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Tribological behaviors of W-doped DLC films

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Abstract. W-doped DLC films were synthesized from CH_4 and W by ion beam deposition and magnetron sputtering, and the influence of W target current on the surface morphology and the mechanical properties of W-doped DLC films deposited were studied. The W-doped DLC films in the study have a smooth dense surface with several particles of about 2micron. The hardness, the modulus, and the film-substrate adhesion of the films are increased with the rise of W target current and the critical load of the scratch test for all the W-doped DLC films is above 70N. The friction coefficient of W-doped DLC films is increased with the increase of W target current while the lowest wear rate is obtained when W target current is 1A.

Introduction

Diamond-like Carbon (DLC) films have been widely used as the protection coatings on machinery parts, cutting blades, and moulds for their high hardness and high wear resistance [1-2]. But the poor adhesion between DLC films and their substrates is a crucial factor for the application of DLC films under severe service conditions, so much efforts have been attached to the technology for the further improvement of the film-substrate adhesion by depositing a gradual transition layer prior to DLC films synthesis [3], introducing metal elements into pure DLC films [4-6], and adopting the multilayered structure [7], and et al. The introduction of metal elements into pure DLC films is a fascinating method to improve the tribological properties of DLC films for it can greatly reduce the difference at the film/metal interface and the residual stress in the films. W-doped DLC films show the excellent performance including a low wear rate and a high load capacity [8], which makes them an ideal wear resistant coating on metal workpiece. Mastering the influence of the deposition parameters on the tribological properties of W-doped DLC films is very important for their applications. In the present paper, W-doped DLC films were synthesized from CH_4 and W by ion beam deposition and magnetron sputtering, and the correlations between W target current and the tribological behaviors of W-doped DLC films were studied.

Experimentation

W-doped DLC films were synthesized by the decomposition of hydrocarbon ion produced using an anode layer ion source and W deposition by direct current magnetron sputtering. Argon with a purity of 99.99% and methane with a purity of 99.99% were feed into the vacuum chamber through an anode layer ion source and the operation parameters of the ion source were determined on the basis of the deposition experience of pure DLC films. The W content in the films was controlled by adjusting the sputtered W target current from 0-5A. After the substrates of 316 stainless steel were cleaned by argon ion bombardment, a gradual transition layer was deposition before the synthesis of W-doped DLC films in order to further improve the adhesion between the films and their substrates. The total thickness of W-doped DLC films was controlled at about 2.3micron.

The surface morphology of W-doped DLC films was observed using a SIRON-200 scanning electron microscope (SEM) with an acceleration voltage of 10kV. The hardness and the modulus of the films were measured with a MTS XP nano-indentation tester with an indentation depth of 1000nm.

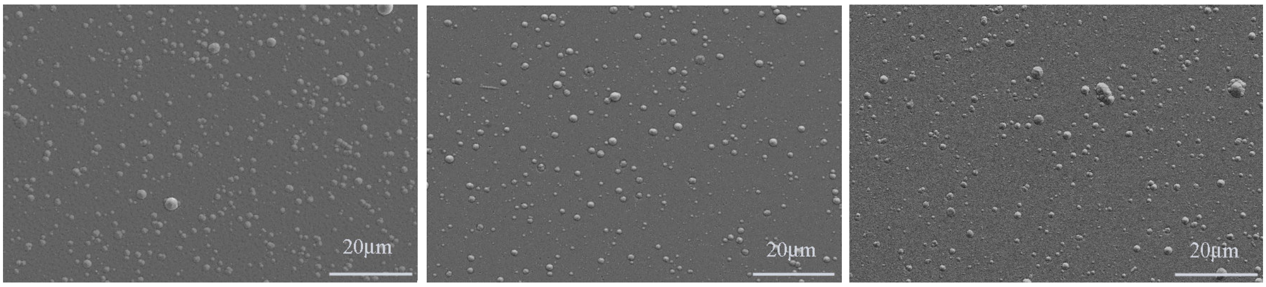

Fig. 1 surface morphology of W-doped DLC films deposited with different W target current (a, left) 0A, (b, middle) 2A, (c, right) 5A

The adhesion between W-doped DLC films and 316 stainless steel was evaluated by a MFT-4000 surface properties tester under the conditions with a load rate of 40N/min, a end load of 100N and a scratch length of 5mm. The tribological behaviors of W-doped DLC films in dry air were studied with a MS-T3000 ball-on-disk friction tester; the coated 316 stainless steel plates were fixed on a rotary sample stage with a rotation rate of 400rpm and the test duration was set as 30min; the counterpart was a Si_3N_4 ball of 6mm in diameter; the friction coefficients were recorded continuously during the test and the wear volume of the abrasion trace was established by the perimeter and the cross-section area of the wear trace after the wear test was finished.

Results and Discussion

The surface morphology of W-doped DLC films deposited with different tungsten target current is shown in fig. 1. Clearly, the films have a smooth surface while several particles of about 2 mm exist in the films. There are two possible ways for the formation of the particles in the films: the first is the droplet emission produced by the sputtering target arcing due to charge accumulation on the insulating zone of the sputtered target surface during W-doped DLC film synthesis, and the other is the macro-particle emission from vacuum arc during the transition layers deposition. The particles aroused by the sputtered target arcing during the top W-doped DLC film deposition introduce metal particles into the DLC films and make the films surface prone to adhere to the counterpart, which is disadvantageous for reducing the friction coefficient and the wear rate of DLC films. The particles induced by vacuum arc have less obvious influence on the tribological properties of DLC films for the structures and the properties in the different zones of the top W-DLC films are similar.

From fig. 1, it can also be found that the size and the quantity of the particles are less affected by W target current. Since the growth behaviors of the insulating layer on the sputtered target surface in reactive sputtering are obviously affected by target current [9], the influence of W target current on the particles should be marked if the particles were produced by sputtered target arcing, while the particles produced by the latter way is not influence by sputtered target current. So it is implied that the key formation way of particles in the films is the macro-particle emission from vacuum arc during the transition layer deposition instead of the droplet emission produced by the sputtered target arcing, and the particles are covered by a layer of the films during the deposition of the top W-doped DLC films, which have been approved by composition analysis in-depth for different zones by AES.

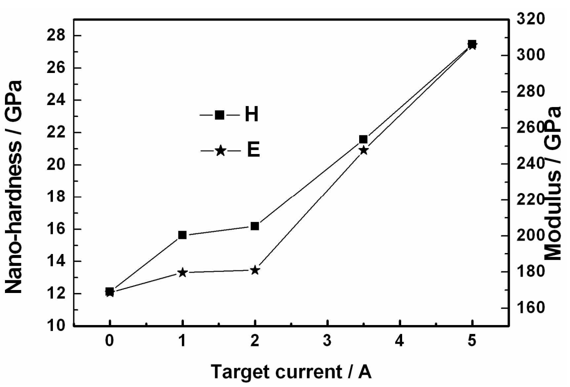

Fig. 2 Influence of W target current on the hardness and modulus of W-doped DLC films

The hardness and the modulus of W-doped DLC films deposited with different W target current are shown in fig. 2. It can be found that the hardness and the modulus of the films are increased with the rise of W target current. The reason for this trend is as followed: with the rise of W target current, more W atoms are introduced into DLC films, which makes more hard WC grains present in the soft amorphous carbon matrix, so the hardness and the modulus of the films become higher. The variety of the critical load of the scratch test with W target current is shown in fig. 3. It can be found that a high adhesion of a critical load (L_c) beyond 70N has been obtained for all the samples through depositing an optimum gradual transition layer before the synthesis of W-doped DLC films, and the adhesion can be improved by increasing W target current.

The friction coefficients and the wear rates of W-doped DLC films as a function of W target current are shown in fig. 4. The friction coefficients are smaller than 0.2 and the influence of W target current on friction coefficients is unconspicuous when W target current is below 2A, but the friction coefficients are increased to 0.35 or above when W target current rise to 3.5 A and above. The wear rates decrease with the increment of W target current first, the lowest wear rates of 1.2×10^{-15}mm^3/m are found for the W-doped DLC films deposited with a W target current of 1A, and then the wear rates began to be increased with the further rise of the W target current. With the introduction of W into pure DLC films in a right amount, some WC particles with a dimension of several nanometers are formed in amorphous carbon matrix, which forms a nano-composite structure relaxing the stress in the films and preventing the cracks from quick spreading during the wear process, so the wear resistance of W-doped DLC films can be obviously improved by doping DLC films with W; but when the W content are too high, the sizes of WC particles are obviously enlarged, the W-doped DLC films become brittle, so the augment of the wear rates is be found when tungsten W current is increased from 3.5A.

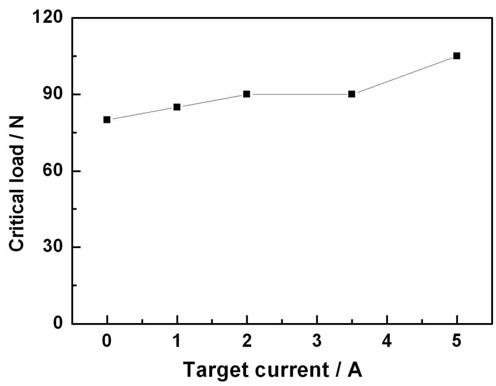

Fig. 3 influence of W target current on L_c of W-doped DLC films

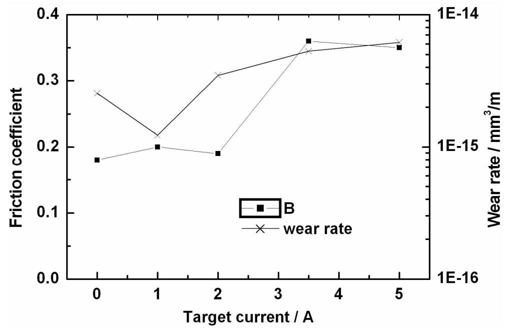

Fig. 4 friction coefficients and wear rates of W-doped DLC films

Conclusion

W-doped DLC films have a smooth surface with several particles of about 2micron in it and the influence of W target current on the surface morphology is unobvious. The hardness and modulus of W-doped DLC films are increased with the augment of W target current. The friction coefficients of W-doped DLC films are increased with the rise of W target current, while a lowest wear rate of 1.2×10^{-15} mm^3/m for the W-doped DLC films deposited with W target current of 1A is obtained.

Acknowledgements

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