OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 3, No. 12, December 2009, p. 1269 - 1272

Retarding field ion energy analysis of an anodic arc carbon plasma

M. BADULESCU, I. GRUIA[a*], C. SURDU-BOB, C. IACOB
National Institute for Laser, Plasma and Radiation Physics, Măgurele, Ilfov, Romania
[a]*Faculty of Physics, University of Bucharest, Măgurele, Ilfov, Romania*

In order to obtain technological control in thin film deposition, the understanding of surface-plasma interactions is essential. Apart from the type and flux of the impinging ions/neutral atoms on the surface, the ion energy distribution is an important parameter in studies of surface modification due to plasma. The Thermo ionic Vacuum Arc (TVA) plasma proved to be an important deposition tool of thin metal films and hydrogen-free diamond like carbon (DLC) films. There is though very little work on the understanding of surface phenomena related to film growth by TVA. In this paper, analysis of the energy of the ions arriving at the substrate in TVA plasma ignited in Carbon vapours is presented. An in-house, computer-controlled retarding field analyser (RFA) was used for experimentally determining ion energy distributions (IED) of the Carbon ions arriving at the substrate. The results have shown that the energies of ions arriving at the substrate are as high as hundreds eV in TVA, much higher than in any other type of low temperature plasma. This fact makes TVA a unique thin film deposition tool.

(Received October 19, 2009; accepted November 23, 2009)

Keywords: Thermoionic vacuum arc plasma, DLC films, Surface-plasma interaction

1. Introduction

In order to obtain technological control in thin film deposition, the study of surface-plasma interactions is essential. Apart from the value of the flux/density of the impinging ions/neutral atoms on the surface, the ion energy distribution is an important parameter in understanding surface modification due to plasma and for film tailoring.

Ion energy distribution functions (IEDF) can be measured by energy selective mass spectrometry [1], by time of flight spectrometers [2], by retarding field ion energy analysis (RFA) [3, 4] or can be determined theoretically by Particle-in-cell/Monte Carlo simulations [5].

One of the simplest devices capable of obtaining the IEDF is the RFA. This is an electrical probe which operates as an energy filter. The basic principle of an RFA is the measurement of an electrical current given by electrically charged plasma species against a retarding voltage. The ion energy distribution function is obtained from the first derivative of the I-U characteristic. The system can work in either ion mode or electron mode, depending on the sign of the constant bias applied on the grid in front of the collector. The device consists on a metal collector and a set of grids placed before the collector and used to repel electrons and to suppress secondary electrons. More details can be found in [6].

Our previous work on Carbon film analysis revealed the presence of sp^3 diamond bonds in the films obtained by Thermo ionic Vacuum Arc (TVA) [7]. This was correlated to the high arc voltage used in TVA and subsequently to the Carbon ion energies. It is only now that the ion energy distribution of Carbon ions generated by the Thermo ionic Vacuum Arc plasma is measured and presented.

2. Experimental setup

2.1. The TVA plasma – brief description

The TVA is a low temperature plasma in a vacuum environment and is obtained by bombarding a metal or graphite anode with energetic electrons. The TVA plasma is localized above the anode – it does not fill the chamber. The experimental setup is presented in Fig. 1.

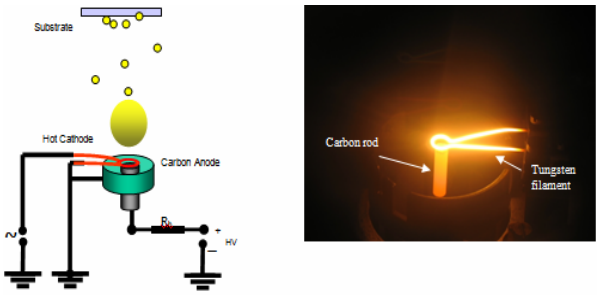

Fig. 1. The experimental setup of the TVA plasma (a) schematic illustration; (b) photo.

A TVA Carbon plasma is ignited using a graphite rod anode. The ignition stages can be observed on the current – voltage characteristic presented in Fig. 2. The processes leading to plasma ignition are described in the following.

The electrons are produced by a heated tungsten filament and accelerated towards the anode. Evaporation of the graphite anode starts to take place once a positive voltage is applied on the anode, due to electron bombardment An increase of the anode potential results in an increase of the vapour pressure of carbon atoms above the anode (points A to B). The first carbon ions appear due to collisions of the carbon atoms with fast electrons (point B). A further increase of the applied voltage produces more ions and electrons (points B to C). The newly created electrons produce more carbon ions and thus an avalanche of electrons and ions is produced. The TVA plasma reaches equilibrium in the C point of the I-V characteristic. A further power input at the anode results in a more intense plasma.

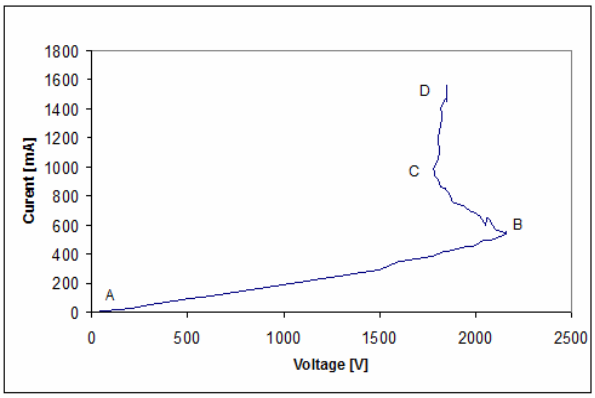

Fig. 2. Typical current – voltage characteristic of t he TVA plasm a ignited in Carbon vapours. Stages A-B evaporation; stages B-C ionization; stage C plasma ignition; stages C-D plasma operation.

The Debye length of this plasma, above the anode, calculated using eq. 1 is 160 μm.

$$\lambda_D = 7.43 \times 10^2 \times \mathrm{SQRT}(T_e/n_e)\ (\mathrm{cm}) \qquad (1)$$

where the values of 5 eV for electron temperature (Te) and $10^{16}/m^3$ for electron density (ne) were approximated using those obtained in a Ni TVA plasma [8].

This value of the Debye length refers to the TVA plasma in equilibrium state, formed above the anode. The RFA was placed away from this localized plasma, where the conditions for equilibrium are not met. There, the ions arrive in beams. More explanation is given in the following.

The ions created in this localized equilibrium plasma escape from the plasma, due to the repelling positive potential of the plasma. The escaped ions travel within high vacuum and therefore the collision probability with other particles is believed to be very small. The energy of these escaped ions can be approximated with the potential difference between the plasma potential and the substrate potential (which is usually ground). This is an important feature of the method, as the ion energy can be directly controlled by the operating plasma parameters, e.g arc voltage.

The TVA plasma source was placed in a vacuum chamber pumped down to a base pressure of 9^x10^{-4} Pa.

The diameter of the filament wire used in this work was 1mm and the heating current was up to 60A. The anode consisted of a pure graphite rod of 12.5mm diameter. The filament was placed 3÷4mm above the anode. The anode is continuously eroded during plasma running. In order to keep the interelectrodic distance constant, a computer controlled in-house system which allows a fine mechanical adjustment of the interelectrodic distance was used. The current-voltage characteristics were acquired using current and voltage transducers.

This paper presents the ion energy distribution at 35 cm distance from the anode, at a remote place from the plasma source.

2.2. Construction of the RFA

In order to determine the ion energy distribution, an in-house Retarding Field Analyzer (RFA) was used to decelerate and filter ions, according to their energy.

It must be reiterated here that the TVA plasma does not touch the RFA analyzer and therefore the Debye length does not pose any constraints for the geometry of the analyzer. Therefore, in contrast to the complicated use of the RFA for other plasmas, the construction in this case is much simpler.

The RFA analyzer was oriented facing the plasma, perpendicularly to the incoming ion beam trajectory direction.

Fig. 3 presents an illustration of the RFA principle. Ions and electrons enter the analyzer. The electrons are repelled by a negatively biased grid whereas the ions are filtered by the positively biased collector.

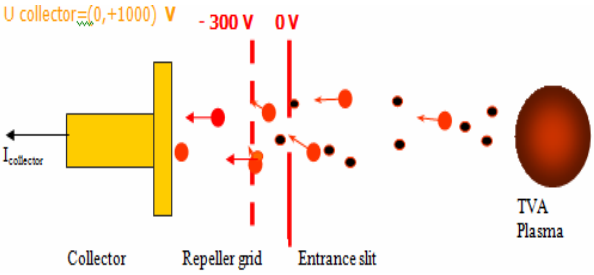

Fig. 3. Schematic illustration of the RFA principle.

The collector bias was swiped from 0 to 1000 V and the collector current was measured. The grid bias had constant values in the (100÷700 V) range.

The main components of the RFA module can be observed in Fig. 4. The RFA had a planar construction consisting of a stainless steel grid (mesh having 30 μm wire and 50 μm gap) and a Molybdenum collector, encapsulated in a stainless steel cylinder and electrically separated by mica insulators of 0.2 mm thickness was used. The entry orifice had 3.2 mm diameter.

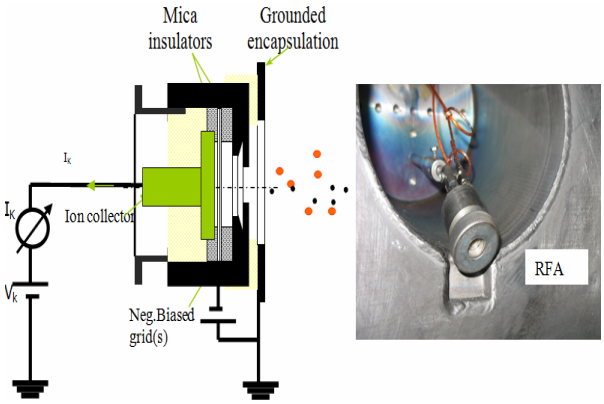

Fig. 4. The retarding field ion analyzer (a) experimental arrangement (b) photo.

3. Results and discussion

Current-voltage characteristics of the collector were acquired for different plasma operating conditions and are shown in Fig. 5.

The voltage applied on the negatively biased grid did not influence the shape of the I-V characteristic at the collector.

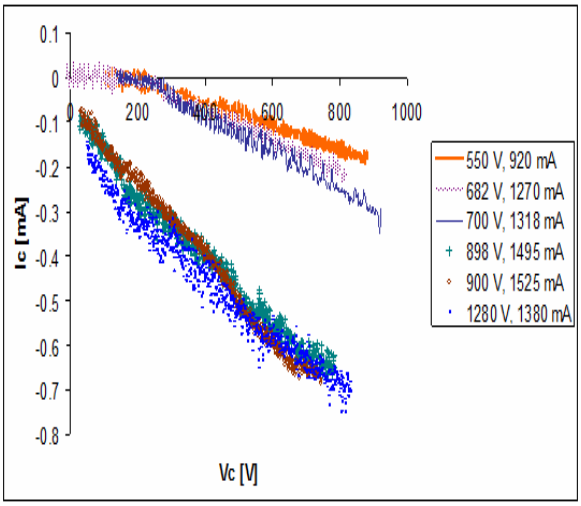

Fig. 5. Current–voltage characteristics of the RFA collector. The colours correspond with the other figures.

Fig. 6 shows the first derivative of the I-V characteristics presented above and represents the ion energy distribution. From this figure it can be observed that the ion energies have relatively high values, not found in other plasma sources.

During thin film deposition, high energy ions and neutrals arrive at the substrate which is placed away from the TVA plasma. The ions are those of the anode material. No carrier gas or buffer gas is used for obtaining energetic ions. Thus, apart from high compactness and smoothness given by the high ion energy, the thin films obtained by TVA are also very pure.

The arc current and voltage for each RFA measurement is given in the legend of Fig. 6. It can be observed that there is a shift of the ion energy distribution with the arc voltage. This clearly demonstrates that there is a direct proportional relation of the ion energy and arc voltage. This suggests that the ions are accelerated in the electric field created between the anode and chamber walls and travel in straight lines (without collisions).

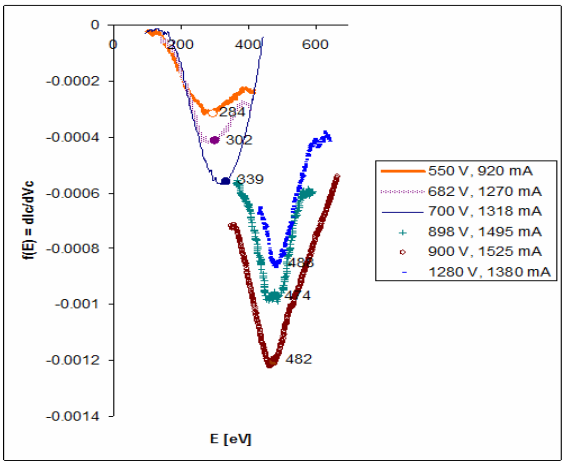

Fig. 6. The first derivative of the I-V characteristics acquired using the RFA which gives the IEDF.

4. Conclusions

The ion energy distribution at the substrate surface is an important parameter in thin film deposition. The TVA plasma is being studied as a potential candidate for thin film deposition technologies. RFA analysis were employed in this study.

A high ion energy was found for the Carbon ions obtained in the TVA plasma, compared to any known low temperature plasma.

It was observed experimentally that the values of the ion energy of Carbon ions vary directly proportional with the applied arc voltage. This fact gives the TVA plasma superiority over other plasma methods in terms of compactness, smoothness and purity of the deposited films.

Acknowledgements

The authors wish to thank the Ministry of Education, Research and Youth (MECT) – Bucharest Romania for financial support.

References

[1] J. K. Olthoff, R. J. Van Brunt, S. B. Radovanov, J. A. Rees, Science, Measurement and Technology, IEE

Proceedings **141**(2), 105 (1994).
[2] F. Richter, Physikalische Blätter **52**, 355 (1996) (in German).
[3] Ivanov et al./Surface and Coatings Technology **92**, 1X-156 (1997).
[4] Y.Yuan, J. Bansky, J. Engemann, A. Brockhaus, Surface and Coatings Technology **74-75**, 534 (1995).
[5] J. K. Lee et al, Plasma Sources Sci. Technol. **14,** 89 (2005).
[6] C. Surdu-Bob, I. Mustata, C. Iacob, J. Optoelectron. Adv. Mater. **9**(9), 2932 (2007).
[7] C. Surdu-Bob, R. Vladoiu, M. Badulescu, G. Musa, Diamond and Related Materials **17,** 1625 (2008).
[8] M. Osiac, C. Surdu-Bob, M. Badulescu, C. P. Lungu, J. Optoelectron. Adv. Mater. **10**(8), 2007 (2008).

*Corresponding author: gruia_ion@yahoo.com