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THERMOELECTRONIC EMISSION OF TUNGSTEN CARBIDE ACTIVATED TUNGSTEN FILAMENT

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Tungsten cathode activation using a carbon vapor discharge is described. The carbon plasma or carbon vapors are generated nearby tungsten cathode as a result of the bombardment of carbon anode by an accelerated beam. Cathode surface analysis prove that the activated cathode is formed from a mixture of tungsten carbonede and tungsten. Comparative volt-ampere characteristics of the cathode electron emission of treated and not traded electrodes clearly proved the activation of the cathode.

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1. Introduction

In a number of technologies for plasma processing of materials, as cathode are used activated electrodes which can ensure at a constant temperature an increased thermoelectronic emission current than pure non-activated metal cathode, the electrode temperature being kept the same. Tungsten is a material of a special interest as cathode having one of the highest melting temperature but unfortunately having also one of the highest work function value (4.5 eV). Because of its high work function value, the density of the emitted thermoelectronic current of a pure tungsten cathode is low. Various solutions have been used to avoid this difficulty by "activating the cathode" changing its work function value. For example as cathode of plasmatrons is used a tungsten rod which has a content of 2 to 4 percent of ThO_2. In the case of the sodium lamps, cathode is from niobium, covered by a thin layer of sodium. For high pressure Hg lamps,and also fluorescent lamps the electrodes are covered with a triple component layers of oxydes of strontium calcium and barium. All these procedures named "activation", have as goal the decrease of the work function of the electron emitting electrode

In this paper we present an original activation procedures of tungsten electrodes by tungsten carbide directly grown on a heated tungsten electrode as a thin layer of carbon, part of the carbon atoms diffussing in the volume of tungsten and forming at the end tungsten-carbide compound.

Tungsten carbide activated electrodes can work at elevated temperatures and are keeping the activation properties after exposure to the air at atmospheric pressure.

2. Experimental arrangement

The experimental arrangement shown schematically in Figs. 1 and 2, is mounted inside of a high vacuum vessel. The cathode (see Fig. 1) is a tungsten filament of 0.6 mm diameters mounted inside of a Wehnelt cylinder. In front of the hole of Wehnelt cylinder is mounted the anode at a distance of 4 mm from the cathode.

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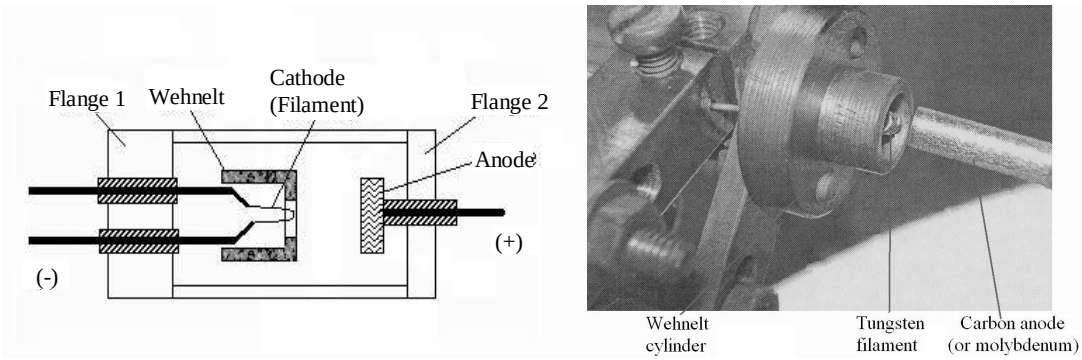

a) Schematic view of the as electrodes arrangement with direct heating of cathode.

b) Photo image of electrodes.

Fig. 1.

The carbon rod anode has a diameter of 5 mm and a length of 30 mm. After heating the filament, a controlled value of the high voltage is applied over cathode-anode space Due to the electron bombardment of the carbon anode, this becomes red-hot and carbon vapors appears in the cathode-anode space. Part of the carbon atoms or ions will condense on the cathode -tungsten filament- and will cover it by a carbon film. Part of the carbon atoms will diffuse in the volume of the tungsten filament. As a result of carbon and tungsten atoms interaction at elevated temperatures- at which tungsten filament operates-on the heated cathode will appear the compound tungsten carbide

This is an “activation” process and due to it, the work function of the cathode will decrease significantly. Direct prove of the activation is the strong increase of the density of the thermoelectronic emission current of the cathode at the same filament heating current

An alternative arrangement of electrodes is given in Fig. 2.

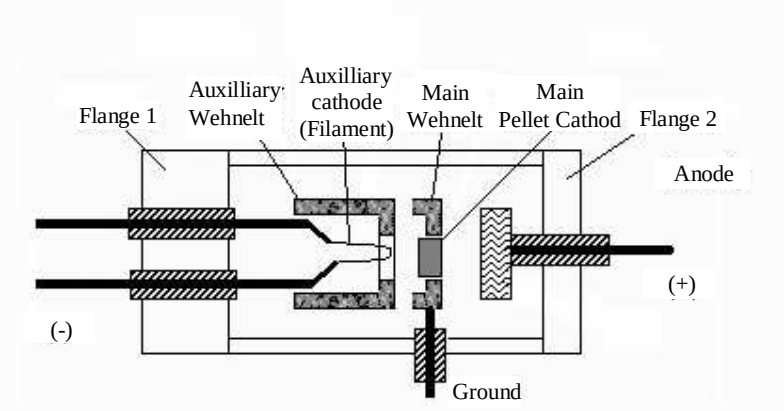

Fig. 2. Schematic view of the electrodes arrangement with auxiliary heating of cathode.

In this arrangement, the tungsten cathode –in shape of a pellet- is heated by an auxilliary electron bombardment unit, using a tungsten filament mounted inside of a Wehnelt cylinder. This arrangement ensure longer lifetime for the cathode because the pellet cathode heated indirectly, is less sensitive than heated filament cathode to the corrosion in time of the tungsten [1]. Indeed, because the filament is heated by the passing electrical current, slightest damage of the filament will quickly increase until the failure of the tungsten filament due to the strong increase of the local temperature of the damaged filament.

Besides the activation of tungsten filament in the vapors of carbon, it is possible to activate the filament also in the carbon vapor plasma generated using Thermionic Vacuum Arc Plasma technology [2-5]. Indeed, in vacuum conditions, at further increase of the applied voltage between

tungsten filament (cathode) and carbon rod (anode), a bright discharge can be established in carbon vapors. The evaporation rate as well as the plasma density increase at the heated cathode arc ignition. An increased number of particles like ions and neutrals are incident on the cathode surface, enhancing the activation process.

After each activation process, special care were taken in order to keep the accuracy of the experimental results During the measurements of the thermoemisive properties of the activated cathode, the carbon rod anode was replaced by a molybdenum anode having the same dimensions as carbon rod. In this way we avoided any possible further deposition of carbon atoms from anode on the tungsten cathode during the activation measurements.

3. Experimental results and discussions

In Fig. 3 are given the experimental results on the dependence of the cathode-anode current on the applied dc voltage across the electrodes, for a given value of the cathode heating current and for various activation procedure.

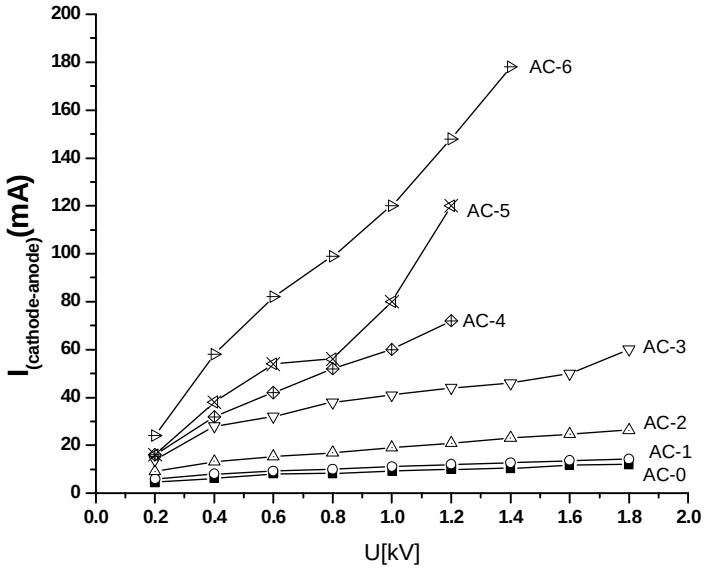

Fig. 3. Successive volt-ampere characteristic of cathode-anode volt-ampere characteristics after each successive activation procedure of the cathode.

The curve marked AC-0, represents the reference voltampere characteristics obtained without any previous activation treatment of the tungsten cathode. A saturation of the current for high voltages can be observed. The thermoelectronic current depends exponentially on the parameter $-\varphi/kT$) where φ is the tungsten work function, k is Boltzmann constant and T the temperature of the thermoelectron emitting cathode. The used reference thermoemission current is low -under 10 mA- and is saturated. The current intensity slightly change in the range of 1 kV and 1.8 kV of the applied voltage across cathode–anode space. We used for the reference curve a low value of the saturation current in order to diminish the electrons space charge effect

Each experimental curve given in Fig. 3 (except reference curve AC-0) was obtained after activation procedure listed in Table 1.

Table 1.

Curve number	Treatment
AC-0	No cathode activation (reference curbs).
AC-1	I_f= 19 A; U=1 kV; t=60 s; No discharge .
AC-2	I_f=19 A; U= 1.4 kV; t=180 s; No discharge
AC-3	I_f=18 A; U=1.4 kV; I_{ar}=160 mA (discharge current); t=45 s.
AC-4 & AC-5	Thermal treatment ; I_f= 18 A; U=0 kV; t=360 s; No discharge.
AC-6	I_f=17.7 A; U=1.4 kV; I_{ar}=160 mA (discharge current); t=45 s.

The experimental points on the curves given in Fig. 3, were measured separatelly, directly applying the needed value of the voltage. The reason was to avoid the heating of the carbon anode due to the incident thermoelectrons accelerated by the applied high voltage. The curve marked AC-1 corresponds to the first cathode treatment consisting in the bombardment of the carbon anode for 1 minut by the accelerated electrons at the application of a high voltage over the cathode-anode space. The curve AC-1 was taken after the described treatment. In order to increase the evaporation rate of carbon atoms, the applied voltage was increased to 1.4 kV, the treatment duration remaining 1 minute. The obtained volt-ampere characteristic after this treatment is marked AC-2. If we consider the point on this curve for 1.4 kV the value of the applied voltage, the power dissipated on the front surface of the anode rod is around 60 watts At such power density, carbon atoms –during the activation process- are continuously evaporating from the anode surface and part of them depositing on the cathode surface.and part of carbon atoms are diffusing in the volume of the tungsten filament. Carbon evaporation is easily proved by the deposited carbon thin films on the mounted glass plates inside of the vacuum vessel Curve AC-3 has been obtained in the same conditions as the curve AC-2 but the duration of the exposure of the carbon anode to the electron bombardment was increased from 1 minut to 30 minutes. All along this time, carbon vapors were continuously generated in the interelectrodic space, part of carbon atoms condensing on cathode surface. The curve AC-3 was obtained after 30 minutes of treatment. The obtained curve stops at a value of the applied high voltage of 1.2 kV because over this value a discharge starts to ignite in the carbon vapors. In this way, we kept the same type of activation described by the curves AC-2 and AC-3. The last cathode activation was obtained using carbon plasma.

In order to obtain a stable operation of the activated cathode, the tungsten wire cathode with carbon contents was heated for one hour (with a check after half an hour) passing a current of 18 A. We assumed that a more stable distribution of tungsten carbide can be established in the tungsten filament. The voltampere characteristics after half time and after one hour marked AC-4 and AC-5 are given in Fig. 3.

For the last treatment of activation, we used Thermionic Vacuum Arc dischsrge for carbon vapor plasma generation. At increased voltage applied across the cathode-anode space, a bright discharge is established in the carbon vapors continuously generated from the anode. In this case the cathode will be bombardet by a flux of energized ions. Also, due to the higher energy input, the density of carbon atoms in the interelectrodic space, will also increase. As a result of the activation process, the corresponding volt-ampere characteristics (in this case the curve AC-6 in Fig. 3) is changed drastically.in comparison with the reference curve AC-O given in the same Fig. 3. The thermoelectronic emission current increase –keeping constant at 18 A the filament heating current-, is more than 20 times. The current dependence on the applied voltage is far away from saturation.

In Fig. 4 is shown the results of X-ray photoelectron analysis (XPS) of the activated cathode surface. The formation of tungsten carbide compound is clearly proved.

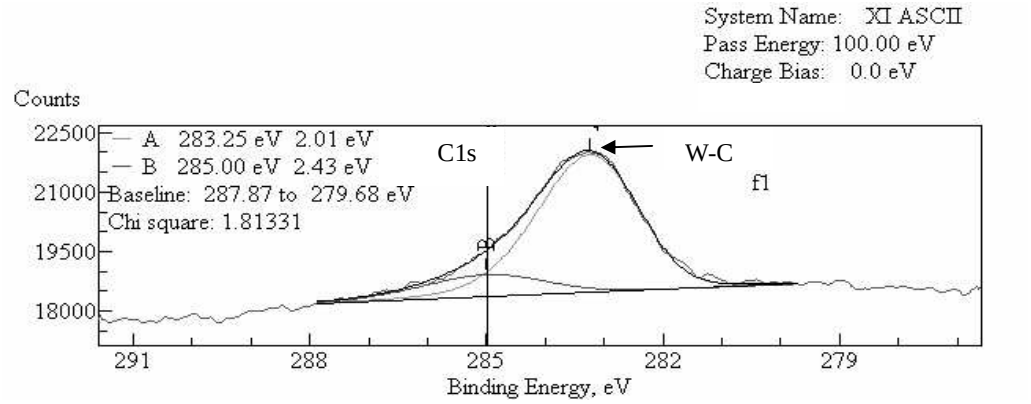

Fig. 4 XDS analysis of the activated cathode surface proving the formation of tungsten carbide compound.

In Fig. 5 is shown the post-operation look of an indirectly heated tungsten pellet – a disk of 4 mm diameter-which, before use was activated.

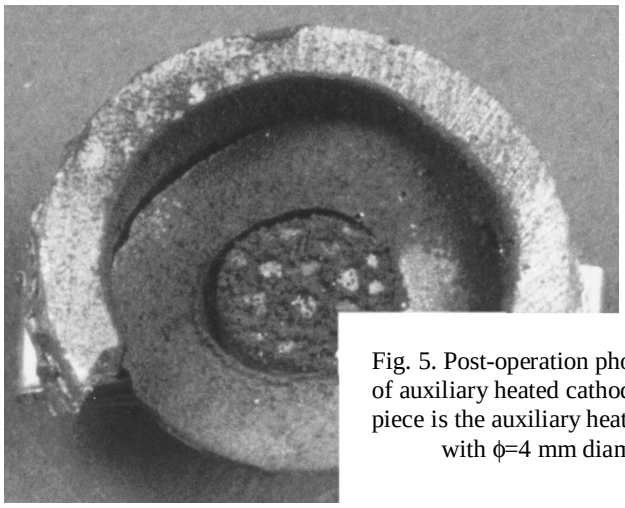

Fig. 5. Post-operation photo-image of auxiliary heated cathode. Central piece is the auxiliary heated cathode with ϕ=4 mm diameter.

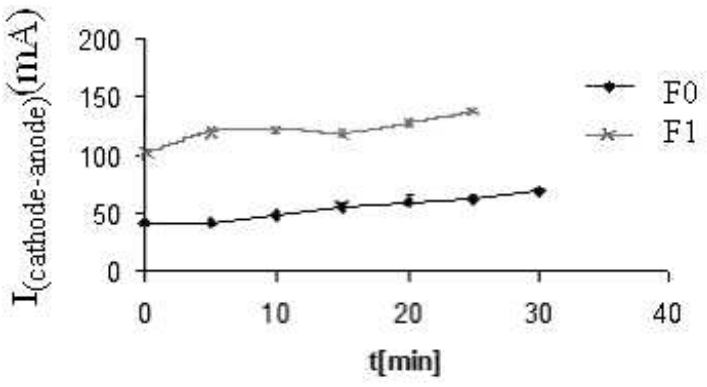

Fig. 6. Stability in time of the thermoemission current for non-activated (F0) and actived (F1) cathodes. Applied voltage 0.9 kV.

The tungsten pellet is mounted inside of a wehnelt cylinder from molybdenum. The cathode is covered by carbon evaporated from the anode. We can observe a numnber of holes going up to the pellet surface in the carbon layer which probably ensure the thermoelectronic current emission.

One of the characteristics of the activated cathode it is also thermoelectronic emission stability in time. This parameter has been checked for 30 minutes measuring the cathode-anode current for a given value of the applied potential across the electrodes of 0.9 kV. This time evolution is shown in Fig. 6. At this stage we can qualify this parameter as acceptable.

In the effective use of the activated cathode, the main advantage is the decrease of the cathode temperature (the value of the filament heating current) keeping higher value of the thermoelectronic emission current in respect with non-activated cathode. An example of how to use the activated cathode is revealed in Fig. 7.

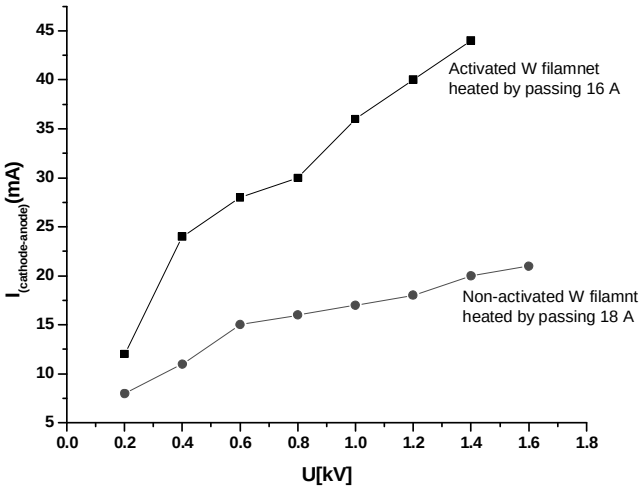

Fig. 7. Comparative volt-ampere characteristics for non-activated and activated cathode.

The activated cathode realized using our technology and heated with a current of 16 A, generates significanly much more electrons per second than a non-activated cathode heated by a current of 18 A.

4. Conclusions

The obtained data prove the possibility of carbon electrodes activation using thermionic vacuum arc in carbon.

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