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STUDY ON TERMIONIC VACUUM ARC- A NOVEL AND ADVANCED TECHNOLOGY FOR SURFACE COATING

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The Thermionic Vacuum Arc (TVA) discharge is an original technology for thin film deposition in high vacuum conditions. The originality of this method consists in the fact that the substrate is bombarded with energetic ions (of 200-500 eV) of the material to be deposited just during deposition and no buffer gas is needed. The TVA plasma is ignited in the vapors of the anode material by heated cathode electron bombardment. The electron temperature of the Thermionic Vacuum Arc in silver vapor plasma was determined by using the optical emission spectroscopy (OES) obtained for different arc parameters.

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1. Introduction

Thermionic Vacuum Arc (TVA) is a new type of discharge first reported in 1985, which ignites in vacuum conditions in the vapors of the anode material, continuously generated by the electron bombardment of the anode. The electrons, emitted from a heated tungsten cathode, are accelerated towards the anode, by a d.c. high voltage applied across the electrodes. At switch on, the anode material first melts and afterwards starts to boil, a steady state metal vapor atoms density being established in the interelectrodic space. At further increase of the applied high voltage, a bright and stable metal vapor discharge is established [1].

Due to the fact that the cathode (the vacuum vessel also) is at the ground potential, the anode and also the metal vapor plasma, will be at elevated potential against the ground. It results that the plasma ions will be accelerated towards the vacuum vessel wall, gaining an energy proportional with the plasma potential against the ground. Consequently, during the deposition of a thin film condensing on a substrate from the metal vapor plasma, the growing film will be bombarded during deposition, by energetic ions, just those of the depositing material. Because the deposition of the thin films using TVA technology is obtained in high vacuum conditions and also under the energetic ions bombardment of the depositing thin films, we may expect a high quality of such obtained films, namely, high purity, increased adhesion, low friction, low roughness, compact and nanostructured films.

TVA can be used to deposit thin films of various materials like metals, alloys, ceramics, DLC (Diamond Like Carbon) and refractory metals such as W, Mo, Ta, Nb, Re and B. This new technology is especially adequate for the deposition of refractory metals due to the high density of the power on the unit surface of the evaporating refractory metals. Also, due to the high power density in front of evaporating materials, the deposited thin film on the sample is droplets free.

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A better knowledge of the TVA discharge can contribute to the increase of the performances of the deposited thin films using the heated cathode vacuum arc with subsequent improvement of the quality of the deposited thin films. Unfortunately, high power density and the quick cover of the electrical probe with the evaporating anode material do not permit the use of electrical probe for the diagnostics of the Thermionic Vacuum Arc except at points relatively away from the main arc plasma body.

In this paper we are presenting data on the TVA plasma using the non invasive methods of plasma spectroscopy using optical emission of the excited atoms of the evaporated anode material.

2. Experimental

The experimental arrangement of the Thermionic Vacuum Arc (TVA) in Silver Metal Vapor Plasmas for the study of the Optical Emission Spectroscopy is shown schematically in Fig. 1. It consists from:

a) Cathode –a tungsten wire with $\phi = 0.5$ mm, four time wraparound and mounted inside of a Wehnelt cylinder; One side of the filament and the wehnelt are both grounded.

b) Anode- a spoon like piece of wolfram with a depth of 3 mm has a width of 12 mm, has a length of 25 mm.

c) OES-Optical Multichannel Analyzer has a spectral range in UV and visible.

Other geometrical parameters are the distance d between electrodes (cathode and anode) and the angle between Wehnelt cylinder axis and a virtual perpendicular line on crucible surface.

Electrodes assembly is mounted inside of a large vacuum vessel, provided with a glass window to observe the arc discharge and also for spectral data acquisition.

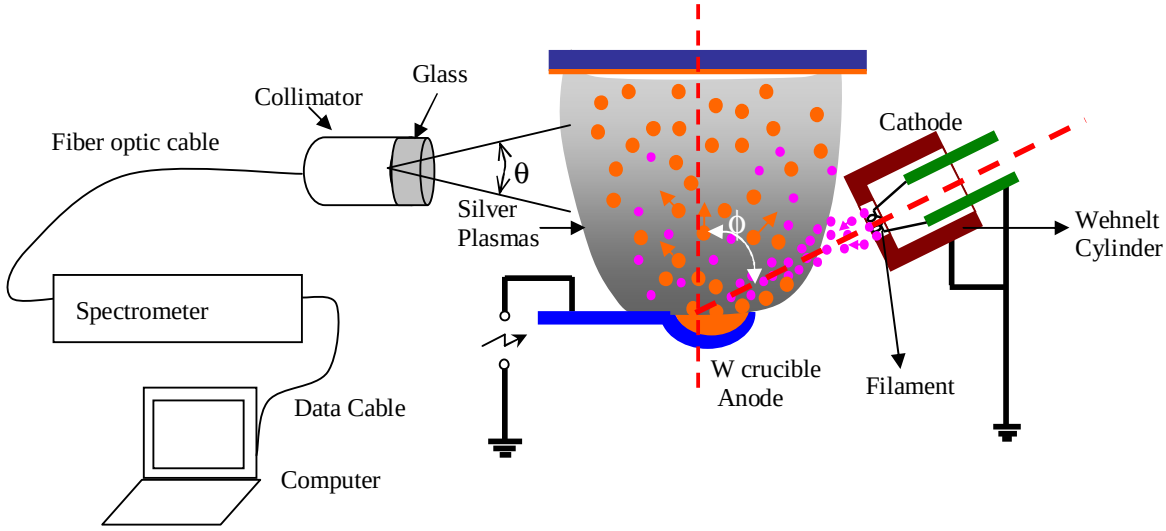

Fig. 1. Experimental arrangement.

For the measurement of the spectral data we used Ocean Optics USB2000 spectrometer (Optical Multichannel Analyzer) with 600 traces/mm grating. The spectral data are collected from silver vapor plasma to spectrometer entrance slit by optical fiber cable. The obtained spectroscopic data were processed by OOIBASE32 program.

The spectral data were registered using 14 collimators, the distance between to adjacent collimators being of 7.5 mm. The light limiting diameter of the holes of each collimator line was 2 mm and the length of each collimator was of 67 mm.

In Fig. 2 are shown the arrangement in space of collimators. The emission spectra are collected by each collimator hole using an optical fiber which is moved from one collimator to another collimator. For each recorded spectra the optical fiber is tightened to the needed hole of collimator.

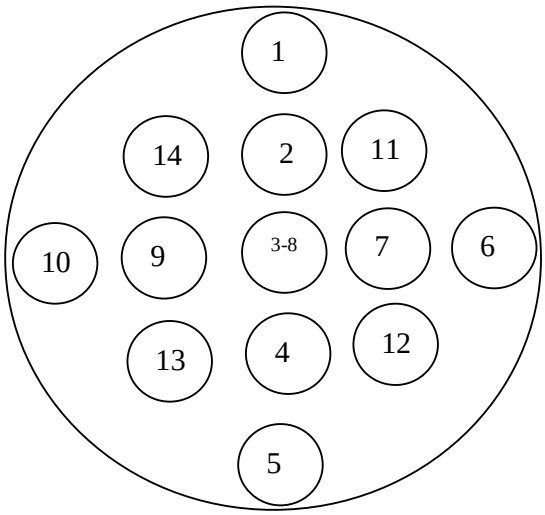

Fig. 2. Schematical diagram of the distribution of the collimators.

The studied discharge was in silver vapors. Due to the relatively low values of the melting points (962 ^{o}C) and of the boiling point (2212 ^{o}C) of silver, the TVA discharge is easily ignited and maintained. The emission spectra of the TVA discharge in silver vapors were taken through the glass window of the vacuum vessel using 14 collimators. The minimum distance between two collimators was 7.5 mm. The optical signal was taken from each collimator using an optical fiber connected to an Optical Multichannel Analyzer (OMA) connected to a computer.

The ignited heated cathode arc was running stable and smooth. The working parameters were: cathode filament heating current of 18.5 A, anode bombarding electron beam current 86 mA (before arc ignition), arc discharge current 400 mA, the applied high voltage across the electrodes had values of 1200 V, 1250 V, 1300 V and 1350 V. The pressure in discharge chamber was 5×10^{-5} mBar for the first two experiments and 3.8×10^{-5} mBar and 3.8×10^{-5} mBar for the last two cases, respectively.

3. Results and discussion

Silver atoms have 4 transitions between 200 to 850 nm which are very strong in respect with other transitions of the silver atoms. These transitions are summarized in Table 1.

Table 1. Neutral silver optical transitions and energy levels [5].

Intensity (I)	Wavelength (nm)	A_{ki} ($10^8 s^{-1}$)	Energy Levels (cm^{-1})	
1000	328.06	1.47	0.00	30472.703
500	338.28	1.35	0.00	29552.061
90	520.90	0.75	29552.061	48764.219
90	546.54	0.86	30472.703	48764.219

Experimental parameters sets and calculated Plasma temperatures (T_e) are summarized Table 2.

Table 2. Experimental parameters sets for TVA silver metal plasma.

	1st parameter set	2nd parameter set	3rd parameter set	4th parameter set
I_f	18.5 A	18.5 A	18.5 A	18.5 A
V	1200 V	1250 V	1300 V	1350 V
P	5.10^{-5} mbar	5×10^{-5} mbar	3.8×10^{-5} mbar	5×10^{-5} mbar
I_B	86 mA	100 mA	120 mA	140 mA
d	5.5 mm	5.5 mm	5.5 mm	5.5 mm
ϕ	50^o	50^o	50^o	50^o
T_e	1950 K	1960 K	2170 K	2660 K

Where; I_f; Filament current, V; Voltage, P; Pressure, I_B; electron bombardment current, d; distance between electrodes, ϕ; Anode angle.

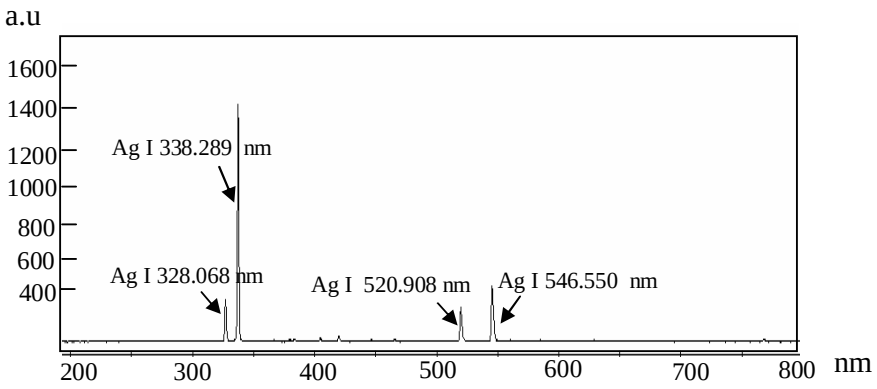

Fig. 3. Typical emission spectrum of TVA plasma running in Ag vapours.

The emitted spectra of the discharge in silver vapors was taken from each collimator line and for various applied high voltages used to sustain the discharge. Fig. 3 shows a typical emission spectrum. Clear silver line can be seen, namely the lines with the wavelengths 328.068 nm, 338.289 nm, 520.908 nm and 546.650 nm. Using the first two line's intensities, we were able to evaluate the electron temperature of the silver plasma as being in the range of 2000-2700 K.

The ratio of the intensity of the two excited atomic emission lines is proportional with the electron temperature [2]. The following equation can be applied for the estimation of plasma electron temperature [2]:

$$T_e = \frac{E_{k1} - E_{k2}}{k} \left\{ \ln \left[\frac{I_2 A_1 g_1 \lambda_2}{I_1 A_2 g_2 \lambda_1} \left(\frac{E_{k2}}{E_{k1}} \right)^{1/2} \right] \right\}^{-1}$$

Indexes 1,2 refer to the two spectral lines; k is the Boltzmann constant; E_k is the upper level energy; g is the statistical weight of the optical transition under consideration with the transition probability A ; λ is the spectral line wavelength and I the measured line intensity. The Ag I 328.068 nm and Ag I 338.289nm lines have been selected to be used to evaluate electron temperature T_e. Data of the optical transitions have been taken from reference [3].

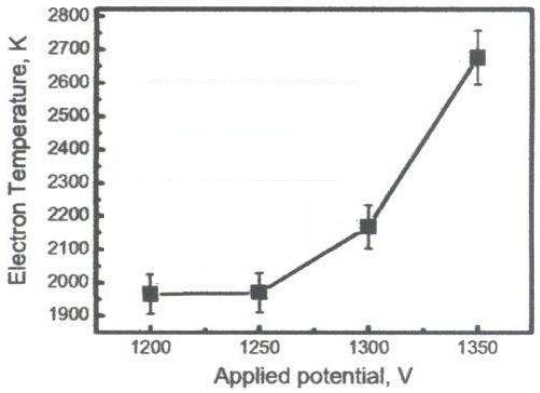

Fig. 4. Electron temperature as function of arc voltage drop across the electrodes during the discharge. Residual pressure in the vacuum chamber remained between 3.8×10^{-5} mbar and 5×10^{-5} mbar during measurements.

The results of calculations, plotted in Fig. 4, show the influence of the applied potential on the electron temperatures.

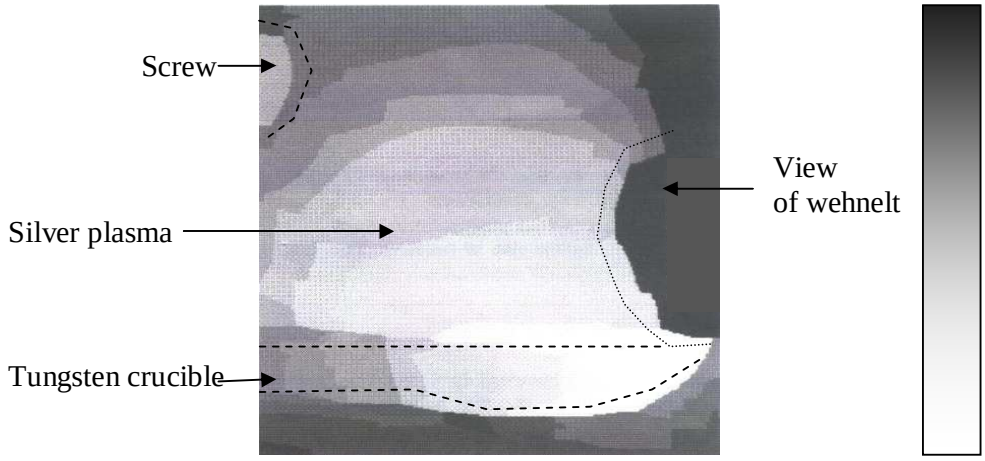

Fig. 5. Photograph of typical silver TVA plasma with levels of the same radiated light intensity.

In Fig. 5 is given a view of the ignited arc, inside of the vacuum vessel on which can be seen the levels of the same radiated light intensity. In spite of the large surface of the crucible, the obtained distribution sustains a spherical symmetry. A possible explanation is the fact that most of the evaporation is coming from the melted surface on which electron beam is incident. On the figure were markets the limits of tungsten crucible, wehnelt cylinder and a part of a screw.

4. Conclusion

The electron temperatures were found to depend drastically on the applied voltage across the plasma. The electron temperature and consequently the energy of species present in the TVA plasma, influence the surface morphology, bonding strength and compactness of the coatings. The plasma spectroscopy can give us valuable information on TVA plasma temperature in very short time using OMA techniques.

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