Defense Technical Information Center Compilation Part Notice

ADP014976

TITLE: Ag-DLC Tribological Film Deposition by Double Thermionic Vacuum Arc

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: International Conference on Phenomena in Ionized Gases [26th] Held in Greifswald, Germany on 15-20 July 2003. Proceedings, Volume 4

To order the complete compilation report, use: ADA421147

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP014936 thru ADP015049

Ag-DLC tribological film deposition by double thermionic vacuum arc

I. Mustata, G. Musa, M. Blideran, V. Zaroschi, A. M. Lungu, C.P. Lungu and K. Iwasaki*
National Institute of Lasers, Plasma and Radiation Physics, Magurele-Bucharest, PO Box MG-37, Romania
*Japan Ultra-high Temperature Materials Research Institute, 573-3, Okiube, Ube, Yamaguchi 755-0001, Japan

A new type of plasma discharge, thermionic vacuum arc (TVA) was used to prepare Ag-DLC composite films to be used as anti-friction layer in automotive applications. The deposition method and film properties are presented.

1. Introduction

A new class of advanced materials with controlled tribological properties and environmental friendliness is currently developed in order to be applied in the automotive industry as anti-friction layer for plain bearing by using electron cyclotron resonance - direct current (ECR-DC) sputtering [1-2]. Thin film deposition process by thermionic vacuum arc (TVA), a new discharge type in pure metal vapor plasma, might become one of the most suitable technologies to improve significantly the tribological properties of the surfaces covered with different materials. TVA can be ignited only in high vacuum (HV) or ultra high vacuum (UHV) conditions between a heated cathode surrounded by an electron focussing Whenelt cylinder and an anode (crucible) containing the material to be deposited [3-4]. Due to the continuous electron bombardment of the anode (positively charged with controllable high voltage supply) by the accelerated thermo-electrons coming from the grounded cathode the anode material first melts and afterwards starts to evaporate ensuring a steady state concentration of the evaporated atoms in the cathode-anode space. At further increase in the applied high voltage, a bright discharge is established inside the vacuum vessel in the vapors of the pure anode material. The energy of ions of the TVA plasma can be directly controlled and established at needed value even during arc running by changing the cathode heating current and anode potential. As mentioned in a recently published paper, ion bombardment ensures better quality of the deposited thin film [5].

2. Experimental setup and method

The experimental set-up is shown in Fig. 1. The cathode of each of two guns consisted of heated tungsten filament surrounded by molybdenum Whenelt cylinder, which had an aperture of 10 mm in diameter. The filament for the silver discharge was made of a tungsten wire of 0.6 mm in diameter while the filament for the carbon discharge was made of thoriated tungsten wire of 3 mm in diameter. The filaments were arranged in the apertures of the Whenelt cylinders in the plane of their front surface. A hydrogen free graphite rod 20 mm in length and 10 mm in diameter was used as the carbon anode in the carbon discharge case and silver grains of 5 mm in diameter filed the anode crucible in the silver discharge case. The inter-electrode gap was adjusted in the range of 4-8 mm. The ion energy was evaluated by using a retarding field analyzer of multiple mesh type. The film composition was measured by using an X-ray fluorescence (XRF) analyzer in the quantitative mode and the crystallographic state of carbon included in the prepared films by a Laser-Raman spectrometer by using 514.4 nm wavelength radiation of an Ar ion laser, 5 mW power and 1 μm spot diameter.

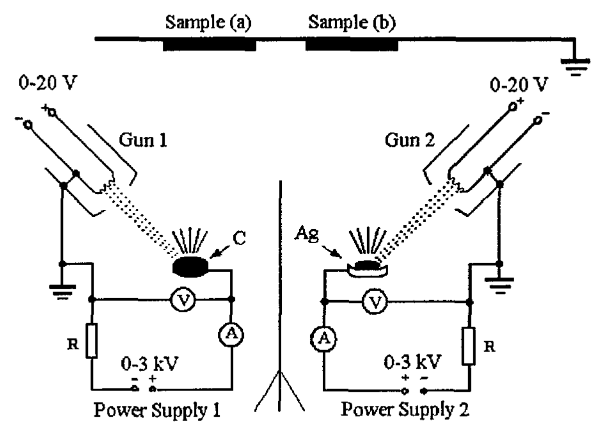

Fig.1 Experimental set-up.

The film morphology was analyzed by using an atomic force microscope (AFM) in contact mode. The coefficient of friction of the deposited film was measured by using a ball-on-disk tribometer at room temperature and 50% relative humidity of air. A bearing steel ball of 6 mm in diameter was used as a counter material. Load of 5 N and sliding radius of 4 mm were chosen. The sliding speed was kept at 0.1 m/s in all the measurements.

3. Results and discussion

Following parameters were fund to control the TVA: Arc current; *Iarc*, Cathode thermoelectronic current, (controlled by the heated cathode temperature); T*c*, Inter-electrode distance; d, The angle between an imaginary perpendicular line on the anode and the axis of the heated cathode. Because both the cathode of TVA and the vacuum vessel are at earth potential the plasma has a positive potential against the vacuum vessel wall, that is roughly equal to the cathode potential fall. In these circumstances, the sample (and the growing layer too) is subjected to an intense bombardment by both evaporated atoms and energetic ions during the film deposition.

The ionic energies in the vicinity of the substrate holder were found to be in the range of 50-300 eV. The high ionic energies led to the formation of composite films with a smooth morphology as was shown by the AFM analysis. The surfaces of the deposited films reproduced properly the initial roughness of the bronze used as substrates, and the "planarization" of the coated surface was not observed, allowing the coating to keep the embeddability of foreign particles in the running-in process of the engine bearings.

X-ray fluorescence of the prepared films showed a concentration of 44.82mass%C in the sample (a) fixed close to the C anode and 19.27mass%C in the (b) sample fixed close to the Ag containing crucible.

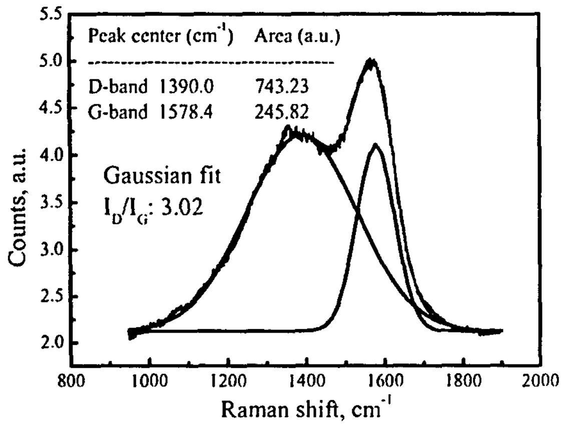

Fig.2 Typical Raman spectrum and Gaussian fit of the 2 peaks assigned asD-band and G-band.

Carbon was incorporated into the composite films as DLC phase, as defined recently by Ferrari and Robertson [6] with a large ratio of characteristic D-band/G-band. Figure 2 shows a typical spectrum of the prepared film and a Gaussian fit made in order to separate the D and G peaks. The D and G peaks are characteristic of the sp^2 sites of all disordered carbons at 1350 and 1570 cm-1, respectively. Development of the D band indicates disordering of graphite but ordering of an amorphous carbon structure; its intensity is proportional to the number and size of sp^2 clusters, while its width is more related to a narrower distribution of clusters with different order and dimensions. The G-band of graphite involves the in-plane bond-stretching motion of pairs of carbon sp^2 atom; this mode does not require the presence of sixfold rings and so it occurs at all sp^2 sites. [6] The influence of carbon incorporation into the film as DLC led to a drastic decrease in the coefficient of friction tested in dry condition. Figure 3 shows the frictional behavior of the Ag-DLC films compared to that of the bronze substrate.

The reduction of the coefficient of friction can be observed for both the coatings compared to that of bronze substrate. A drastically decreases in the coefficient of friction of the Ag-DLC coating with increasing carbon content was observed during the ball-on-disk test in dry conditions. This suggests the predominant influence of the DLC acting as a solid lubricant inclusion in the silver matrix.

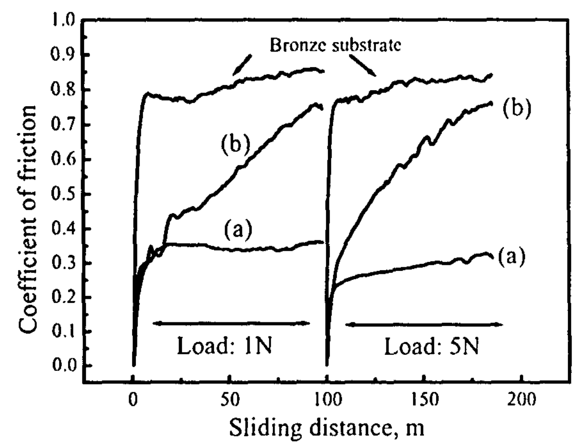

Fig.3 Coefficient of friction versus sliding distance.

Due to the ion bombardment the thin films are compact and very smooth with no columnar structure. Due to the incident energetic ions, the adherence of the thin film to the substrate increases remarkably. In this case the adherence was directly related to the value of the energy of ions, increasing with the energy of ions. Taking into consideration the peculiarities of the carbon film deposition, TVA is considered to be one of the most adequate technologies for this field of applications. Indeed, due to the ensured high purity of the deposition process (in vacuum vessel only carbon and silver being introduced besides refractory metals used as electrodes) completely hydrogen free carbon film can be obtained. At the same time, TVA technology ensure high efficiency in producing high energy ions spent to heat carbon which needs temperatures higher than 4000K.

Because of vacuum conditions and high sublimation temperature of the carbon, and relative low melting temperature of the silver the main energy losses are practically only by radiation. Taking these advantages into account TVA is expected to be very promising for preparation of Ag-DLC tribological coatings.

4. References

[1] K. Iwasaki, C. P. Lungu, S. Takayanagi, K. Ohkawa, Int. J. of Applied Mechanics and Engineering **7** (2002) 351.

[2] C. P. Lungu, K. Iwasaki, Vacuum **66** (2002) 385.

[3] G. Musa, H. Ehrich, J. Schuhmann, IEEE Transactions of Plasma Science, **25** (1997) 386.

[4] H. Ehrich, J. Schuhmann, G. Musa, A. Popescu, I, Mustata, Thin Solid Films **333** (1998) 95.

[5] C. Biloiu, H. Erich, G. Musa, J. Vac. Sci. Technol. **A19** (2001) 757.

[6] A. C. Ferrari, J. Robertson, Phys. Rev. B **61** (2000) 14095.