Ion energy distribution analysis of the TVA plasma ignited in carbon vapours using RFA

C. C. Surdu-Bob, M. Badulescu, C. Iacob, C. Porosnicu, C. P. Lungu
National Institute for Lasers, Plasma and Radiation Physics, Atomistilor No.409, POBox MG-36, Magurele-Bucharest, Romania
cristina.surdubob@plasmacoatings.ro

Abstract. In order to understand plasma processes and to obtain technological control in thin film deposition, the study 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 (IED) is an important parameter in understanding surface modification due to the plasma. In this paper, results of ion energy analysis of the Thermionic Vacuum Arc (TVA) plasma ignited in carbon vapours are presented. An in-house, computer-controlled retarding field analyzer was used for determining experimentally ion energy distributions of the carbon ions arriving at the substrate. The correlation of the carbon IED with the applied arc voltage in the TVA plasma was put in evidence for the first time.

1. Introduction
Ion energy distribution is an important parameter in understanding surface modification due to plasmas. 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] or can be determined theoretically by Particle-in-cell/Monte Carlo simulations [4].

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 current-voltage characteristic I-V. The system can work in either ion mode or in 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, which are used to eliminate electrons and to suppress secondary electrons. More details can be found in [5]. The fact that in Thermionic Vacuum Arc (TVA) the plasma does not fill the vacuum chamber, and thus it does not enter into the analyzer, a simpler design was chosen in this case, with only one electron-repelling grid.

We report here for the first time on the correlation of the plasma operating parameters with the ion energy distribution for carbon ions generated by the TVA plasma.

2. Experimental Setup
The TVA is a localized plasma in a vacuum environment and is ignited using a metal or graphite anode and an electron gun. The ignition is initialized by thermo-electrons generated by the externally heated tungsten filament – the cathode. The experimental arrangement is presented in figure 1 and further details can be found in [6].
The ions created in this localized plasma are accelerated towards the chamber walls (and subsequently towards the substrate) due to the potential difference between the plasma and the grounded walls. Due to a low background pressure ($9 \times 10^{-4}$ Pa) the energy of ions is directly proportional to this potential difference. This is an important feature of the method, as the ion energy can be directly controlled by the operating plasma parameters.

The TVA plasma source was placed in a vacuum chamber pumped down to a base pressure of $9 \times 10^{-4}$ Pa. The anode consisted of a pure carbon rod of 12.5 mm diameter. As the anode is continuously eroded during plasma running, a computer controlled in-house system which allows a fine mechanical adjustment of the interelectrodic distance was used. The in-situ acquisition of the arc and analyzer I-V characteristics were also performed using current and voltage transducers and LabView software.

![Figure 1. The experimental setup of the TVA plasma](image1)

![Figure 2. The retarding field ion analyzer.](image2)

As the TVA plasma does not fill the vacuum chamber, the energy of the carbon ions formed in the plasma is given by: $E = e(V_0 - V_p)$, where $e$ is the charge of the electron, $V_0$ is the potential of the
arriving point of the ion, and \( V_p \) is the plasma potential. Thus, for a given \( V_0 \) (which can be ground or any other voltage), the ion energy is directly proportional to the plasma potential which, in turn, is directly correlated to the arc voltage and current.

This paper presents the ion energy distribution at 35 cm distance from the anode.

In order to determine the ion energy distribution, an in-house RFA was used to decelerate and filter ions, according to their energy. A planar RFA consisting of one stainless steel grid (mesh having 30 μm wire and 50 μm gap) and a molybdenum collector, encapsulated in a stainless steel cylinder was used. The grid was polarized with a constant potential. The collector also serves as the retarding electrode. The main components of the RFA module can be observed in figure 2.

3. Results and Discussion

A typical I-V characteristic of the carbon TVA plasma containing the ignition stages of the plasma can be found in [7].

The RFA data presented in figure 3 were obtained for the plasma operating conditions shown in the figure legend.

The voltage applied on the negatively biased grid, which has the role to repel the electrons, did not influence the shape of the I-V characteristic at the collector. The only difference observed was the relative position of this characteristic to the abscissa. The explanation for this behavior is that the negatively biased grid is partially successful in repelling the secondary electrons resulted from the collector due to ion impact. As Bohm [5] pointed out also, in order to obtain the real value of the collector current the electronic contribution to the current must be taken out. Thus, the I-V characteristic of the collector should be shifted with the value given by the saturation of the current signal. For simplicity, we did not shift the characteristics, as at this stage we are interested on the energy distribution function only. In this respect, further studies will be undertaken for the estimation of the ion flux.

![Figure 3. I-V characteristics of the RFA collector.](image)

Figure 4 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 values in the range 300-600 eV and do not depend significantly on the applied voltage at the anode. These are very high values of the carbon ion energy and are not found in other plasma sources. During thin film deposition, high energy ions and neutrals arrive at the substrate. This fact gives them superiority over films obtained by other plasma methods, in terms of higher compactness and smoothness.
4. Conclusions

A relatively high ion energy was found for the carbon ions obtained in the TVA plasma. It was observed experimentally that the values of the ion energy of carbon ions vary within a relatively small range around 450 eV for arc voltages in the 700–1250 V range. This high energy is not encountered in the ions formed in other types of plasma. This fact gives them superiority over films obtained by other plasma methods, with higher compactness and smoothness.

Further investigations for the measurement of the ion flux for different plasma conditions are envisaged.

References

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