THERMIONIC EMISSION OF Mo-Y_2O_3 FILAMENT CATHODE①

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ABSTRACT A new thermionic electron emission material has been studied. The electron emission properties and microstructure of Y-Mo(Mo-Y_2O_3) wire with content of 3% ~ 5% Y_2O_3 have been systematically investigated by means of electron tube emission and electron microscope. The results showed that the Y-Mo material has very good electron emission ability, higher emission efficiency and lower operation temperature than those of Th-W cathode, respectively. In addition, Y-Mo cathode electron tube exhibits more stable emission current than that of La-Mo ones.

Key words Mo Y_2O_3 cathode thermionic emission

1 INTRODUCTION

Today, large or medium-power electron tubes are being one of the most important and irreplaceable electron vacuum instruments with the rapid development of broadcast, television, industrial induction heating and so on. The cathode of large-power tubes has always been made of tungsten-thorium oxide (W-ThO_2) wire for its high temperature-resistance, as well as good and stable electron-emission capacity. But the disadvantages of its drastic brittleness, low formability, radioactive pollution and high operation temperature (1 900 ~ 2 000 K) have not been solved so far. From the late 1970s, molybdenum doped with lanthanum oxide (Mo-La_2O_3) which is a promising cathode to replace the radioactive Th-W cathode has been used as a thermionic emission cathode, such as indirect Mo-La_2O_3 sintered cathode, direct Mo-La_2O_3 wire cathode[1-5]. In our previous research, it is shown that the La-Mo cathode not only has high strength and good ambient ductility, but also possesses very good electron emission ability, high emission efficiency superior to that of Th-W cathode. However, it is found that the emission current of La-Mo electron tube is gradually attenuated with time[6]. A series of research including many kinds of special treatments was done for the current stability of La-Mo cathode[7]. At the same time, molybdenum doped with yttrium oxide (Mo-Y_2O_3) wire which is a new style of directly heated cathode material was studied. In this paper, the testing diodes equipped with this new cathode material were tested, in comparison with the La-Mo and Th-W cathode. The microstructures of cathode wire and carbonized layer were observed by means of electron microscope. The effects of rare earth oxides were discussed.

2 EXPERIMENTAL PROCEDURE

2.1 Preparation of Y-Mo wire

The 3% ~ 5% Y_2O_3 was added to molybdenum oxide powder as aqueous solution of $Y(NO_3)_3$. The doped molybdenum oxide or powder was reduced to metal molybdenum in dry hydrogen. The Y-Mo powder was pressed in steel dies and sintered by electric resistance heat-

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ing. The sintered bars were swaged and drawn to wire with different diameters.

2.2 Electron-emission property test

The experimental diodes were designed specially with a filament cathode of d 0.26 mm Y-Mo wire and a cylinder anode. The electron-emission properties and life span have been systematically examined in comparison with the tubes equipped with Th-W and La-Mo cathode wire of the same diameter.

2.3 Microstructure observation of Y-Mo cathode wire

The microstructures of Y-Mo cathode wire and its carbonized layer were observed with AMARY-1910FE field emission microscope and HITACHI S-450 scanning electron microscope with accelerating voltage of 5 kV and 20 kV, respectively.

3 RESULTS

3.1 Electron-emission property of Y-Mo cathode

The results of typical continuous emission current for Y-Mo cathodes as well as the comparative Th-W and La-Mo cathode are listed in Table 1. The emission current of Y-Mo cathode got to saturate and did not attenuate with time.

The results indicated that the electron emission ability of Y-Mo cathode under lower working power approached or surpassed that of Th-W cathode. Meanwhile, the thermionic-emission efficiency of Y-Mo was between that of Th-W cathode and La-Mo cathode.

In this work, life span test for 120 h was carried out under on-off working condition. The result showed that emission current was stable.

3.2 Formability and microstructure of Y-Mo cathode wire

Our study showed that the Y-Mo material's processing property and formability for cathode is as good as that of La-Mo material[8].

The microstructure of Y-Mo cathode wire is shown in Fig. 1. Fig. 2 and Fig. 3 show the surface and interior of the cathode, respectively. The carbide layer of the cathode wire shows granular grain structure with many boundaries perpendicular to the wire axis. The fibrous structure of Y-Mo wire was remained at the working temperature with very fine substructures in the fibre. The rare earth yttrium oxides distributes dispersively at the grain boundaries.

4 DISCUSSION

The electron emission characteristics of the Y-Mo, Th-W and La-Mo thermionic cathode materials may be attributed mainly to their physical and thermodynamic properties. The collected data relating to physical and thermodynamic properties are listed in Table 2.

The melting point of Y_2O_3 is higher than that of La_2O_3, and ThO_2 has the highest melting point in these oxides. The Y(Y_2O_3) can migrate rather easily and arrives the cathode surface continuously, but in the case of the Th-W cathode, the migration of Th (ThO_2) needs higher temperature or operation power. On the other hand, in the case of La-Mo cathode, the migr-

Table 1 Continuous emission current of Y-Mo, Th-W and La-Mo cathode

Cathode	Anode Current/mA										I_f /A	U_f /V	I_k /mA	Emission Efficiency /mA·W^{-1}
	20 V	40 V	60 V	80 V	100 V	120 V	140 V	160 V	180 V	200 V				
Y-Mo	5	10	15	19	24						3.5	2.2		
	16	31	46	60	70	78	86				4.0	2.5	70	7.00
	18	35	60	86	100	120	140	140			4.5	3.0	140	10.37
Th-W	9	22	39	58	76	95	108	122			4.0	3.9	95	6.09
	9	24	42	63	84	105	126	146	165		4.2	4.2	126	7.14
La-Mo	9	24	43	64	86	107	130	52	171	186	3.0	2.4	152	21.11
	11.02	9	25	46	69	94	127	140				3.6	3.2	127

Fig. 1 Microstructure of Y-Mo cathode wire
(Carburized, longitudinal section)

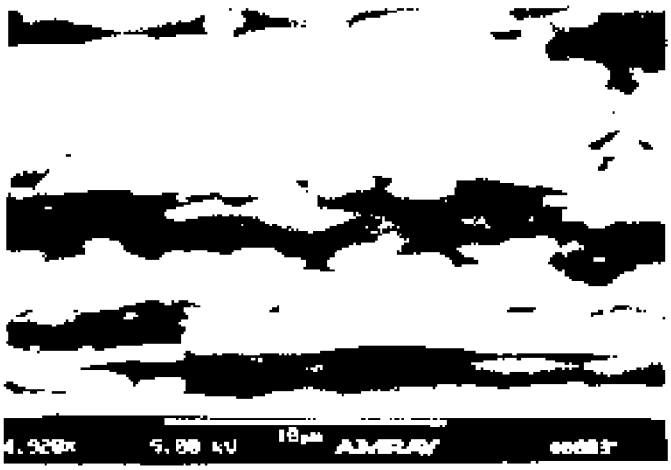

Fig. 2 Carburized surfare

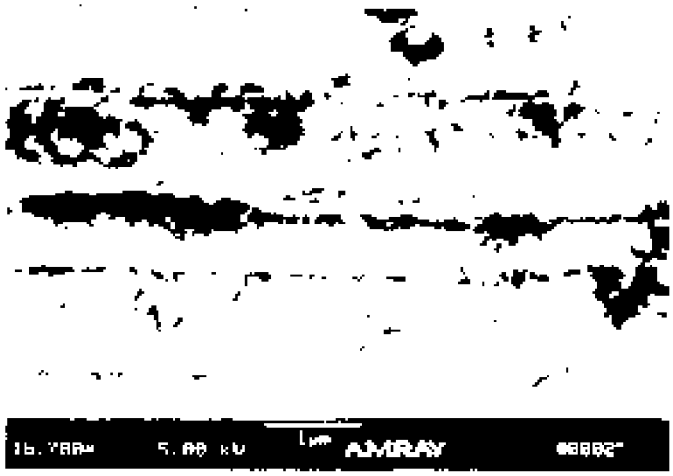

Fig. 3 Fibrous structure of wire

ation rate of La(La_2O_3) is much higher than that of Y(Y_2O_3). Thus, at lower temperature, there are enough La(La_2O_3) arriving at the cathode's surface to work as a good emitter.

Table 2 Physical properties of W, Mo, Y_2O_3, ThO_2 and La_2O_3

Materials	MP / ℃	Work Function / eV	Density / $g \cdot cm^{-3}$
W	3380	4.55	19.3
Mo	2610	4.20	10.2
Y_2O_3	2410	2.80	5.01
ThO_2	3390	2.74	10.001
La_2O_3	2217	2.00	6.51

As to the stability of Y-Mo cathode, the Y_2O_3 has higher melting point; at its working temperature, the vaporization rate of the Y(Y_2O_3) on surface may be lower than the migration rate, so it can stablely emit for a long time. But in La-Mo cathode, when the emission current is relatively high, the evaporation rate of La atoms is higher than the diffusion rate from the interior of wire to the surface of cathode, so the emission current attenuates with time.

The suitable carburization is very important for the electron emission. The carburized layer with granular grain structure (as shown in Fig. 1, 2) is favourable for Y(Y_2O_3) to migrate much easily and to feed to the surface. The carburized surface could give more stable combination with Y(Y_2O_3).

Additionally, the main parts of the Y-Mo cathode have fibrous structures, as shown in Fig. 3, with the ductile property of molybdenum. The addition of Y_2O_3 to molybdenum not only improves electron emission capacity, but also increases the recrystallization temperature and high temperature strength, which results from the dispersive distribution of the second phase Y_2O_3 in molvbdenum. The Y-Mo carburized cathode is not so drastically brittle as the thoriated tungsten wire.

The Y-Mo cathode possesses very good electron emission ability, higher emission efficiency and lower operation temperature than those of

Th-W cathode. Exceptionally, the Y-Mo cathode shows more stable emission current than that of La-Mo cathode. This new style material is hopeful to replace the radioactive pollutant Th-W cathode and to solve the stability problem of La-Mo cathode. Its optimum operation condition, thermionic emission mechanism and so on still need to be studied.

5 CONCLUSIONS

(1) The new style cathode material Y-Mo containing 3% ~ 5% Y_2O_3 possesses good electron emission ability, higher emission efficiency and lower operation temperature than that of Th-W cathode.

(2) The Y-Mo cathode exhibits more stable emission current than that of La-Mo cathode, which is carburized only by some processing.

(3) The carburization structure is very important for the electron emission. The granular grain structure may be helpful for electron emission.

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