JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 9, No. 4, April 2007, p. 867 - 870

Gaseous Thermionic Vacuum Arc(G-TVA) - an extension of TVA (Thermionic Vacuum Arc) input materials from solid samples to gases and liquids for carbon thin film deposition

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The aim of this paper is to find out the possibilities to extend the area of applications of Thermionic Vacuum Arc technology developed by our group for high quality thin fim deposition. We named this new technology Gaseous Thermionic Vacuum Arc (G-TVA). Through using a sintered filter various gaseous flows can be obtained, a process which is similar to anode evaporation under electron bombardment of anode by electrons as in the case of TVA discharge. The first step in our programme is to generate G-TVA discharges in carbon compounds like methane, acetylene, etc and to compare the obtained results with hydrogen free carbon films obtained using TVA.

(Received November 2, 2006; accepted February 28, 2007)

Keywords: Gaseous thermoionic vacuum arc, Carbon, Thin films

1. Introduction

Along more than a decade of efforts, our group has developed a new type of discharge namely Thermionic Vacuum Arc (TVA) which in vacuum conditions can generate an intense plasma in the vapors of the evaporating anode material. Thermionic Vacuum Arc (TVA) has a simple construction; the cathode is a tungsten filament surrounded by a Wehnelt cylinder and the anode – an adequate crucible containing the material necessary to generate the vapors. At the application of a high dc voltage over the electrodes, the accelerated electrons incident on the anode, heats the anode material which first melts and afterwards starts to boil and evaporate. A steady state concentration of the anode material's atoms is established in the interelectrodic space. At a further increase of the applied high voltage, **in vacuum conditions,** a bright Thermionic Vacuum Arc (TVA) is established. Practically, any solid material mounted at the anode can be evaporated and transformed to bright plasma. Even intense plasma of the refractory materials is obtained easily. Due to their high melting points, instead of crucible as anode are used rods of refractory materials.

This new technology for thin films (or even thick films) deposition has a number of sounding advantages like:

-thin film is condensing exclusively from the plasma state of the material to be deposited

-during deposition, the growing thin film is bombarded by the energetic ions just of the atoms of the anode material plasma.

-the energy of the ions can be fully controlled and even changed during the deposition

-because the TVA plasma is localized around the arc electrodes, a number of independent and simultaneous discharges (eventually with different materials) can operate in the same time and in the same vacuum vessel in order to realize co-deposited thin films.

TVA technology appears to ensure the most desired performance for surface coatings.

The extension of Thermionic Vacuum Arc technology to coatings using gases or evaporable liquids instead of solid materials is of great interest. Indeed, the number of materials which can be used for TVA deposition will increase dramatically.

We will consider in what follows the possibility to put in operation G-TVA as a promising new technology able to use as input material various type of gases or vapors for thin film deposition. In the case of TVA technology, where the evaporated atoms are produced at the surface of the melted anode material, a high gradient of the neutral particles density is observed. So, the discharge is concentrated nearby anode. Similar gradient of pressure can be realized in G-TVA technology for coating.

2. Experimental arrangement

This new type of discharge - Gaseous Thermionic Vacuum Arc (G-TVA) consists from a heated thermionic cathode (as in the case of TVA) while the anode is a disk type sintered powder piece tightly bounded to a stainless steel tubing connected adequately to the gas supply bottle. (Fig. 1).

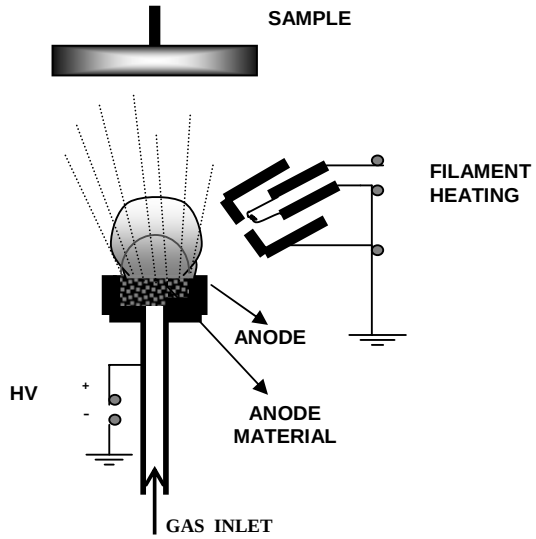

Fig .1. Schematically configuration of the electrodes in the case of G-TVA.

The anode consists from a stainless-steel pieces with a diameter of 16-25 mm, provided with a tubing necessary to connect this anode to an out vacuum chamber gas sources. Inside of the hole of the stainless steel piece is mounted a disk of sintered metal powder with an average size of 100 μm. In the Fig 2 are shown various used anodes through which working gas can diffuse in the cathode-anode space.

A leak valve is used to select the gas inlet flow and a manometer the pressure of the gas before entering in vacuum chamber. Due to the use of a sintered powder piece in construction of the anode, the coming gas flux to the anode is dispersed by the sintered powder. In this way the full surface of the anode is participating to the sustain of the uniform distributed plasma an anode surface.

Fig .2. Different types of the disk of filter (powder of brass) after encapsulation.

In order to localize the arc discharge just around the electrodes, we established like in the case of TVA, a strong gradient of the gas from anode surface away. If the vacuum vessel is pumped down with a high speed and the gas flux through the sintered filter is low, we can limit the presence of the gas needed to ignite and sustain the discharge just around the electrodes. That means that a high enough pressure is maintained part around the anode falter, where the Paschen conditions for plasma agnation are fulfilled A gradient pressure of two order of magnitude for the gas has been obtained (fig. 3) Away from to anode the gas pressure as well as the gas residual gas density is low enough to avoid the plasma expansion.

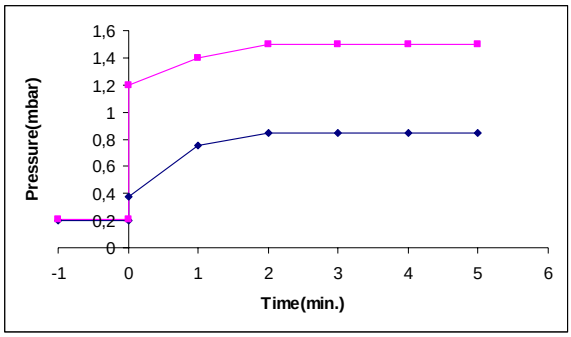

Fig. 3. Time evolution of the pressure at the inlet of gases at the order of 1.2 torr.

A peculiarity of the G-TVA discharge is the critical value of the interelectrodic distance. In deed, for small distance, a cold cathode discharge can ignite (fig. 3). For distance higher than this critical distance we will have a real G-TVA discharge because only if the cathode is heated the discharge can ignite. In this case, the G-TVA discharge is sustained by the thermoelectron emission current from the cathode. Further researches are necessary to establish all plasma parameters controlling G-TVA ignition and operation.

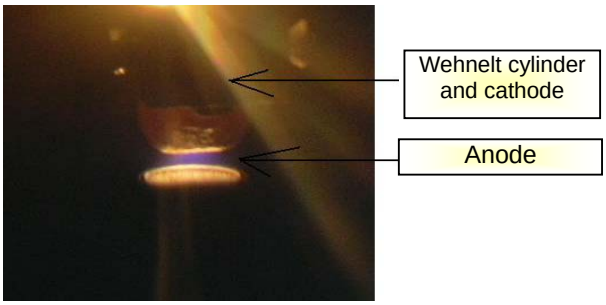

Fig. 4. Photo of the G-TVA discharge in methane.

We tested the ignition and the operation of this gaseous TVA diffusing through the sintered powder anode, a flux of CH_4 (sintering powder size: 0.006-0.009 clG, porosity 30 %).

Table 1. Working conditions from the GTVA discharge.

I_{arc}(mA)	U_{arc} (V)	$I_{filament}$(A)	Interelectrodic distance (mm)
350	1600	25	5

The experimental results were performed at the conditions shown in Table 1. Only the distance between anode and sample was different, as we can see in the data from Table 2.

3. Results and discussion

We tested the ignition and the operation of the gaseous TVA diffusing through the sintered powder anode, a flux of CH_4 (sintering powder size: 0.006-0.009 clG, porosity 30 %), at different anode sample distances (Table 2), and the XPS (X-ray photoelectron spectrometry), showed a very interesting feature for all the samples.

Table 2. Bonding energy and the content of sp^2 and sp^3.

Sample	sp^2 bonding (eV)	sp^3 bonding (eV)	Bonding Energy ΔEn, (eV)	$\%sp^2$	$\%sp^3$	Anode-sample dist (mm)
III-3	284.99	285.93	0.94	57.4	41.1	55
IV-2	285.06	285.94	0.88	58.7	37.3	50
IV-4	285.02	285.89	0.87	57.4	38	60
IV-7	285.06	285.90	0.84	74.7	23	75

A very interesting feature especially for the sample III – 3 was found (Fig. 5). XPS spectra were performed in the following conditions: P≈10^{-9} torr, Ume=3.2 kV;RX: U=14kV, I=20mA,P=280W;Mgk_{α} (E=1253.6eV), Flood gun: U=3V, I=0.2 mA;

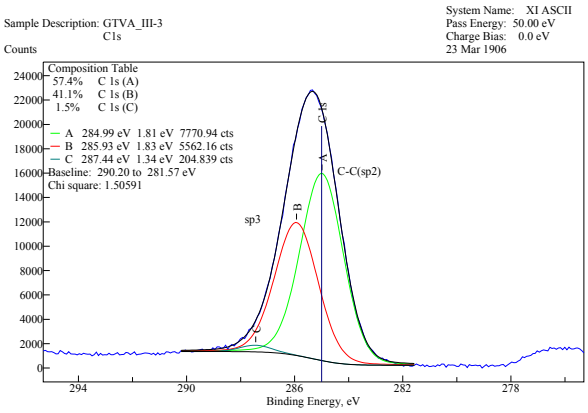

Fig. 5. High rezolution of the GTVA III-3 sample.

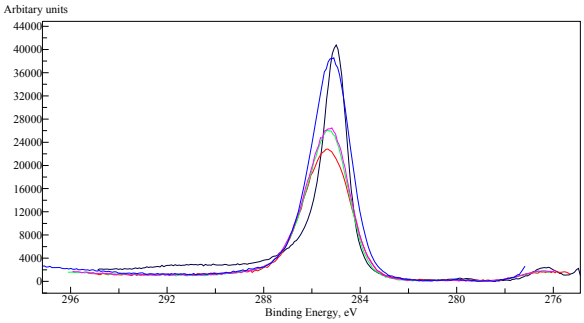

Fig. 6. Superposed XPS spectra for all the samples presented in Table 2.

We can notice the higher density of sp^3 bonding in 41.1% in comparison with only 57.4% sp^2 bonding in the case of GTVA III-3 sample

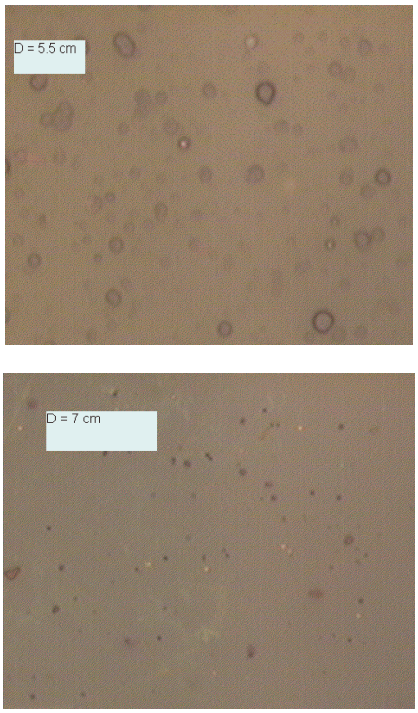

Fig. 7. The morphology of the film in the case of two distances between the anode and the sample.

The obtained thin films are very smooth, with roughness under 5 nm, compact, with high adherence and well nanostructured. In the Fig. 7 is presented the morphology of the film and we can see some grain size of

carbon thin films under 2-4 nm, larger in the case of smaller distance between the anode and sample (d=5 mm).

4. Conclusion

The shape of the discharge produced in gas using the newly proposed G-TVA technology is similar with those obtained in the case of TVA in the metal vapors. Extended researches are necessary to compare all parameters of the two mentioned discharges. Also, we obtained carbon film deposited on glass samples mounted at different distances away from the G-TVA anode. Obtained results confirm our initial hypothesis that G-TVA might be an useful tool for high quality thin film depositions.

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