

## THERMIONIC VACUUM ARC (TVA) - CARBON THIN FILM DEPOSITION

G. Musa<sup>\*</sup>, I. Mustata, V. Ciupina<sup>a</sup>, R. Vladiou<sup>a</sup>, G. Prodan<sup>a</sup>, C. P. Lungu, H. Ehrich<sup>b</sup>

National Institute for Physics of Laser, Plasma and Radiation, Bucharest-Magurele, Romania

<sup>a</sup>Department of Physics, “Ovidius University”, Constanta, Romania

<sup>b</sup>Department of Physics, University of Essen, Essen, Germany

Amorphous carbon (a-C) films were prepared using the novel thermionic vacuum arc (TVA) method. The prepared films, 30 nm in thickness, sp<sup>3</sup> rich (up to 90%) were identified as diamond like (DLC) nanostructures. The nanohardness of the films is of the order of 50 – 60 GPa, and the coefficient of friction of 0.05 – 0.1. HRTEM (High Resolution Transmission Electron Microscopy), SAED (Selected Area Electron Diffraction), XPS (X-ray photoelectron spectroscopy) and Raman spectroscopy were used for the characterization of the deposited films.

(Received May 6, 2005; accepted September 22, 2005)

*Keywords:* Thermionic Vacuum Arc, Carbon thin film deposition, HRTEM

### 1. Introduction

Presently, there is great interest in amorphous carbon (a-C) films, which contain significant fractions of sp<sup>3</sup> bonding. [1,2]. This bonding gives diamond-like carbon (DLC) structures with many valuable properties, such as wear resistance, adhesion, electrical conductivity, hardness, smoothness and oxidation resistance [3, 4]. Furthermore the optical constants, like the refractive index, can be adjusted for the desired application. The a-C films are used as protective anti-reflection coatings on e.g. glass plates in bar-code laser scanners and protective, wear and corrosion reducing, coatings [5].

DLC is an amorphous material, having both sp<sup>3</sup> and sp<sup>2</sup> hybridized bonds, with no long-range crystalline order.

In this paper, Thermionic Vacuum Arc method for DLC layer deposition is described. HRTEM (High Resolution Transmission Electron Microscopy), SAED (Selected Area Electron Diffraction), XPS (X-ray photoelectron spectroscopy) and Raman spectroscopy were used for the characterization of the deposited films. We present also the values of the nanohardness, roughness and the coefficient of friction of the films.

### 2. Experimental set-up

Because this system can heat any material at elevated temperature, it is one of the most adequate technologies for carbon evaporation. In this case, instead of a crucible containing the material to be evaporated, a carbon rod is used directly. Moreover, the discharge can be ignited in high vacuum condition, ensuring high purity and deposition of the hydrogen-free nanostructured carbon layer.

For carbon film deposition using TVA technology the main used working parameters are presented below:

- Anode carbon rod diameter: 10 mm

---

\* Corresponding author: musageavit@yahoo.com

- Anode carbon rod length: 15 mm
- Interelectrode distance: 2 mm
- Intensity of the arc current: 270 mA
- Applied high voltage: 1.8 kV
- Working pressure:  $5 \times 10^{-5}$  torr
- Time of deposition: 150 s
- Deposition rate: 2 Å/s
- Thickness of the film: 30 nm

The cathode filament was made by thoriated tungsten wire with 1,5 mm diameter, three times wound and heated by a current of 100 A. During the arc running and C thin film deposition, the anode was continuously rotating with 6 rotation/minute, and also the cathode-anode distance was adjusted each time when the arc current was decreasing more than 10%.

### 3. Results and discussions

The deposited C films were studied using TEM electronic microscopy with a magnification of 1.4 M and a resolution of 1.4 Å. The samples of deposited carbon films (deposited on NaCl or KCl monocrystals) have been solved in water before TEM examination. They have shown nanostructure films. Fig. 1 shows the contrast fringes given by complex crystalline particles included in the amorphous film. The arrows indicate the interplanar distance corresponding to the crystalline structures.

Particles are embedded in the film with graphite zone that covers the particles.

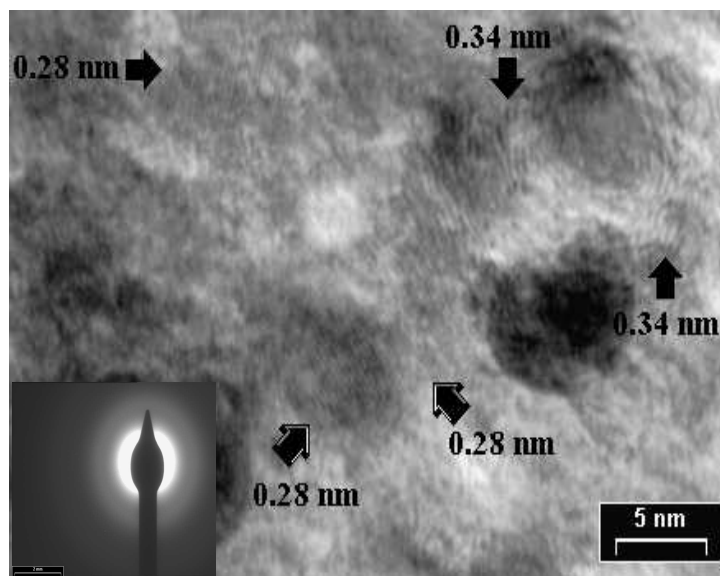


Fig. 1. High-resolution TEM image of the film deposited using TVA (inset SAED).

Rhomboedral structure with lattice parameters:  $a = 0.25221$  nm,  $c = 4.3245$  nm (ASTM pattern: 79 - 1473) of diamond/carbon has been obtained from electron diffraction pattern.

For the chemical state of the top layers X-ray photoelectron spectroscopy was used. The binding energy spectra of the C-1s, provided direct information on the  $sp^3/sp^2$  ratios. Films with  $sp^3$  bondings up to 90% were obtained.

Microhardness of the prepared films was found in the range of 50-60 GPa as was measured by nanoindentation.

The roughness ( $R_a$ ) of the films measured using a Mitutoyo profilometer was found in the range of 2-3 nm.

Raman spectroscopy was used to identify the carbon phase of the deposited films. Raman spectra were obtained in a back-scattering configuration using the 514.5 nm line of an Ar<sup>+</sup> laser with 5 mW power and 50  $\mu\text{m}$  spot diameter. The signal was detected with a photomultiplier using a standard photon counting system with the acquisition time of 60 s.

Fig. 2 shows the Raman spectrum of a film grown in conditions presented above. One can clearly observe two asymmetric bands. For deeper analysis this spectrum was fitted with gaussian functions using a commercial fitting computing program. The fitted peak shape, have their maximum value at  $1416\text{ cm}^{-1}$  and at  $1577\text{ cm}^{-1}$  and correspond to D and G bands respectively

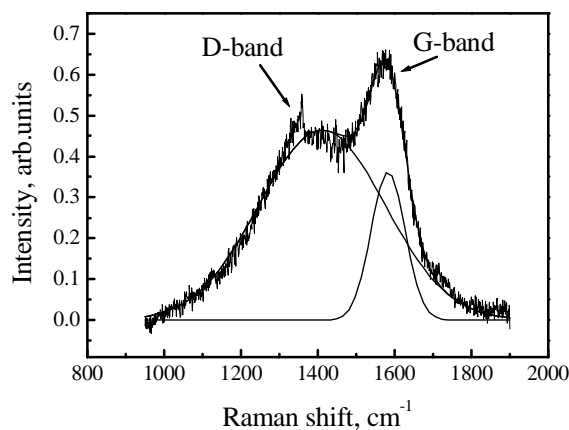


Fig. 2. Typical Raman spectrum and Gaussian fit of the 2 peaks assigned as D-band and G-band.

#### 4. Conclusions

We can conclude that Thermoionic Vacuum Arc (TVA) can be used successfully for a-C, DLC-type carbon film deposition. Super hard (50-60 GPa) nanostructured films with low value of roughness and coefficient of friction can be obtained quite easily. Further developments will be related mainly to the improvement of the TVA stability at the transition from electron bombardment heating of carbon rod to the TVA arc plasma ignition and running. In this paper, we have presented the first results on the characteristics of DLC films obtained using TVA.

#### References

- [1] S. Ainsenberg, F. Kimock, *Materials Sci. Forum*, Vol. 52 & 53, Trans. Tech. Switzerland, 1-40 (1990).
- [2] J. Robertson, *Diamond Relat. Mater.* **2**, 984 (1993).
- [3] T. Ishiguro, K. Esaki, Y. Hirishima, *Appl. Surf. Science* **127-129**, 553 (1998).
- [4] P. Martin, *IEEE Trans. Plasma Sci.* PS-18, 885 (1990).
- [5] F. Piazza, D. Grambole, L. Zhou, F. Talke, C. Casiraghi, A. C. Ferrari, J. Robertson, *Diamond and Related Materials* **13**, 1505–1510 (2004).