Thermionic Vacuum Arc Diagnostic Using Emissive Probe

Vasile Tiron, Constantin Aniculaesei, Gheorghe Popa

Abstract:

In this paper, experimental results are presented on study of the copper thermionic vacuum arc using emissive probe. Experimental results show that plasma potential is direct related to the discharge voltage and it shows non-linear distribution from the anodic melted spot towards to the plasma extremity.

Keywords: *thermionic vacuum arc, emissive probe.*

1. Introduction

Thermionic vacuum arc (TVA) is an electrical discharge burned in the vapours of a metal anode, vapours produced by bombarding anodic material with an energetic thermoelectronic beam [1]. The main advantage of this method is the easy control of the ion energy and the fact that during deposition of the metallic thin layer this is continuously bombarded with energetically ions without the need to bias the substrate [2]. Another advantage of the method is the presence of a high energetic electron density around the anode which provides a high rate of deposition, and that this method is very useful in deposition of refractory or ceramic materials [3]. These benefits correlated with discharge that occurs under high vacuum conditions, the deposited layer is characterized by high purity and hardness, good adhesion, low roughness and high compaction [4].

1.1. Experimental set-up

The experimental setup consists of a stainless steel chamber, equipped with various ports for attachment of electrical and optical diagnostic systems, in which the electrodes of the discharge are placed. To obtain a high vacuum condition it is used a pumping system consisting in a preliminary vacuum pump and a turbo-molecular pump. Electrodes system consists of an anode and an electronic gun with role of cathode (Figure 1). The anode is shaped as a crucible which contains the material to be evaporated, in this case copper. Cathode is made in the form of a coil with 4 loops of tungsten wire (0.5 mm thickness) surrounded by the Wehnelt cylinder used for termoelectrons focus. Both, the cathode and the vacuum vessel are grounded, while the anode is at a very high potential to them. Electronic gun is mounted on a linear displacement system that allows modification of the distance between electrodes during operation of termionic vacuum arc. The angle between the cathode axis and normal direction to anode surface is in this case fixed at value of 60°.

For ignition and maintaining of the discharge is necessary that thermoelectrons coming from tungsten filament to be focused and accelerated towards the anode so as to cause melting and evaporation anodic material and to ensure in interelectrodic space a sufficiently high pressure vapours of the anodic material [5].

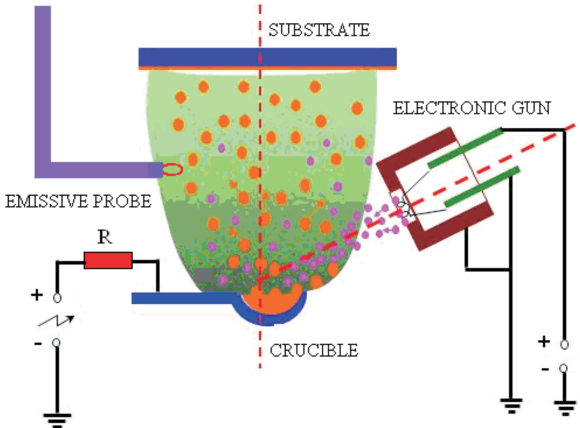

Fig. 1. Experimental setup.

1.2. Results and discussions

Thermionic vacuum arc can be established in vacuum conditions between a heated cathode and an anode placed at small distances in front of the cathode. For a convenient applied d.c. voltage across the cathode and anode space, a melted spot appears on the anode surface and a continuous evaporation of the anode material from this melted spot is established due to the accelerated electrons emitted from the cathode and incident on anode. Consequently, in vacuum, a steady state density of the metal vapors appears in the interelectrodic space. At further increase of the applied high voltage, suddenly a bright discharge appears in the interelectrodic space in the vapours of the anode material, with a simultaneous decrease of the voltage drop between electrodes and with a significant increase of the current. The anode fall must be high enough to ensure the vapor production at the anode after ignition. The cathode fall, which depends on the relative position of the electrodes and the cathode temperature, must ensure enough ions in proximity of the cathode. Since the cathode is connected to the grounded vessel, the potential drop between the interelectrodic plasma and the vessel is about the cathode fall. Ions produced in the interelectrodic plasma arrive at the metallic walls of the vessel with the energy represented by plasma potential (hundreds of volts).

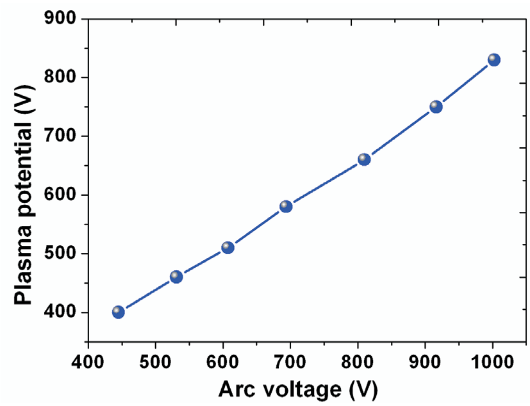

Fig. 2. Plasma potential versus discharge voltage measured at a fixed position (3 cm from anode).

The ions energy depends on the operating parameters like arc voltage, current intensity through filament and the geometrical parameters, like the relative position of the electrodes. Thus, plasma potential is an important parameter in thin layer deposition process.

To determine the plasma potential an emissive probe was used. In the Fig. 2 the plasma potential, measured as floating potential of the emissive probe placed in a constant distance from the anode (3 cm), is presented versus discharge voltage.

a)

b)

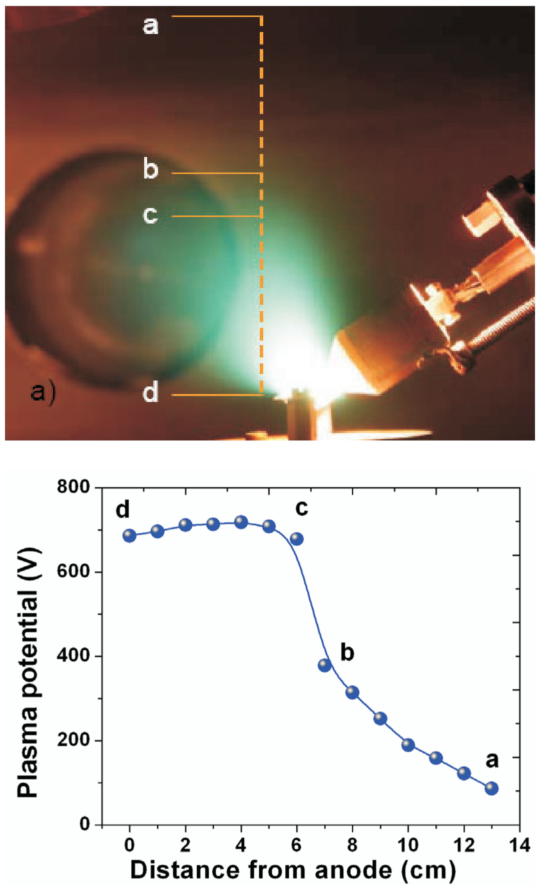

Fig. 3. TVA plasma image (a) and corresponding axial distribution of plasma potential (b), arc current - 180 mA, arc voltage - 750 V; dashed line - emissive probe path.

In Fig. 3b is illustrated the spatial distribution of plasma potential measured on normal direction to the anode surface. Depending on the operating parameters (arc current, arc voltage, filament temperature, relative position of the electrodes and anode material) this dependence presents different sectors with different evolution rate of plasma potential.

Branch ab corresponds to the weakly ionized plasma where the plasma potential increases linearly from vessel wall towards anode. Next branch (bc) corresponds to the transition region where plasma potential increases rapidly to a high value which corresponds to a double layer. Branch cd corresponds to the bright plasma area where the plasma potential is almost constant close to the anode potential. This area is like a "fireball" where the termoelectrons are trapped and forced to excite and ionize the metallic atoms evaporated from anode.

a)

b)

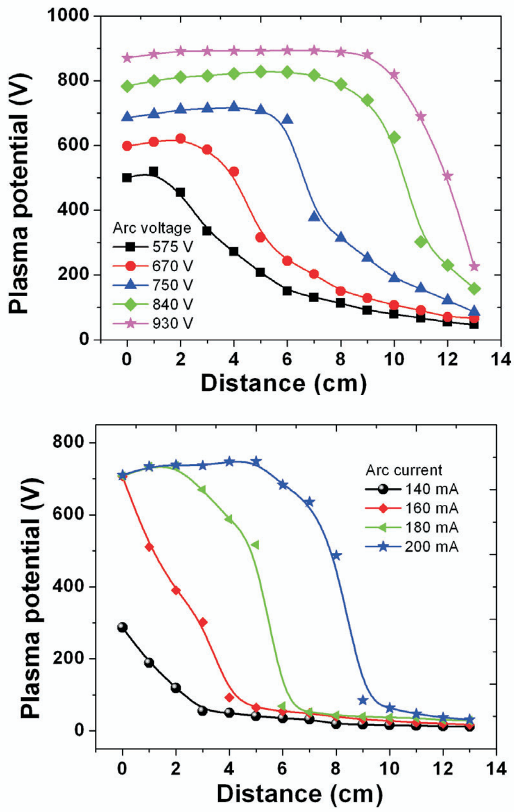

Fig. 4. Axial distribution of plasma potential for a constant arc current and different voltage arc (a) and for different values of arc current (b).

The spatial distribution of plasma potential strongly depends on operation parameter like arc voltage and arc current and its value is direct related to the voltage arc (fig. 4). For plasma processing (thin film deposition) is necessary to produce plasma with high energetic ions and high ionization degree. Consequently, is useful to operate the arc discharge at high anode voltage and low current value.

2. Conclusion

The TVA is a valuable tool for basic physical investigation related to plasma assisted deposition process due to its flexibility and accessible range of operation parameters. The energy of ions is direct related to plasma potential which can be fully controlled and changed even during deposition.

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