Wear monitoring of amorphous carbon films by embedding luminescent wear-sensing layer

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This research aims to present the concept of wear monitoring of amorphous carbon (a-C) films through luminescence from a wear sensing layer embedded between a-C film and substrate. Fabrication and characterisation of the coatings are also presented. The wear sensing layer consists of luminescent ZnS:Cu powder dispersed in epoxy resin (EP/ZnS:Cu) coating. The a-C films are deposited onto EP/ZnS:Cu coatings by sublimation of fullerenes (C_{60}) in electron beam excited plasma (EBEP) method and pulsed vacuum arc deposition (VAD) method. The results show that the EP/ZnS:Cu coatings exhibit the green luminescence when irradiated with the UV light. After deposition of a-C films, the luminescence from the EP/ZnS:Cu coating is undetected. A ball-on-disk friction test is carried out not only to examine the coefficient of friction, but also generate the wear track on the a-C films. It is found that after the friction test, the a-C films deposited by EBEP method are completely worn out and the luminescence from the EP/ZnS:Cu can be re-detected. In contrast, the a-C film deposited by VAD is durable and is not worn out, therefore the luminescence from the EP/ZnS:Cu cannot be re-detected.

1. Introduction

Amorphous carbon (a-C) films have been attractive for a several decades in the mechanical field due to their exceptional properties such as high hardness, wear resistance and low friction properties [1,2]. With proper design, they can offer a long lifetime as a tribological coating. However, these properties depend on many factors, for example, sliding speed, temperature, load and environment [3], in which wear monitoring is difficult while in service. This occasionally leads to the pre-mature failure of the coating.

Luminescent spectroscopy has been proposed and applied to monitor the health of thermal barrier coatings [4,5]. The coatings are multilayer consisting of a top coating and a luminescent layer embedded between the top coating and substrate. The monitoring mechanism is that when the top layer is worn out, the luminescence can be detected.

The present research aims to extend such concept for monitoring the wear life of amorphous carbon (a-C) films. Deposition of a-C films onto the wear sensing layers, which consist of luminescent ZnS:Cu powder dispersed in epoxy resin is presented. The coating performance are examined and discussed.

2. Experimental

The wear sensing layer, which consists of luminescent ZnS:Cu powder dispersed in epoxy resin (EP/ZnS:Cu), was fabricated initially. As-purchased ZnS:Cu powder of 5 wt.% to the base resin was mixed with an epoxy resin. The mixture was dropped onto silicon wafers and covered with polystyrene films. The mixture coatings were finally cured at 40°C for 12 h.

The cured EP/ZnS:Cu coatings were subsequently coated with amorphous carbon (a-C) films by two methods, namely sublimation of fullerenes (C_{60}) in electron beam excited plasma (EBEP) method and pulsed vacuum arc deposition (VAD) method. The detail of deposition of a-C films by sublimation of C_{60} in EBEP method was given in elsewhere [6]. In this method, a-C films were deposited at -200 V and 0 V bias voltages for 60 min. For the a-C coated by the pulsed VAD method, the EP/ZnS:Cu coatings were placed 12 cm apart from the arc plasma gun in which the graphite rod was used as the carbon source. The arc plasma voltage was 100 V, capacitance for arc discharge was 720 μF, discharge frequency was 1.0 Hz and the number of discharge was 6000 counts, respectively.

Photoluminescence (PL) properties of the EP/ZnS:Cu before and after being coated with a-C films were investigated by irradiating with the UV light at 365 nm and collecting the PL spectra from the coating by the spectrometer. The coatings were tested in the ball-on-disk friction test. The coatings were rubbed with stainless steel (SUS440C) balls 4.76 mm in diameter at the normal force of 0.3 N and rotational speed of 50 rpm. The sliding distance of the test was 50 m. After the friction test, PL spectra were collected again at the wear tracks of the coatings in order to investigate the sensing capability.

3. Results and discussion

Photoluminescence (PL) spectra of the as-prepared EP/ZnS:Cu coating is shown in Fig.1(a). The spectrum shows the peak center at 525 nm with a small shoulder at 450 nm, corresponding to the characteristic spectrum of ZnS:Cu powder [7]. The PL spectra of EP/ZnS:Cu after being coated with a-C films by various deposition conditions as shown in Fig. 1(b)-(d) are not detected. This suggests that a-C films can protect EP/ZnS:Cu from the UV excitation.

Friction behaviour of a-C coated EP/ZnS:Cu coatings obtained from various conditions are illustrated in Fig. 2. The a-C coated EP/ZnS:Cu coatings deposited by EBEP show the coefficient of friction (COF) of 0.2 at the starting period and the COF suddenly increases to the higher value in the short sliding distance. Finally both coatings reach the COF values of 0.7 as shown in Fig. 2(a) and (b). On the other hand, a-C coated EP/ZnS:Cu coatings deposited by VAD at 6000 counts shows the lower COF value of 0.36 as shown in Fig. 2(c).

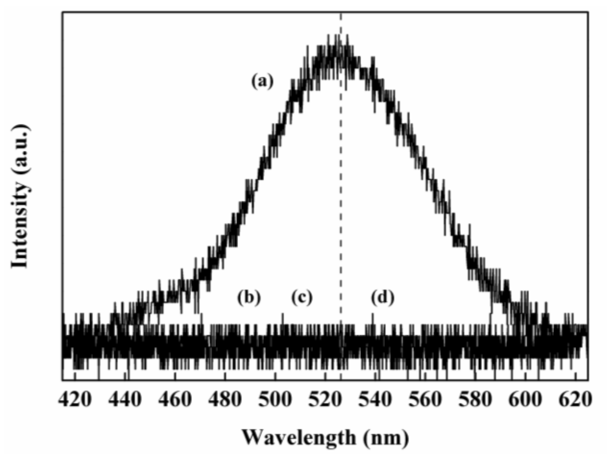

Fig. 1 Photoluminescence spectra of EP/Zns:Cu coatings (a) before and (b) after being deposited with a-C films by EBEP at -200 V, (c) EBEP at 0 V and (d) VAD at 6000 counts

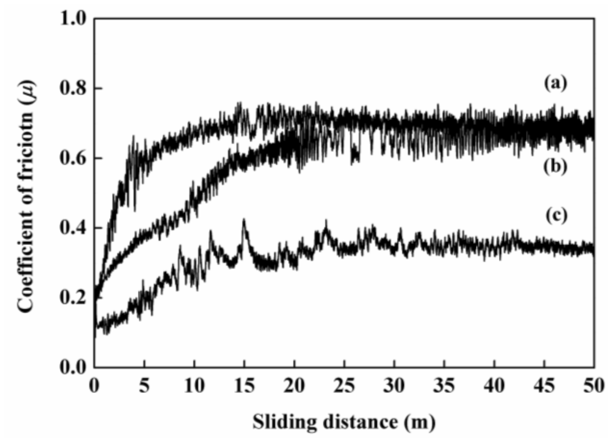

Fig. 2 Friction behaviour of a-C coated EP/ZnS:Cu coatings deposited by (a) EBEP at -200 V, (b) EBEP at 0 V and (c) VAD at 6000 counts

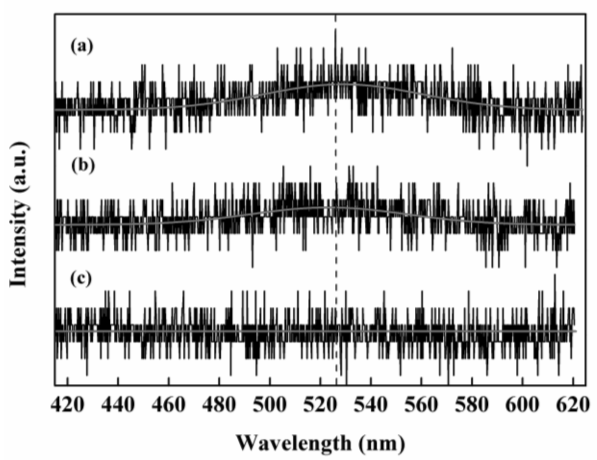

Fig. 3 PL spectra collected at the wear track of a-C coated EP/ZnS:Cu coatings deposited by (a) EBEP at -200 V, (b) EBEP at 0 V and (c) VAD at 6000 counts

Fig. 3 shows the photoluminescence (PL) spectra plotted together with the fitted spectra collected from the wear track of the coatings after the friction test. It shows that PL spectra with the peak position of 525 nm can be detected from the wear tracks of the a-C coated EP/ZnS:Cu coatings deposited by EBEP at both -200 V and 0 V as shown in Fig. 3(a) and (b). This corresponds to the PL spectra of the EP/ZnS:Cu coating. Moreover, this also indicates that a-C films has been worn out resulting in the exposure of EP/ZnS:Cu to the UV excitation. Therefore, the luminescence can be redetected. However, the PL spectrum from the a-C coated EP/ZnS:Cu coating deposited by VAD at 6000 counts is undetected, which indicating that the coatings are not removed and still durable.

4. Conclusion

The fabrication and demonstration of amorphous carbon films with wear sensing layer is presented. The wear sensing layer consists of EP/ZnS:Cu coating, which shows strong and detectable green luminescence. After the EP/ZnS:Cu coatings were coated with amorphous carbon (a-C) films by sublimation of fullerenes in electron beam excited plasma (EBEP) and pulsed vacuum arc deposition (VAD), the luminescence from the EP/ZnS:Cu was not be detected. This suggests that the a-C films can protect the sensing layer from the excitation. The a-C deposited on EP/ZnS:Cu by two methods show the different friction behaviour. The a-C films deposited by EBEP method show a higher value of COF than those deposited by VAD method. Moreover, the luminescence from the wear tracks could be detected for the coatings deposited by EBEP method, while it could not be detected for the coatings deposited by VAD. This is caused by the removal of a-C films deposited by EBEP methods after the friction test and durability of the a-C film deposited by VAD method.

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