THERMIONIC EMISSION OF CARBONIZED La-Mo CATHODE①

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ABSTRACT Lanthanum-containing cathodes are an attractive alternative to thorium tungsten cathodes because of their low work function and their comparatively low operating temperatures. A La-Mo carbonized cathode was described, which had a high thermionic emission; it was made up in a similar way to the Th-W cathode, but possesses high emission values. The thermionic tube equipped with La-Mo carbonized cathode was designed for comparison with Th-W cathode tube. It was experimentally verified that La-Mo cathode has higher thermionic emission effectiveness and its operating temperature is about 200 ℃ lower than that of Th-W cathode. The emission current density of La-Mo wire satisfies for electron tubes as Th-W filament. A stable emission current has been obtained with La-Mo carbonized cathode tubes for more than 1 800 h. From the results it is clear that the emission stability of La-Mo cathode satisfies the requirements for the replacement of Th-W filament.

Key words cathode rare-earth molybdenum thermionic emission La_2O_3

1 INTRODUCTION

The cathode is the core part of electronic device because it serves as the electron resource and its quality directly influences the lifetime and characteristics of the device. Th-W is still widely used in the fields such as high-power signal emission in electronic techniques and industrial medium heating etc. But its radioactive contamination during production and operation is obviously unacceptable in the world-wide trend of environmental protection. The recent researches[1-6] on the molybdenum filament containing high contents of rare earth oxide have opened a new field of study on its replacement of Th-W filament in vacuum emission tube.

In our research, La-Mo is shaped in the form of filament. After tube-packaging, the material's hot emission parameters are measured and compared with those of the Th-W filament under the same condition. The whole procedures of cathode production, packaging, measurement and lifetime experiment are carried out in a professional electronic tube factory.

2 EXPERIMENTAL

The experimental material of La-Mo filament whose diameter is 0.26 mm and La_2O_3 content is 4% ~ 5% was manufactured by powder metallurgy and pressure working process. The anode was produced by welding pure molybdenum plates together into a tube shape and was pierced in the middle for the measurement of cathode temperature. The cathode luminous temperature was measured by using an optical thermometer. After tube packaging, air elimination, activation and lower temperature ageing, the tube was sealed in vacuum environment and tested for direct current and pulse emission. The emission current was tested at the same time when the activation process was going on. Whether the activation is successful or not is dependent on the presence of emission current.

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Another tube with the same filament diameter and shape equipped with Th- W cathode was also manufactured for reference.

3 CATHODE PRODUCTION TECHNOLOGY

3.1 Forming

La- Mo filament has a good room temperature toughness and can be easily and conveniently formed mechanically at room temperature. After the cutting and spiral winding, the filament is formed together with its mode in hydrogen atmosphere for 15 ~ 30 min at the temperature of 1 250 ~ 1 400 ℃. The cleaning process is carried out by soaking the filament into acid and basic solution. Electropolishing, drying and air elimination are the final procedures.

3.2 Carbonization

The cathode surface carbonization is an important process to improve the emission efficiency and stability. The carbonization technology of Th- W cathode is referred when the experimental La- Mo filament, with specific technological parameters which are different from those of Th- W, is processed.

After the removal of air by supplying hydrogen into the carbonization room, the benzene vapor is led in and the cathode is heated to the temperature of carbonization. The purity of hydrogen must be above 99.9 % and the dew point should be below - 40 ℃. The environment temperature should be kept constant, at least the benzene's temperature be fallen down to 15 ~ 23 ℃. The carbonization is one of the key procedures of cathode production because it determines the emission ability and stability of the cathode. Through large amount of experiments and repeated practices, the appropriate La- Mo cathode carbonization parameters are acquired as follows:

Forming: 11 A, 7.5 V, 15 s

High temperature annealing: 14.5 A, 14.5A, 15 s

Testing: 7.5 V, I_1

Carbonization: 9 V, 11 A, 15 s, twice; benzene flowing rate 10 L/ min

Carbon removement : 9 V, 11 s

Testing: 7.5 V, I_2

Carbonization rate: $S = (I_1 - I_2)/I_1 \times 100\,\%$ (Generally, 8 % ~ 14 % is the satisfactory value)

3.3 Activation and ageing

After tube packaging and air remove, the carbonized cathode has already possessed the emission ability to some extent. Through the ageing, the cathode emission ability, stability and consistence of the cathode surface can be improved. While ageing, the cathode must go through a short time of sparkling(high temperature activation). The experimental procedures are as follows:

After the system vacuum has reached 10^{-4} ~ 10^{-5} Pa and the tube has been treated with high frequency processing (for fully eliminating air), the cathode is activated by imposing direct current(3 A, 1 min; 3.5 A, 1 min; 4.5 A, 30 min) without adding the anode voltage.

Direct current testing: The filament current is 3 A/ 3.5 A/ 4.0 A/ 4.5 A and the anode voltage is 20 V, 40 V, 60 V, …, 180 V, 200 V.

Ageing: direct current ageing, 3 A/ anode voltage 60 V; pulse ageing, 3 A/ anode voltage 600 V; time, 15 ~ 20 min.

4 HOT EMISSION PARAMETERS MEASUREMENT AND LIFETIME TESTING

On the professional testing table, DC and pulse $I - U$ characteristics of the tube are tested, and saturation emission current values are obtained through the curves. The double-logarithm method[7] is used to figure out the emission current values. In the $\lg I_a - \lg U_a$ coordinates, curves of 3/2 times of the emission current values are drawn and the anode current value of the starting point deviating the straight line is defined as the saturation or deviation value, which is the limit current value of the normal tube operation. The typical cathode curves are shown in Fig.1. While the working temperature of the tube falls between 1 400 and 1 450 ℃, the average value of the deviation current is 118 mA, with the corresponding cathode emission current density of 318 mA/ cm^2. The typical data reflect-

Fig.1 $I - U$ curves of La-Mo cathode

Table 1 Typical emission parameters of La-Mo cathode

Number of tube	1	2	3	4	5	6	7	8	9	10
Deviation current / mA	127	82	125	174	141	127	104	126	83	92
Emission efficiency /(mA·W^{-1})	12	9	12	15	15	11	11	14	10	9

ing overall testing level are shown in Table 1. This level has reached the minimum value of the Th-W cathode required by the electronic tube.

The emission efficiency, which is defined as the cathode emission current corresponding to per unit of cathode heating power and reflects the cathode hot emission efficiency, is greatly affected by the shape and sticking structure of the cathode. Hence, the same tube structure must be used to compare with the emission efficiency of different cathodes. It is indicated from Table 1 that the average value of La-Mo cathode efficiency is 11.8 mA/W (the practical value of commonly used tubes is 5 ~ 30 mA/W). The working temperature of Th-W cathode with the same tube structure falls between 1 600 and 1 650 ℃ in terms of reaching the same level of the former. Thus the working temperature of La-Mo cathode is 200 ℃ lower than that of the Th-W cathode. In addition, the data above is not the best level of this batch of materials due to the limitation set by tube anode dissipation.

At the cathode working temperature around 1 300 ℃, the lifetime tests have been carried out on the tubes. The lifetime of the tubes surpasses 1 800 h and their emission is still stable (Fig.2), which shows that their emission stability has approached practical level.

Fig.2 La-Mo curve of lifetime test (anode current vs time)

5 WORK FUNCTION ESTIMATION OF CARBONIZED La-Mo CATHODE

The ionization energy is defined as the energy required for removing an electron from an atom. The work function is defined as the work consumed by removing an electron from the surface of solid metal. Among the parameters of evaluating the cathode emission characteristics, the emission constant A and work function Φ in the Richardson Equation are two important parameters. The evaluation of work function can make us understand the emission mechanism more better, but the work function's computation and measurement have always been difficult. The quantitative computation of work function for pure metal has never been perfect[8,9], and furthermore, it is much more difficult for the practical cathode. Richardson straight line method is commonly used for the experimental measurement.

The hot cathode emission equation is[10]:

$$J_0 = AT^2\exp(-\Phi/kT) \quad (1)$$

where J_0 is the zero field emission current density, A/cm^2; T is the cathode temperature, K; A is the emission constant, the theoretical value is 120 A/(cm^2·K^2); Φ is the work function, eV; and k is the Bolzman constant, 8.62×10^{-5} eV/K.

After calculating the value of J_0 at different temperatures, A and Φ can be obtained by drawing out the Richardson straight line. In or-

der to calculate the value of A and Φ, T, I_0 and S must be obtained in advance. Here, I_0 is the zero field emission current, S is the emission area and I_0/S is J_0.

Generally, after calculating the emission current density value at a temperature, the work function can be figured out by substituting A with its theoretical value. This is the effective work function under the specific temperature value T and is symbolized by Φ_T.

Because it is very difficult to get precise value of zero field emission current in practical testing, the deviation current values are used for estimation and comparison in the case of La- Mo and Th- W cathode tubes in this article. According to the equation $\Phi_T = -kT\ln J_e/120T^2$, the effective work function of La- Mo cathode are figured out and listed in Table 2.

The work function value of 3.40 eV of the Th- W cathode for reference is also obtained by this method.

The data above are apparently greater than that of the carbonized Th- W. The reason mainly lies in the difference of emission constant A. Film cathode emission constant is much smaller than the theoretical value of 120 A/(cm^2·K^2). By revising A in accordance with W- Th system value of 3 A/(cm^2·K^2) and W- La system value of 8 A/(cm^2·K^2), the results of re-computation are 2.56 eV as well as Φ_T^{Th-W} 2.83 eV approximately[11]. The conclusion is that the work function of La- Mo cathode is 10 % less than that of the Th- W cathode.

6 ANALYSIS AND DISCUSSION

The above discussion has introduced the experimental research on the hot emission of La- Mo cathode material. The appropriate technology, as well as the technological parameters including forming, heat treatment, carbonization and ageing are studied. At its working temperature (1 400 ~ 1 450 ℃), that is 200 ℃ lower than that of the Th- W cathode at the same emission efficiency, the average value of deviation anode current is 118 mA (the maximum value is 174 mA) in the case of this batch of cathode tube. The corresponding cathode emission current density is 0.318 A/cm^2 and the cathode emission is stable, which has reached the minimum requirement of Th- W cathode set of electronic tube. It is estimated by the available method and relevant equation that when the working temperature falls between 1 400 ~ 1 450 ℃, the effective work function of La- Mo cathode is 2.56 eV approximately, which is 10 % lower than that of the carbonized Th- W cathode and shows a good emission ability of the La- Mo cathode.

The decreasing of La- Mo cathode working temperature can effectively restrain grid emission, improve the electronic tube's working environment, reduce the size of the tube and whole device. La- Mo filament material has a good room temperature toughness, high temperature strength, shake-resistance, and it does not easily fracture after carbonization. These good properties lead to great convenience during the production, transportation and operation of the electronic tube. In the lifetime testing, 10 tubes' lifetime have surpassed 1 800 h and their emission currents remain stable without power decline, which is the highest level in the world in the case of La- Mo cathode filament.

It is considered that the emission ability of this batch La- Mo cathode material has improved greatly and approached the practical application level. If this material can be used in practical

Table 2 Effective work function of La- Mo cathode

Number of tube	1	2	3	4	5	6	7	8	9	10
J_e/(A·cm^{-2})	0.342	0.221	0.337	0.469	0.380	0.342	0.280	0.340	0.224	0.248
Φ_T/eV	2.98	3.05	2.99	2.94	2.97	2.98	3.01	2.98	3.05	3.03

application, the heat efficiency of the electronic tube can be greatly enhanced and the radioactive contamination of Th-W can be eliminated ultimately.

As a new type of material, many problems must be settled before it can be put into practical use. Its heat-impact resistance is weaker than that of the Th-W materials, its working temperature scale is relatively narrow, its requirements for manufacture and operation process remain stern, its emission current density has only reached the minimum value of Th-W and its lifetime is much shorter than that of the Th-W cathode of 3 000 h. Thus, its lifetime must be extended and its manufacture technology must be optimized. Finally, understanding its microstructure and form of matter existence during high temperature operation is the key to disclose La-Mo emission mechanism and give theoretical guidance to its technological improvement of manufacture process.

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