STUDY ON THE OXIDE CATHODE FOR HIRFL-CSR ELECTRON COOLER

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Abstract

The oxide cathode is still wildly used in vacuum electronic devices as electron sources. With the ongoing development of electronic devices, the requirements for the emission characteristics of the cathode have to be enhanced to suit the new applications. It is a promising research direction improving the emission characteristics of the cathode at a low operating temperature and simple manufacture technology.

This paper studied the manufacture technology and properties of the oxide cathode and its emission mechanism. Then a new type of oxide cathode is developed and tested for its emission properties and lifetime. Its emission characteristic is better than that of the conventional oxide cathode. Part of properties of the cathode used in HIRFL-CSR Electron cooler is tested. The results show that the new oxide cathode is suitable to the electron cooler applications.

Keywords: Electron cool, Oxide cathode, Emission current

INTRODUCTION

The oxide cathode is a cathode coated BaSrCa(CO_3) on the surface of Ni base or W filament. When heated it in vacuum, the BaSrCa(CO_3) is decomposed into BaSrCaO, and Ba is produced when BaO reacted with the activators like Si and Mg in the Ni base, which make the cathode emit electrons. The oxide cathode has been developed more than 100 years. It is widely applied in electric light source, transmitter-receiver tube, grid control tubes, CRTs, space TWTs, high power klystrons[1,2,3,4] and electron cooler[5,6] because of its low operating temperature, large pulse emission current density, simple manufacture technology and low cost. However, the application of the oxide cathode is restricted in dc and wide pulse, high duty ratio pc emission tube because of its coating resistance and the interface layer resistance produced during the cathode operating process. For many years, worldwide scholars have programed a great deal of research to solve this problem.

In 1986, Saito[7] developed the rare-earth doped oxide cathode, doping 0.12-0.20% rare-earth oxide (Sc_2O_3 or Y_2O_3) in the coating of the conventional oxide cathode. The emission capability and lifetime of the rare-earth oxide cathode exceed that of the conventional oxide cathode because of its high coating electrical conductivity with the free Sc released by $BaSc_2O_4$'s reaction with the oxide in the coating. In the 1970's, a new type of oxide cathode has been developed in IECAS[8]. With the low coating resistance and little interface layer resistance, the cathode has high reliability, large current and long lifetime and has been applied to high power klystrons, long lifetime satellite TWTs and some special devices.

This paper analyzed the material composition of the oxide Cathode for HIRFL-CSR Electron cooler, and the emission characteristic such as dc, pc and the lifetime of this cathode is compared with that of the new oxide cathode developed by us through diode testing. The result shows that the lifetime and reliability of the electron gun for HIRFL-CSR electron cooler can be improved.

THE CATHODE STRUCTURE IN ELECTRON COOLER

The main parameters of the cathode: the convex radius of the cathode is 48mm, the diameter is Φ30mm, the Ni sponge is sintered on the cathode surface and its diameter is 28mm, a layer carbonates is sprayed on the Ni sponge. This kind of cathode is Ni sponge oxide cathode. The Ni sponge oxide cathode has ever been used in gird-control emission tube with 3% duty ratio in our insititute, but it was not succeed. However, this gird-control emission tube using the new oxide cathode operated successfully with 4～6% duty ratio in radar.

ELECTRON EMISSION PHYSICAL PROCESSES OF THE CATHODE

The Conventional Oxide Cathode

The basic structure of the conventional oxide cathode is shown in figure1. The process of the electron emission of the oxide cathode is following three steps:

A.By heating, the carbonate on the Ni base decomposes into oxide:

$$(BaSrCa)CO_3 \rightarrow (BaSrCa)O + CO_2\uparrow$$

B.The activator (Si, Mg, W) in the Ni base diffuses to cathode's surface which reacts with the BaSrCaO and produces excess Ba:

$$BaO + Si \rightarrow SiO_2 + Ba$$

$$BaO + W \rightarrow WO_3 + Ba$$

C. The excess Ba diffuses to the surface of the （BaSrCa）O grain and is activated by SrO, then releases two electrons and emit vacuum through micro-ostium in the coating. The excess Ba loses two electrons and becomes Ba^{++} which needs obtaining electron and keeps its electric charge balance. At the same time, the interface layer ($BaSiO_3$) is produced by the reaction between SiO_2 to BaO:

$$BaO + SiO_2 \rightarrow BaSiO_3$$

The interface layer prevents the diffusing of the electron from Ni base to its surface. So the conventional oxide cathode can not provide large dc emission current and pc emission current with wide pulse.

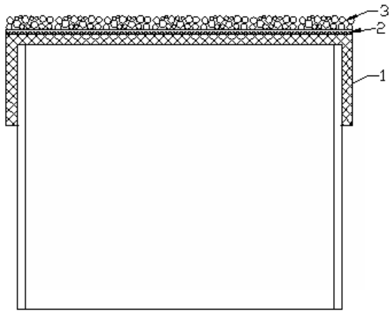

Figure 1: The structure of the conventional oxide cathode. 1. Ni base 2. Interface layer 3. Carbonates.

New Type of Oxide Cathode

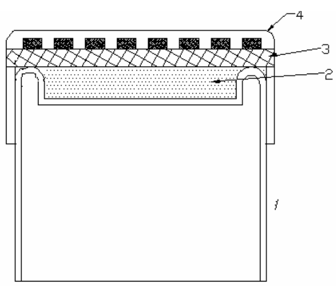

Figure 2: The structure of the reservoir oxide cathode. 1. Ni base 2. Reservoir material 3. Ni net 4.Carbonates

The structure of the new type of reservoir oxide cathode is shown in Fig. 2. Based on the process of production, diffusion and emission electrons of the excess Ba of the cathode, the structure and the emission material of this oxide cathode was devised. This type of oxide cathode is a reservoir dispenser oxide cathode. Its excess Ba comes from the reservoir emission material in a cell of the cathode:

$$Ba_5Ca_3Al_2O_4+2Ti \rightarrow 2BaAl_2O_4+2Ba+Ca$$

The excess Ba diffuses to the surface of the cathode to emit electrons through the Ni sponge, which avoids producing the interface resistance layer and has very low coating resistance, then can provide high emission current density.

EMISSION CHARACTERISTICS OF THE CATHODE

A diode test was done for detecting the characteristics of the Ni sponge oxide cathode and the new type of oxide cathode applied in cooler devices. The characteristics included dc emission, pc emission and lifetime.

A cathode with diameter of 3 mm and a Mo anode with diameter of 30 mm and thickness of 0.4 mm are used in the test. The distance between the cathode and the anode is 1.2–1.5 mm. The operating temperature of the cathode is measured by a Ni–Mo thermocouple spot-welded on the cathode cap, which is 0.5 mm away from the cathode emission surface. After decomposing, activating and aging of the cathode for 50h, we tested their emission current and lifetime.

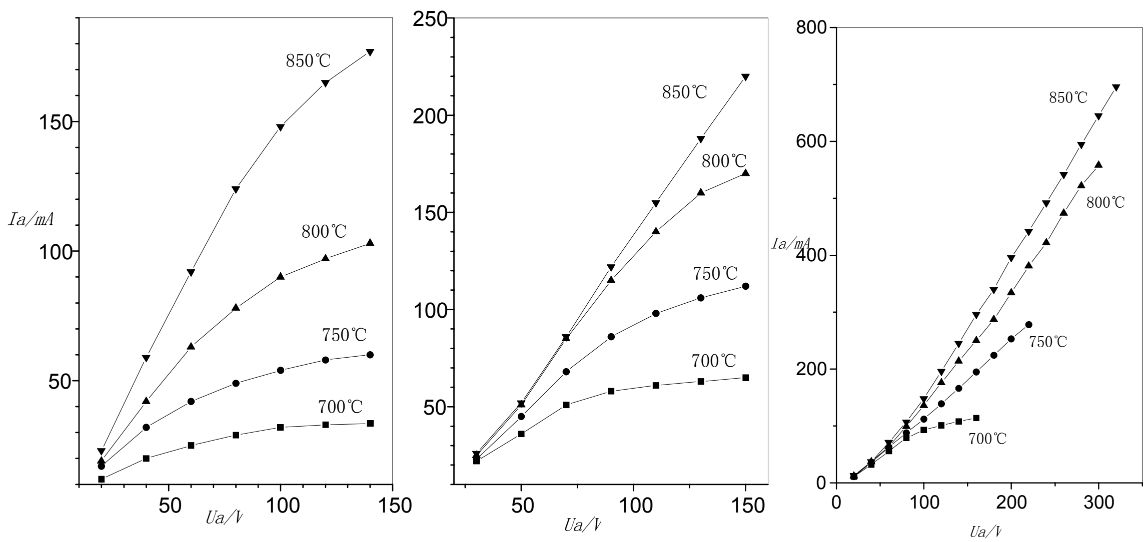

Figure 3: The emission characteristics in dc mode.（a）Ni sponge oxide cathode （b）new type of oxide cathode （c）improved new type of oxide cathode

Direct Emission Current Density

The dc emission characteristics of the Ni sponge oxide cathode, the new type of oxide cathode and the improved new oxide cathode under different temperatures are respectively given in Fig.3(a), Fig.3(b), Fig.3(c). The emission current density of the Ni sponge oxide cathode is 250mA/cm2 at 700 ℃, 500mA/cm2 at 750 ℃, 1000mA/cm2 at 800℃ and 1600mA/cm2 at 850℃. The emission current density of the new type of oxide cathode is 500mA/cm2 at 700 ℃, 1100mA/cm2 at 750 ℃, 2000mA/cm2 at 800℃ and 3000mA/cm2 at 850℃. The emission current density of the improved new type of oxide cathode is 1300mA/cm2 at 700℃, 3000mA/cm2 at 750℃, 5000mA/cm2 at 800℃ and over7000mA/cm2 at 850℃.

The dc emission characteristics of three kinds oxide cathode results show that the dc current density of the new type of oxide cathode is 2 times that of Ni sponge oxide cathode at same operating temperature, the dc current density of the improved new oxide cathode is 4 times that of the new oxide cathode under same condition, and the dc emission current of the Ni sponge is sensitive on its operating temperature.

Pulse Emission Current Density

The pulse emission current density at short pulse width of the Ni sponge oxide cathode and the new type of oxide cathode is shown in Table 1 for three different operating temperatures with pulse duration of 10μs and a repetition rate of 100Hz, which shows that the short pulse emission current density of the new type of oxide cathode is lower than that of the Ni sponge oxide cathode at same temperature.

Table 1: The Pulse Emission Current Density （A/ cm2）

	750℃	800℃	850℃
New type of oxide cathode	7	13	28
Ni sponge oxide cathode	9.1	15.7	30.6

Figure 4 shows the relation of emission current with the pulse widths. It is clear that the pulse emission of the new type of oxide cathode is very steady with the increase of pulse duration. In contrast, the pulse emission current of the Ni sponge oxide cathode increases with the increase of its pulse width, which shows that the temperature of the cathode surface increase with the increase of its pulse width due to the high interface resistance. The two different results indicate that the Ni sponge oxide cathode has good emission capability at short pulse, but the new type of oxide cathode has good emission capability at long pulse because of its low interface resistance.

Lifetime Testing

The results of the lifetime testing for two kinds of cathodes in a temperature range of 800～820℃ and dc load of 1.5A/ cm2 are given in Fig.5, which shows that the emission current of the Ni sponge oxide cathode decreases to 80% of the preliminary emission current at 1800h lifetime, but the emission current of the new type of oxide only decreases 5% after 3000h lifetime.

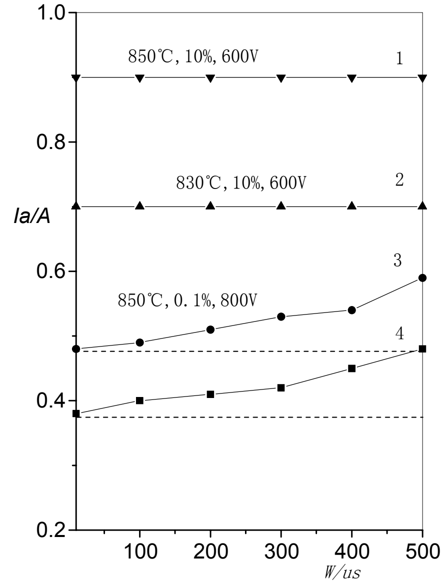

Figure 4: The emission current versus pulse width of cathode. 1,2 new type of oxide cathode, 3,4 Ni sponge oxide cathode.

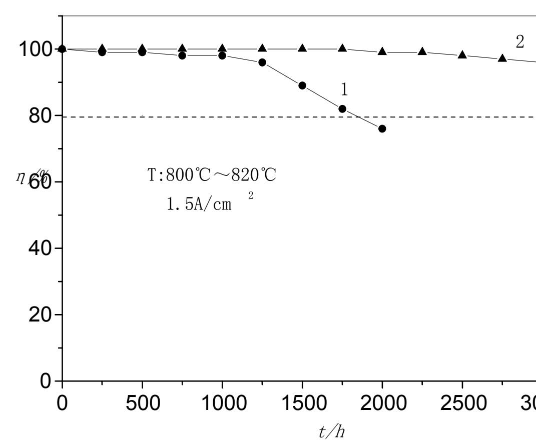

Figure 5: The lifetime curve of the cathode. 1. Ni sponge oxide cathode, 2.new type of oxide cathode.

Application of the Cathode in Microwave Devices

In order to rationally appraise the characteristics of a cathode, the cathode should be applied to a vacuum device so as to test how much current density it can provide, how long its lifetime is in practical applications and so on. Several application examples for the cathode in microwave device are given in this subsection.

(a) High power grid-controlled transmitting tube: The cathode provides an emission current density of 3A/ cm2 with 4～6% duty ratio at 820℃ and a lifetime of over 3000h.

(b) TWT for space satellite communications: The cathode provides a dc emission current density of 0.3A/cm2 at 820℃ and a lifetime of 3 years.

(c) Moderate power TWT: The cathode provides a dc emission current density of 0.5A/cm2 at 750℃ and a lifetime of 12000h.

THE APPLICATION OF THE NEW OXIDE CATHODE USED IN HIRFL-CSR ELECTRON COOLER

The main characteristics of the cathode for HIRFL-CSR electron cooler: the dc emission current density of the cathode is 0.5A/ cm2, the heating power is 36W～100W, and the lifetime is 5000h. The main parameters of the cathode: the convex radius of the cathode is 48mm, the diameter is Φ30mm, the Ni sponge diameter is 28mm and no emission current on cathode edge. The cathode high is 5mm and uphold by a indium steel strip. The cathode picture shows in Fig.6.

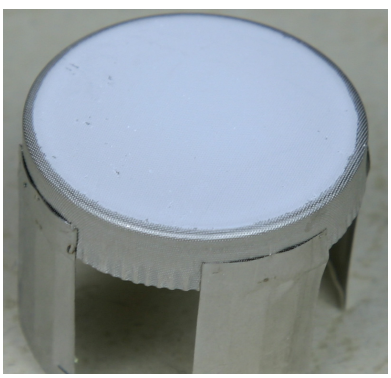

Figure 6: The cathode picture in HIRFL-CSR Electron cooler.

The temperatures of the cathode under different heating power are given in table 2. The results show that the surface temperature of the cathode is uniform, which will be beneficial to the uniform of the electron bind during the process of the electron cooler.

Table 2: The cathode temperature under different heating power (℃)

Heating power	1	2	3	4	5
13V/3.5A	703	699	701	704	703
14V/3.7A	733	730	730	737	740
15V/3.9A	751	759	760	754	761
17V/4.1A	837	838	842	835	842

CONCLUSION

Comparing to Ni sponge oxide cathode, the above-mentioned results for the experiments and applications of the new oxide cathode show that the new oxide cathode has good emission characteristics with high reliability and long lifetime. And it also has good resistance to poisoning, low evaporation and good resistance to shaking and shock, which will not be discussed in detail here. The new oxide cathode can not only substitute completely for Ni sponge oxide cathode in electron cooler but also enhance emission current, prolong operating lifetime, and improve of reliability of the electron gun in electron cooler.

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