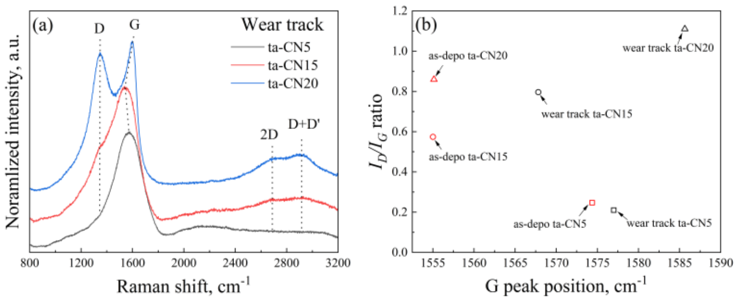

Fig. 4 (a) Raman spectroscopy of wear track, (b) G peak position and ID/IG ratio

4. Conclusion

In this study, the effect of in-situ DBD on the friction coefficient of ta-CN_x coating various nitrogen contents was investigated. The results show that the friction coefficient decreases with increasing nitrogen content. The surface analysis showed that the different friction coefficients were related to the formation of a graphite layer on the surface.

References

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