STRONG DOUBLE LAYER STRUCTURE IN THERMIONIC VACUUM ARC PLASMA*

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Experimental results are presented on plasma properties of a thermionic vacuum arc (TVA) produced in copper vapor. Plasma parameters as spatial distribution of the plasma potential and electron temperature were measured using emissive probe technique and double probe, respectively. The former parameter clearly shows presence of a strong double layer (DL) structure surrounding the anodic plasma, which separates low density plasma formed downstream within cathode region and high density plasma formed upstream in the anode region. The potential drop across DL is of the order of the anode potential (kV) so that kinetic energy gained by charged particles crossing DL is much larger than their initial thermal energy.

Key words: double layer, anodic plasma, thermionic vacuum arc.

1. INTRODUCTION

Basically, the thermionic vacuum arc plasma (TVA) is an electrical discharge fired between a hot filament as cathode and a metallic anode of a plasma diode. The main characteristic of the TVA is it ignites in the anode material vapors continuously generated by bombardment with electrons emitted by the filament and accelerated towards anode in a vessel, which is depressurized down to a residual pressure less than 10^{-6} mbar [1]. Due to the very low pressure in the vessel but high vaporization rate of the hot anode a rather large gradient of the concentration metallic vapors is produced. This gradient can explain plasma formation in the anode region where vapor pressure is large enough to assure electron-metallic atom collisions and ionizations so that anodic plasma may appear. On the other hand, very low pressure in the rest of the chamber allows the metallic atoms to move

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freely and deposit and condensate on any surface placed in the vessel including internal surface of the vacuum chamber. Consequently, the TVA is a very suitable method for deposition of high purity metallic thin films [2].

Moreover, due to the low pressure the metal ions generated within the anode plasma are accelerated towards the chamber wall and move almost without collisions and bombard the internal surface of the vessel and the thin metallic layer produced by condensation of the anodic metal vapors. This bombardment of a growing film by energetic particles strongly influences the growth mechanisms and the structure of the film leading to a more compact structure and low roughness of the deposited metallic thin layer [3].

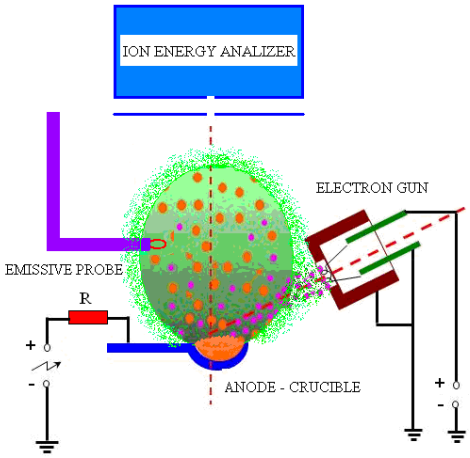
The aim of this contribution is to show that in some experimental conditions as low residual pressure, low discharge current intensity but high anode voltage a well spatially defined anodic plasma can be formed surrounded by a well defined potential structure, which indicates formation of a strong double layer (DL). The energy of the ions bombarding the internal surface of the vessel is determined by potential drop across the DL surrounding the anodic plasma.

2. EXPERIMENTAL SET-UP

The experimental setup consists of a stainless steel chamber (cylinder of 70 cm diameter and 30 cm in length) equipped with various ports for electrical and optical plasma diagnostic systems. Typical residual pressure inside the vacuum vessel was about 10^{-6} mbar obtained with a pumping system consisting of a preliminary vacuum pump and a turbo-molecular one. The discharge electrode system consists of a metallic anode and an electron gun as cathode (figure 1). The anode consists of a crucible (made of tungsten) which contains the material to be evaporated (copper). The cathode consists of a filament (4 loops of tungsten wire, 0.5 mm diameter) surrounded by the Wehnelt cylinder (used for termo-electrons focus). Both, the cathode and the vacuum vessel are grounded, while the anode was biased positively up to about 1.5 kV. The cathode system acting as an electron gun was mounted on a mechanical system that allows control and correction of the distance between electrodes during operation of the TVA. The angle between the cathode axis and normal direction to anode surface was fixed at the value of 60°.

Plasma potential was measured using an externally heated emissive probe. It consists of a loop (about 2 mm in diameter) made of tungsten wire (0.2 mm diameter). Floating potential of the probe was measured for different position of the probe as a good approximation of the local plasma potential [4]. Electron temperature was measured using either cylindrical Langmuir probe or a double probe system [5]. In both cases probes were made of tungsten wire (0.2 mm diameter and about 3 mm in length).

Fig. 1 – Experimental setup.



3. RESULTS AND DISCUSSIONS

With increasing the anode bias a slight increasing of the current intensity flowing between the hot cathode and the anode as in a vacuum diode (the *AB* branch of the current voltage characteristic in figure 2) was observed. For a given d.c. anode voltage (point *B* fig. 2) a melted spot appears on the anode surface and a continuous and constant evaporation of the anode material on that hot spot is established. Consequently, a steady state but not uniform density of the metal vapors appears in the inter-electrode space. With further increase of the anode bias a bright discharge appears in the inter-electrode space but localized in the anodic region, where relatively high vapor density of the anode material is present. Moreover, simultaneous decrease of the voltage drop between electrodes followed by a significant increase of the discharge current intensity (branch BC in figure 2) is registered. It corresponds to a typical negative resistance of an arc discharge [6].

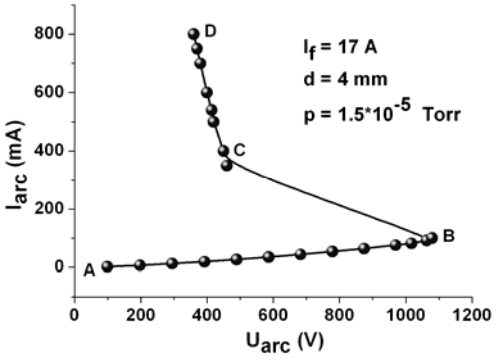


Fig. 2 – Voltage - ampere characteristic of the thermionic vacuum arc.

Specific for the TVA regime is the fact that the most intense radiation is delivered by the plasma region around the anode, which behaves as anodic plasma surrounded by a rather sharp light boundary as is presented in figure 3. Consequently, spatial distribution of the plasma potential was measured with respect to the ground using the emissive probe. The probe was passed through the plasma in the radial direction of the expanding plasma as it is presented in fig.3a, dashed line. Spatial distributions of the plasma potential measured as floating potential of the emissive probe in direction mentioned above starting from the anode surface are presented in fig. 3b for constant discharge voltage but different discharge current intensities. These distributions clearly show a strong DL structure in which potential drop is of the order of 10^5 V/m [7]. Moreover, the potential drop across the DL is of the order of 10^3 V, which shows that kinetic energy gained by both ions and electrons crossing the DL is much larger as their thermal energy in the plasma of their origin.

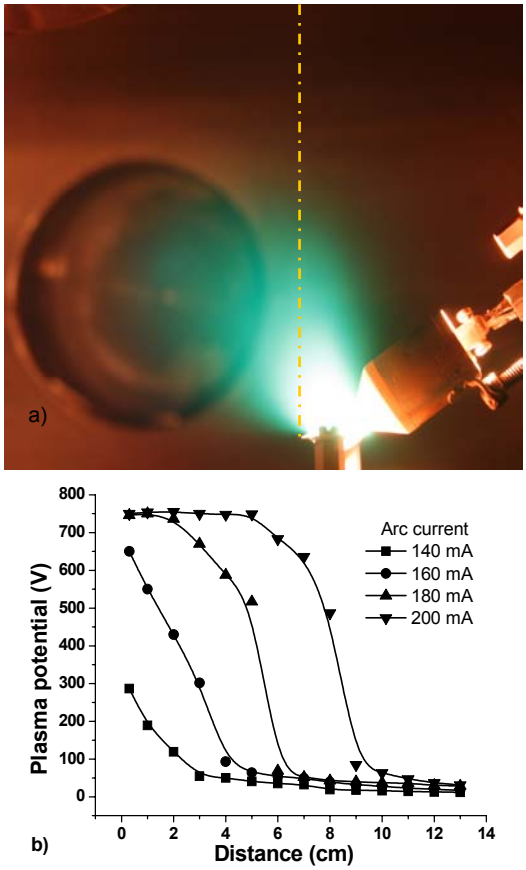


Fig. 3 – (a) TVA plasma image and dashed line - emissive probe path; (b) corresponding axial distribution of plasma potential. The arc voltage: 800 V; and discharge current intensity as parameter.

For a constant anode bias but increasing discharge current intensity the anodic plasma is expanding into the vessel and potential drop within surrounding DL becomes larger too.

The electrons temperature within the plasma regions on both sides of the DL was measured using a screened cylindrical probe on cathode side of the DL and a double probe system within the anodic plasma. Downstream region towards the cathode or the wall vessel contains a rather low plasma density in which plasma potential is closed to cathode potential. It also contains a rather mono-kinetic high energy ion beam, which asks for a screen to protect the cylindrical probe and makes possible the recording of the probe characteristics in its shadow. Electron temperature in this region is of the order of 20 eV, while the plasma density of the order 10^9 cm^{-3}. Upstream region of the DL towards the anode has a rather high plasma potential which ask for a double probe to be used for plasma diagnostic. Before recording data, the probe was cleaned by electron bombardment to diminish the influence of the copper film deposition onto the probe. Electron temperature in the anodic plasma is of the order of 50 eV and plasma density of 10^{11} cm^{-3}. Presence of the fast electrons entering the anodic plasma is not easy to be emphasized but their presence can be pointed out by faster increasing of discharge current intensity with increasing anode bias. Increasing the anode bias the potential drop within DL becomes larger and those energetic electrons which collide the copper atoms produce an additional ionization processes.

4. CONCLUSIONS

The experimental results presented in the paper show that in some experimental conditions within TVA a strong double layer surrounding the anodic plasma can be produced. Plasma parameters as spatial distribution of the plasma potential, electron density and temperature on both sides of the DL were measured using emissive probe technique and double probe, respectively. The energy of the ions bombarding the internal surface of the vessel is determined by potential drop across the DL surrounding the anodic plasma. The DL accelerates the ions towards the cathode or any grounded surface and by ion bombardment may produce better quality of the metallic deposited layer.

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