Aerospace Information Research Institute(AIR)
Chinese Academy of Sciences(CAS)

Research Progress in new types of Thermionic Cathodes

Xiaoxia Wang, Xingqi Wang, Qinglan Zhao, Yun li, Qi Zhang

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- Plasma-sprayed oxide cathode
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- Nanometer tungstate cathode
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Introduction

- Thermionic cathodes serve as electron sources in numerous vacuum electron devices, including traveling wave tubes, klystrons and magnetrons et al.

- These devices use in military, space applications and commercial, for which the requirement to thermionic cathode is different.

  - Space traveling wave tubes emphasize a long and reliable operating lifetime with several hundred thousand hours.
  - High power require high emission current density and ten thousand hours lifetime.
  - High power continuous wave magnetrons think a lot of low operating temperature and good secondary electron emission coefficient.
  - High frequency devices require higher emission current density.

■ Introduction

- According to the requirement of the above different vacuum electron, various thermionic cathodes are developed, such as directly heated metal cathodes , oxide cathodes , impregnated coating Ba-W cathodes and Sc series Ba-W cathodes et al .

- At present, oxide cathodes and impregnated coating Ba-W cathodes are most widely used in klystrons, traveling wave tubes and part magnetrons, and directly heated metal cathodes are used in high power magnetrons. Sc series Ba-W cathodes have been used in high frequency devices.

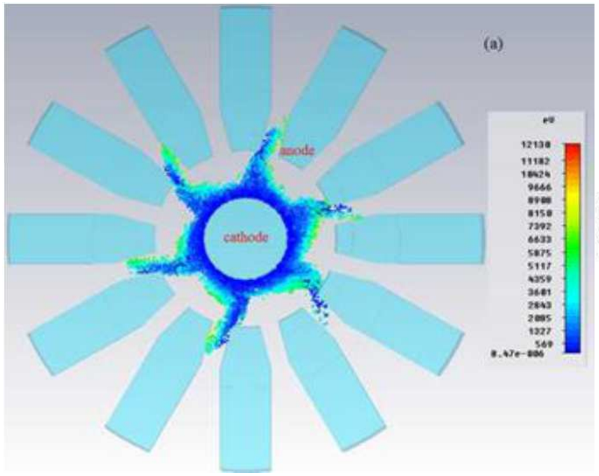
■ Introduction

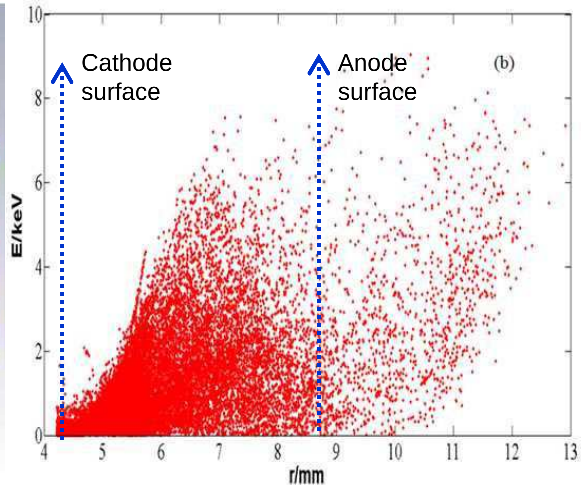
- In order to satisfy the further development of the vacuum electron devices to high power, high frequency and long lifetime, various new types of thermionic cathodes have been developed in IECAS.

- **In this report** we mainly describe Re-W alloy , ThO_2-W and Y-Gd-Hf-O W base directly heated cathode, plasma-sprayed oxide cathode, ammonium perrhenate impregnated W matrix Ba-W cathode and nanometer tungstate cathode.

■ Directly heated cathodes

● Emission simulation of the high power continuous wave magnetron cathode





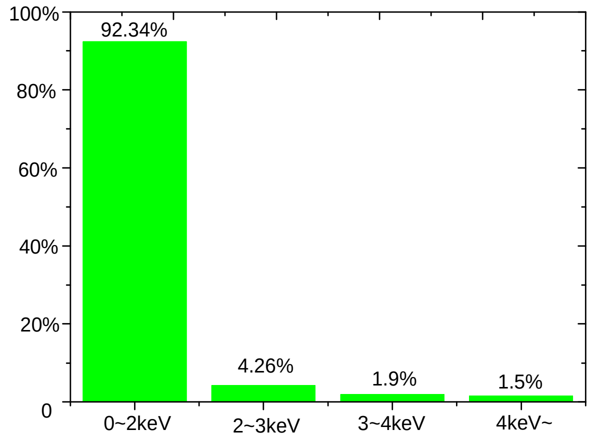


Fig.1 Diagram of energy and local distribution of the electron around the cathode

Fig.2 Energy distribution of electron versus vertical distance from the cathode

- ◆ The cathode is bombed by rotating electron stream which is near the cathode;
- ◆ Electrons inside of the spoke belong to low energy electron(0-3keV), only very few electrons outside of the spoke get high energy;
- ◆ The number of electrons with the energy of 0<E<2keV reaches 92.34% of the total electrons.

■ Directly heated cathodes

● Re-W alloy cathode

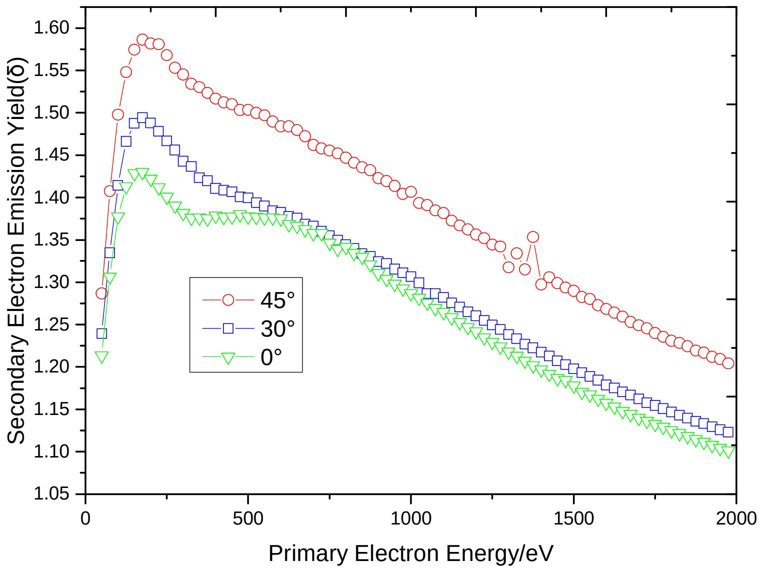
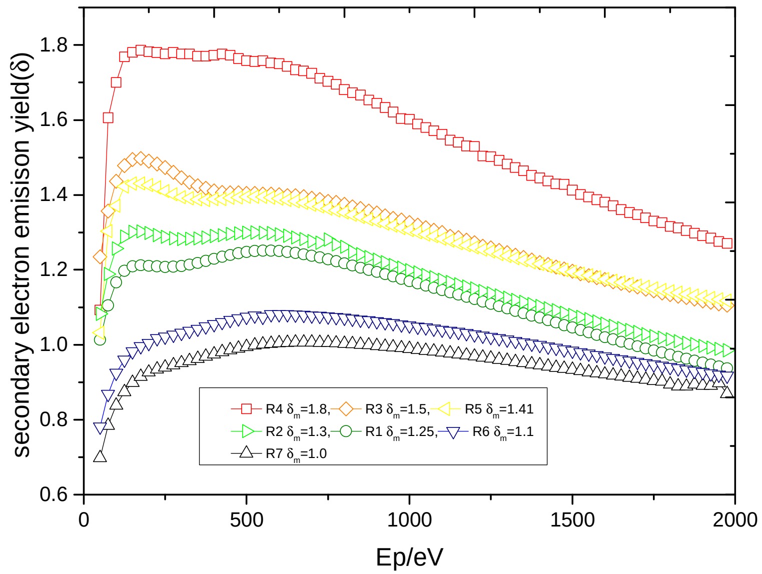


Fig.3 δ vs incidence angle of PE



R1—20wt%Re
R2—10wt%Re
R3—6wt%Re
R4—5wt%Re
R5—4wt%Re
R6—3wt%Re
R7—PureW

Fig.4 SEEY curves of the different mass percentage of Re doping W-Re alloy cathode

- When the incidence angle of PE reaches 45^0, the SEEY of the cathode reaches the maximum value.
- When the percentage of Re doping decreases to 5%, the SEEY of the cathode reaches the maximum value 1.8.

■ Directly heated cathodes

● Re-W alloy cathode

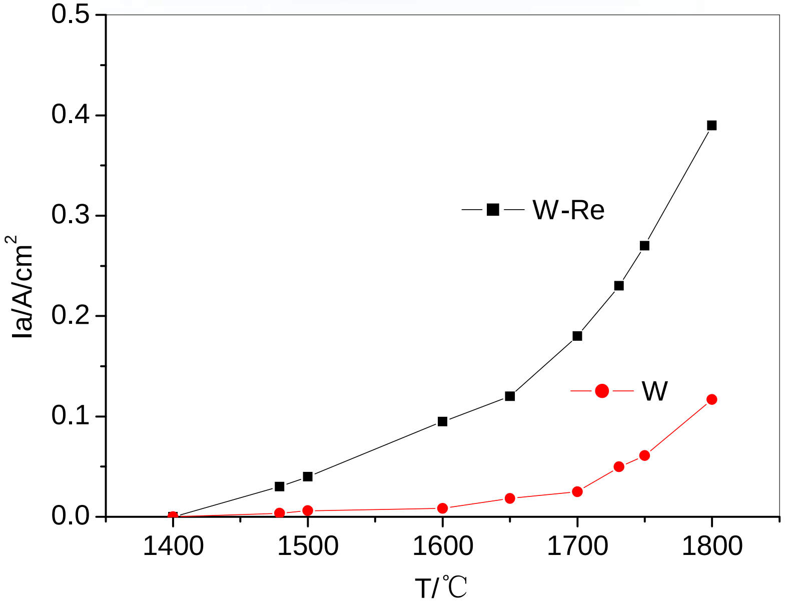


Fig.5 Ia-T curves of the 5wt% Re doping W-Re alloy cathode and the pure W filament cathode

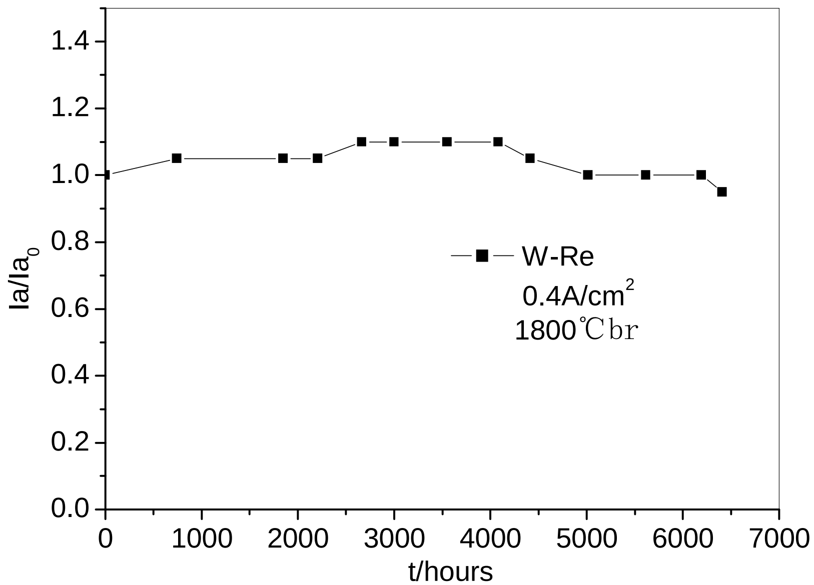


Fig.6 Lifetime curves of the W-Re alloy cathode

- ◆ The thermionic emission current density of the 5%wt W-Re alloy cathode is 0.4A/cm^2 at 1800 ℃, which is higher than that of the pure W filament cathode obviously .
- ◆ The emission current of the cathode decreased after 6000 hours of continuous operation.

■ Directly heated cathodes

● ThO_2-W alloy cathode

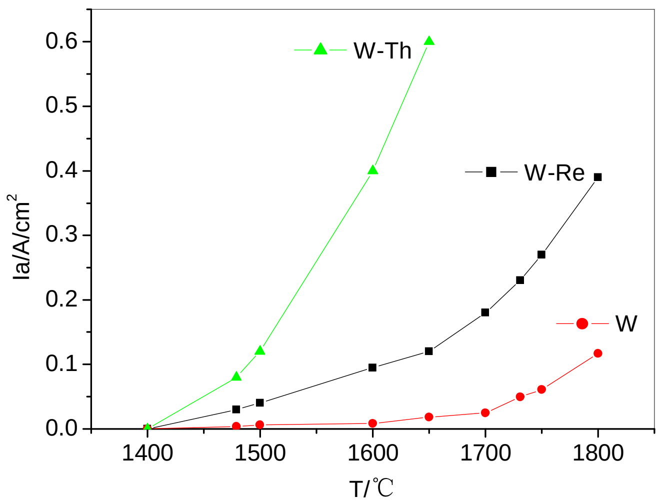


Fig.7 Ia-T curves of the ThO_2 -W cathode, the Re-W alloy cathode and the pure W filament cathode

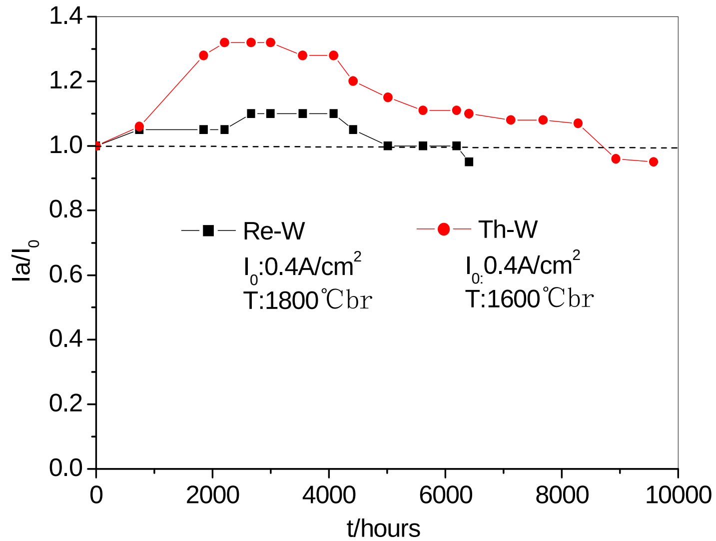
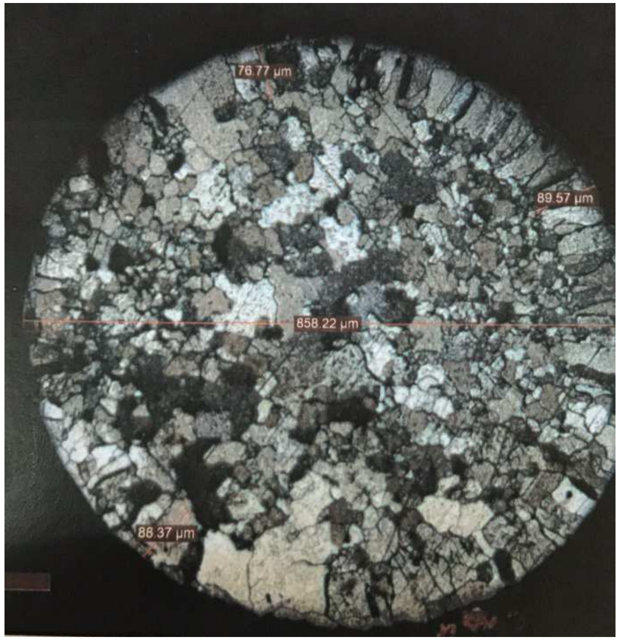


Fig.8 Lifetime curves of the W-Re and the ThO_2 – W cathodes

- ◆ The thermionic emission current density of the ThO_2 -W cathode is 0.4A/cm^2 at 1600 ℃, which is higher than that of the pure W filament cathode obviously .
- ◆ The emission current of the ThO_2 -W cathode decreased after 9000 hours of continuous operation.

■ Directly heated cathodes

● ThO_2-W alloy cathode



(a) we development

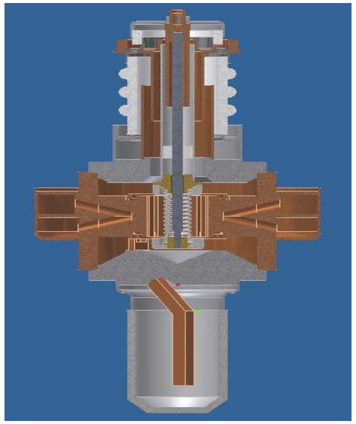
(b) traditional

Fig.9 SEM of the ThO_2 –W cathode cross section after carbonization(100X)

- ◆ The carbonization layer deepness of the new development ThO_2 –W cathode is 89μm (859μm), which is higher than that of tradition ThO_2 –W cathode(33μm /852μm).
- ◆ The grain size of the new development ThO_2 –W cathode is bigger than that of traditional ThO_2 –W cathode.

■ Directly heated cathodes

● Application in 20 kW continuous wave magnetron tubes



20kW continuous wave magnetron tubes	Out power (kW)	Anode voltage (kV)	Anode current (A)	Per-heating current(A)	Operating current(A)	Cathode temperature (°Cbr)	Magnetron tubes lifetime (hours)
Pure W cathode	20	12.5	2.3	47	29	＞2000	2000～3000
5wt%Re-W cathode	20	12.5	2.3	40	24	1800	400h Degenerate W cathode
ThO_2-W cathode	20	12.5	2.3	30	8	1600	6200

- The pre-heating current and the operating current of the ThO_2 –W alloy cathode is 30A and 8A respectively applied in 20kW continuous wave magnetron.
- The lifetime of the 20kW continuous wave magnetron has been beyond 6000 hours.

■ Directly heated cathodes

● Y-Gd-Hf-O W base cathode

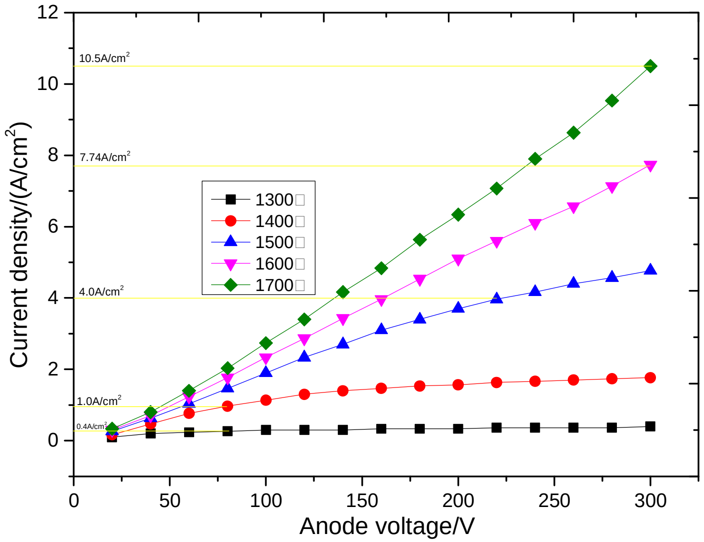


Fig.10 Ia-Ua curves of the Y-Gd-Hf-O W base cathode under different temperature

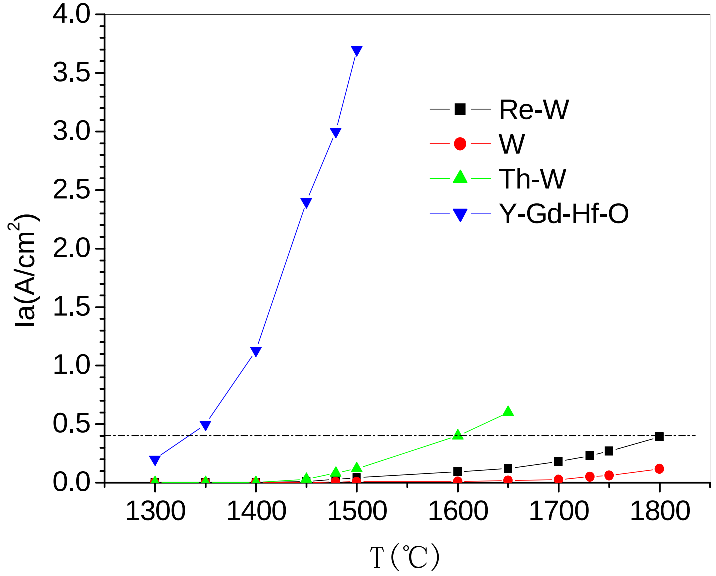


Fig.11 Ia-T curves of the Y-Gd-Hf-O W base cathode, ThO_2-W cathode, Re-W alloy cathode and pure W filament cathode

- ◆ The emission current density of the Y-Gd-Hf-O W base cathode is beyond 3.7A/cm^2 at 1500 ^{o}Cbr.
- ◆ The emission current of the Y-Gd-Hf-O W base cathode is far higher than that of the other directly-heated cathodes.

■ Directly heated cathodes

● Y-Gd-Hf-O W base cathode

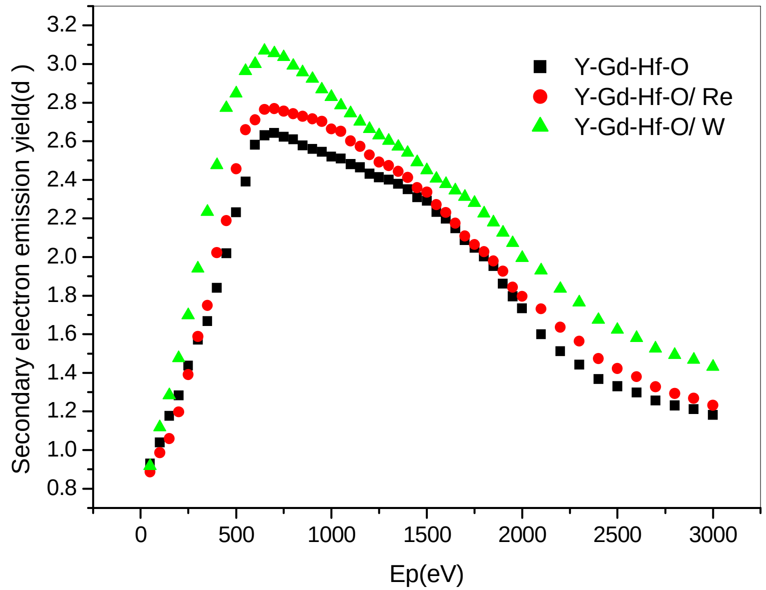


Fig.12 SEEY curves of the Y-Gd-Hf-O W base cathode at room temperature.

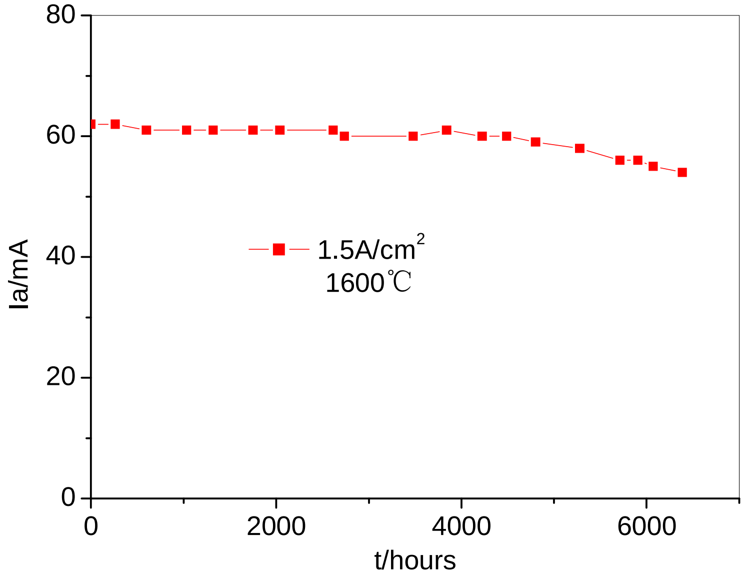


Fig.13 Lifetime curves of Y-Gd-Hf-O W base cathode

- ◆ Re and W doping can enhance the SEEY of the Y-Gd-Hf-O W base cathode.
- ◆ The SEEY of W doping Y-Gd-Hf-O W base cathode reaches 3.1 at room temperature..
- ◆ The lifetime of the Y-Gd-Hf-O W base cathode is reached 6000 hours with 1.5 A/cm^2 at 1600 ºChr.

■ Directly heated cathodes

● Y-Gd-Hf-O W base cathode

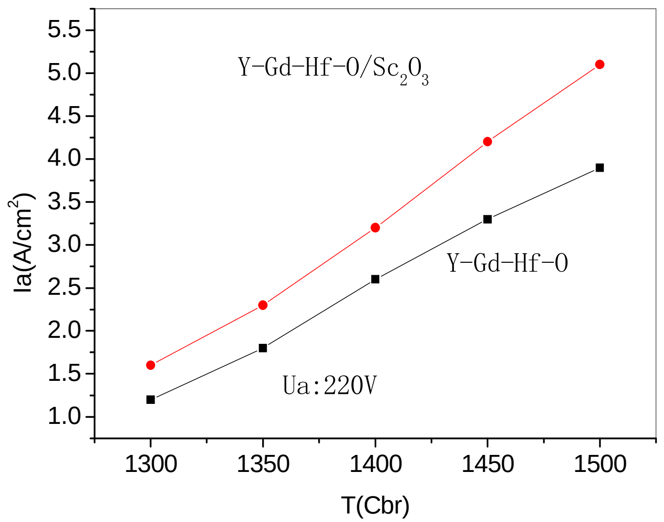


Fig.14 The DC emission density vs. temperature curves for 5%wt Sc_2O_3 doped Y-Gd-Hf-O W based cathode and a conventional Y-Gd-Hf-O cathode.

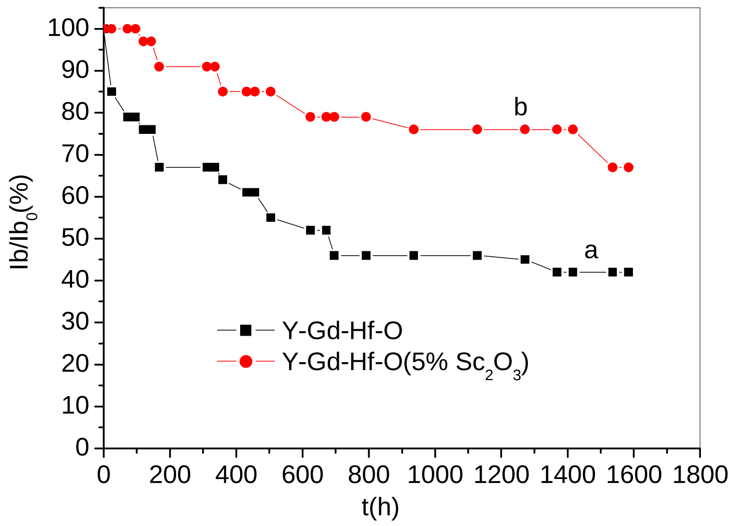


Fig.15 Current density curves as a function of bombing time for 5%wt Sc_2O_3 doped Y-Gd-Hf-O W based cathode and the conventional Y-Gd-Hf-O cathode at same initial emission current.

Electron Bombing power: 12W/cm²

- ◆ The emission current density of the 5%wt Sc_2O_3 doped Y-Gd-Hf-O W base cathode is reached 5.0A/cm² at 1500 ºCbr.
- ◆ Ant-electron-bombing capability of the 5%wt Sc_2O_3 doped Y-Gd-Hf-O W based cathode is better than that of the conventional Y-Gd-Hf-O cathode.

■ Plasma spraying coating oxide cathode

- In order to enhance adhesion between the Ni base and the coating and decrease coating resistance, we developed plasma spraying oxide cathode.

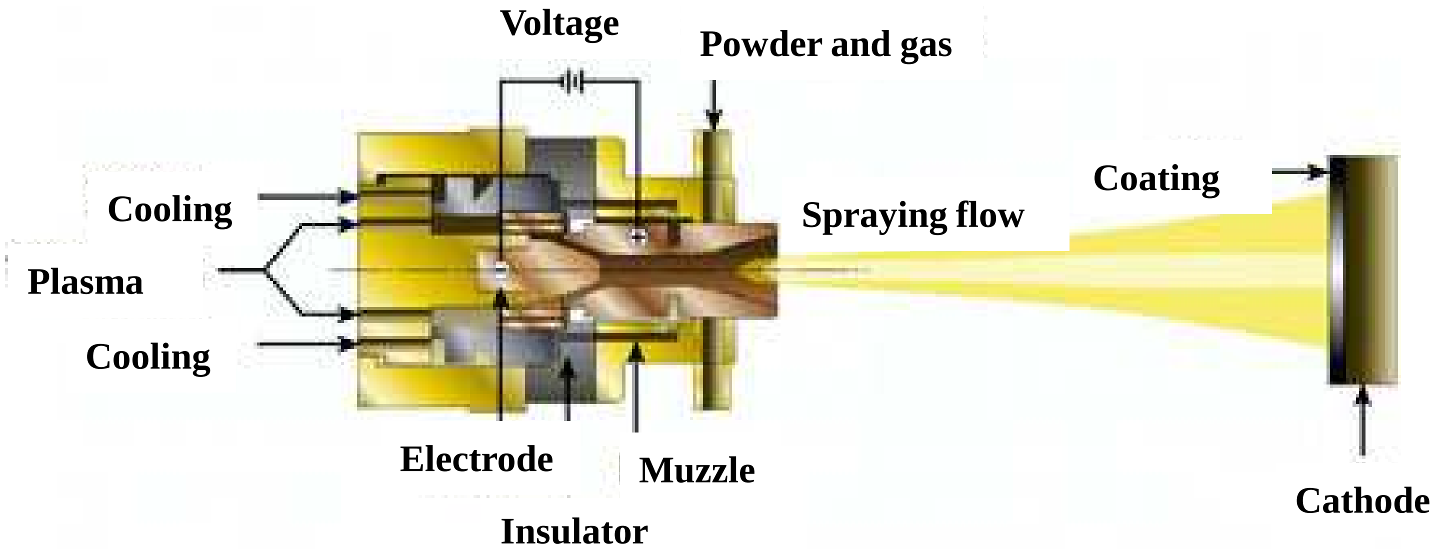


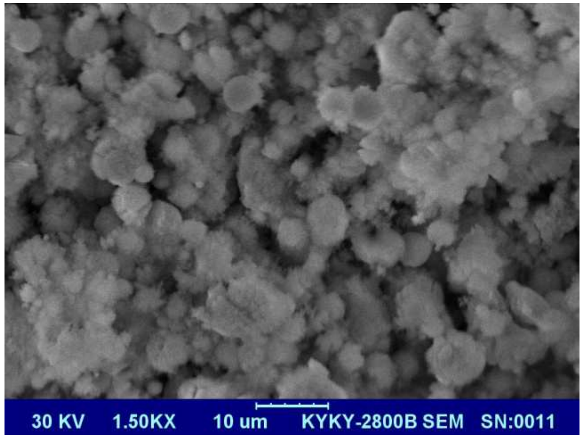
Fig.16 Plasma spraying equipment

Spraying temperature : 7000 ℃ Spraying speed: 500 m/s

Plasma spraying coating oxide cathode

Coating characteristic:

- Adhesion between the Ni base and the coating: improved
- Coating density: improved
- Coating resistance :decreased（10^{-2} ～10^{-1}（$\Omega^{-1}*cm^{-1}$）
  Conventional coating：8×10^{-4} ～2×10^{-3}）



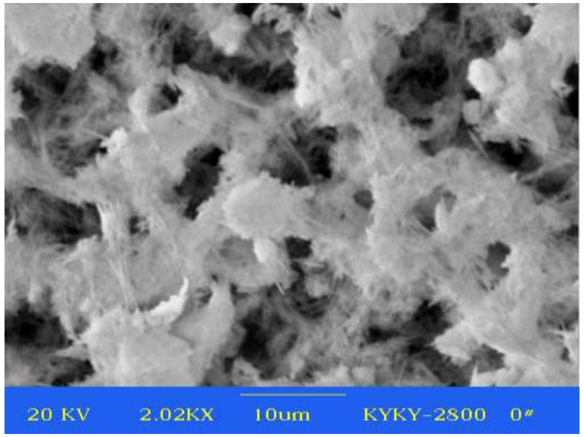


Fig.17 SEM of the oxide cathode surface (1500X)

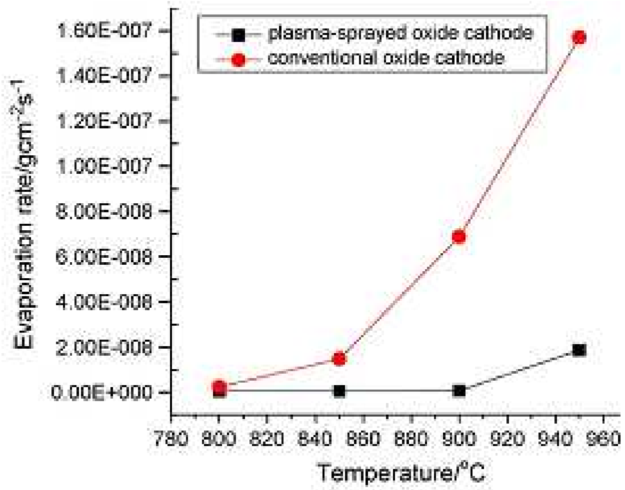


Fig.18 Evaporation rate of the plasma spraying coating oxide cathode

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■ Plasma spraying coating oxide cathode

● Emission characteristic

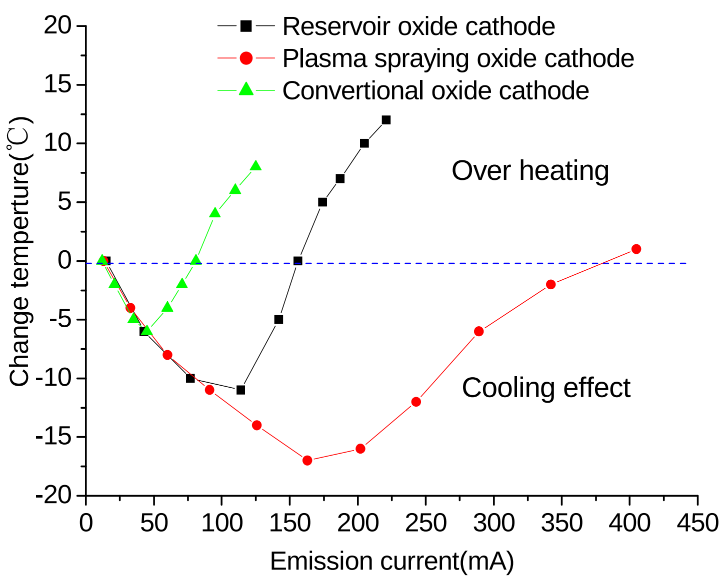


Fig.19 The temperature character of the plasma spraying oxide cathode compared with conventional oxide cathode and reservoir oxide cathode.

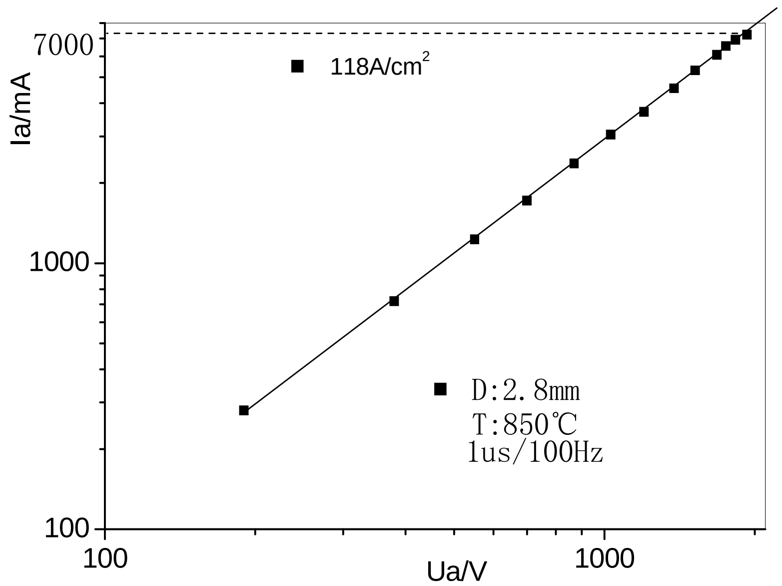
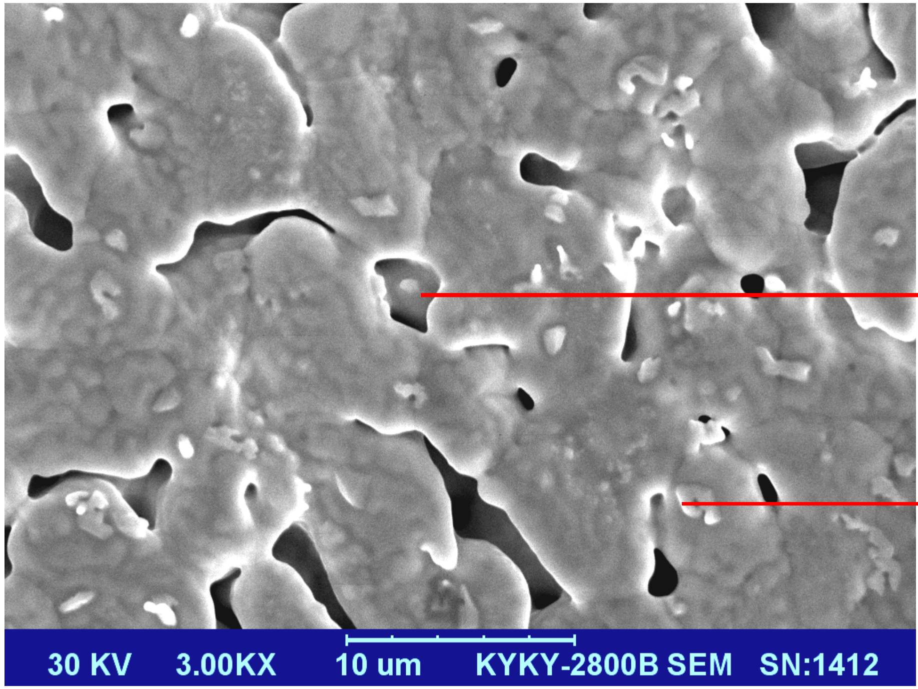


Fig.20 I-V PC emission characteristics of the plasma spraying coating oxide cathode.

- ◆ The plasma spraying oxide cathode has better coating eletricity conductance and heat conductance than the conventional spraying oxide cathode.
- ◆ The pc emission current density of the plasma spraying coating oxide cathode is reached 118A/cm^2 at 850 ºCbr.

■ Ammonium perrhenate impregnated W matrix Ba-W cathode

● The SEM and EDS of the impregnated W- Re matrix



Atom %

Re: 34.5%
W : 65.5%

Re: 19.6%
W : 80.4%

Fig.21 SEM of the impregnated W-Re matrix (3000X)

- ◆ The Re-W particles on the W matrix are well-distributed;
- ◆ The atom percent of Re and W in the hole is respective 34.5% and 65.5%.
- ◆ The atom percent of Re and W on the surface is respective 19.6% and 80.4%.

■ Ammonium perrhenate impregnated W matrix Ba-W cathode

● Emission Characteristics of the cathode

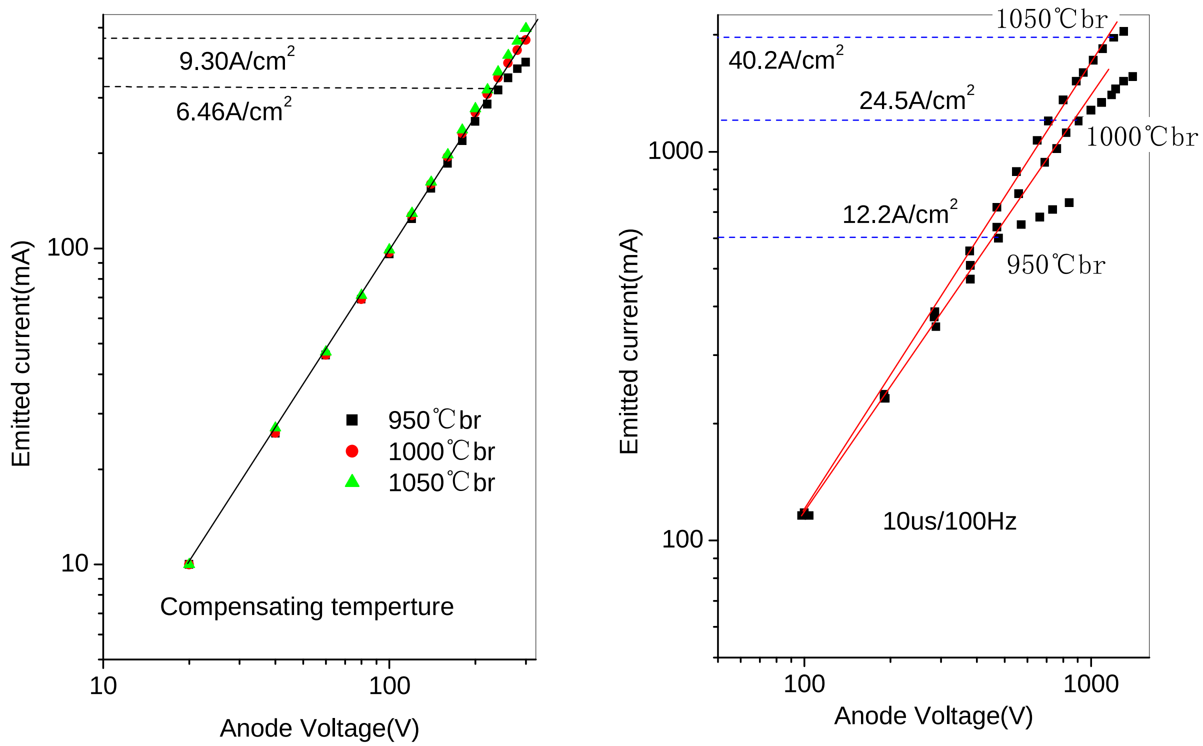


Fig.22. I-V DC/PC emission characteristics of the cathode. The knee-point emitted current density is indicated for each operating temperature.

■ Ammonium perrhenate impregnated W matrix Ba-W cathode

● Miram curve and PWDF before lifetime

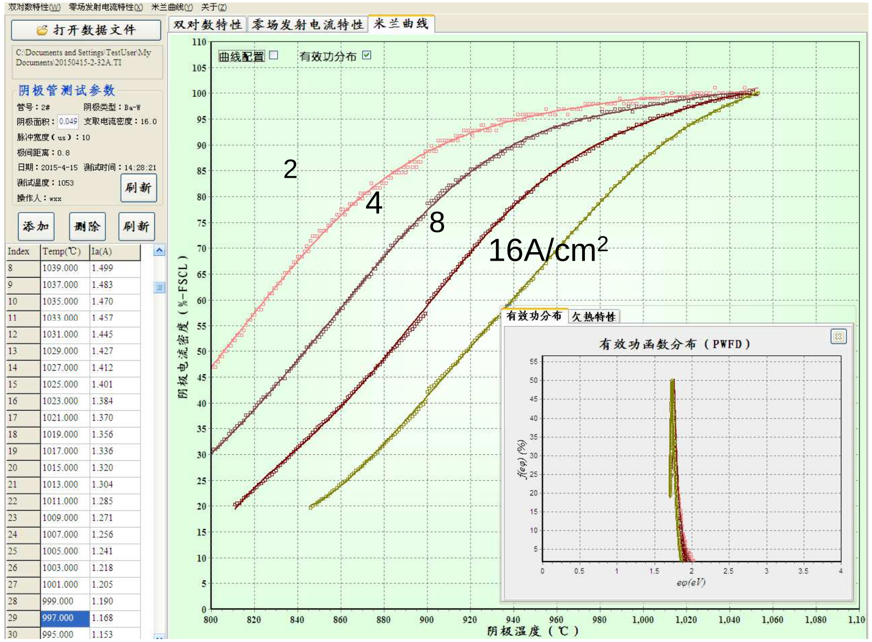


Fig.23 Miram curve of the cathode (the emission current vs temperature)

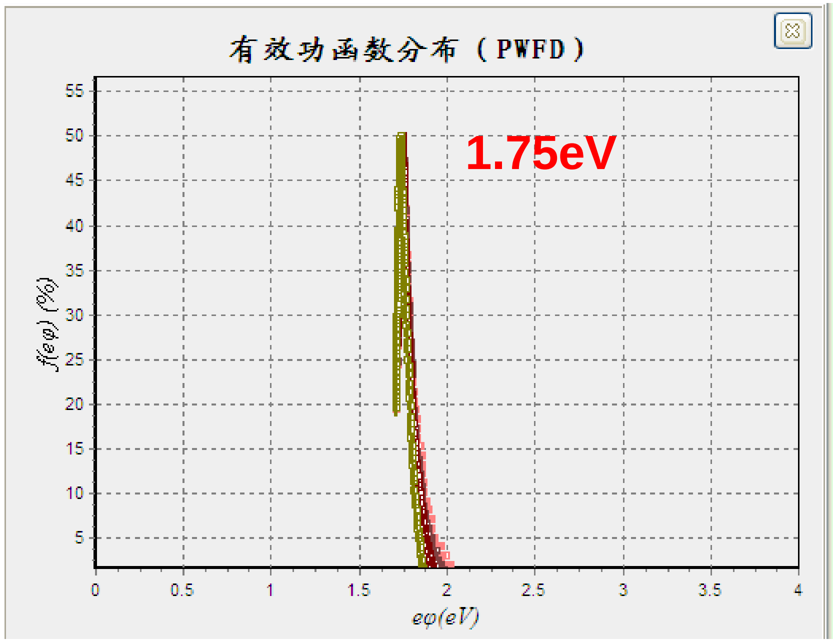


Fig.24 The practice work function distributing(PWFD) of the cathode before lifetime

- ◆ All PWFD curves are almost same at different current.
- ◆ The practice work function distributing is narrow.
- ◆ The average practice work function is about 1.75 eV.

■ Ammonium perrhenate impregnated W matrix Ba-W cathode

● Lifetime testing and PWDF after lifetime

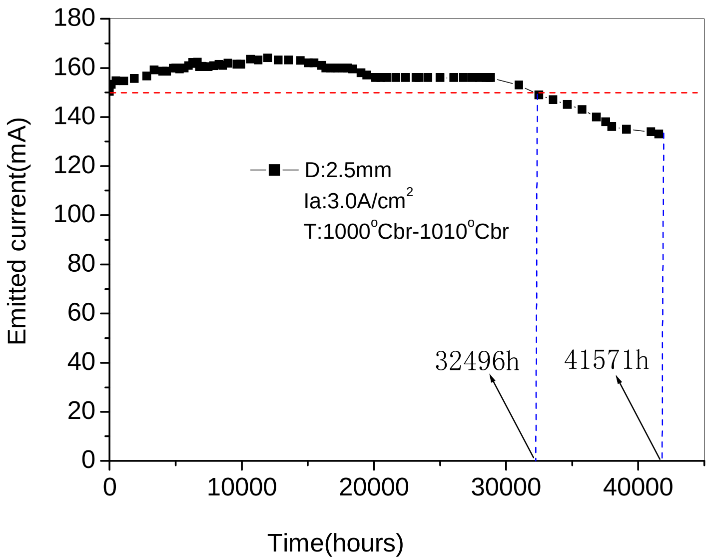


Fig.25 Lifetime curves of the cathodes

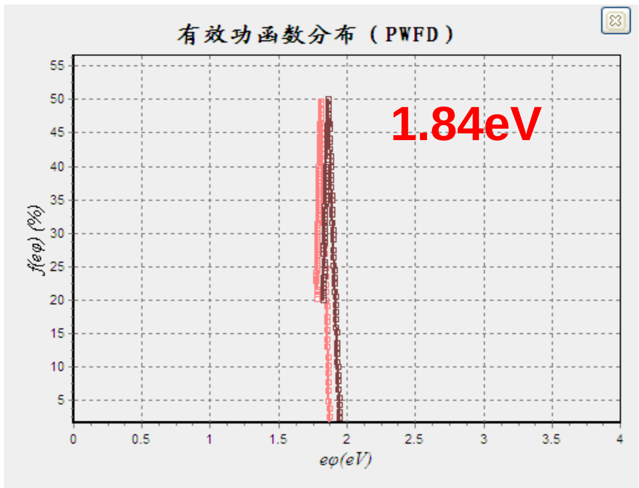
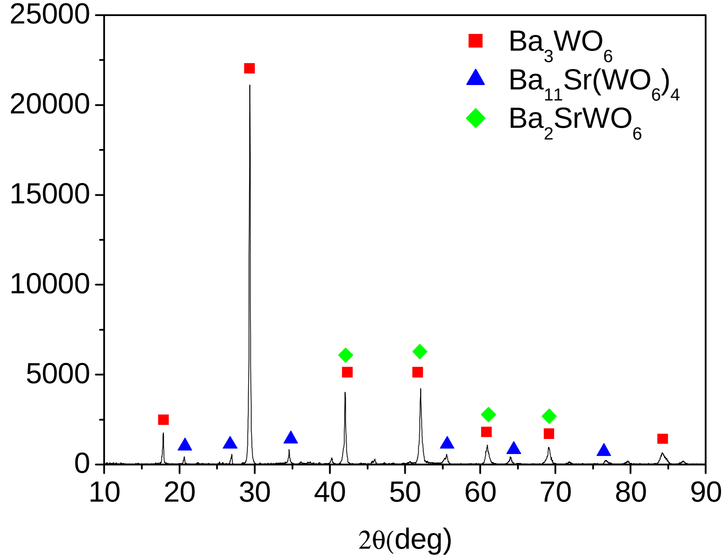


Fig.26 The practice work function distributing(PWFD) of the cathode after lifetime

◆ Figure 26 shows the PWFD curves of the ammonium perrhenate impregnated W-Re matrix Ba–W cathode under 8A/cm^2 and 16A/cm^2 after 41571 hours lifetime, which shows that the average practice work function of the cathode is increased to 1.84eV after 41571 hours lifetime.

■ Nanometer tungstate cathodes

● XRD analysis and Evaporation rate



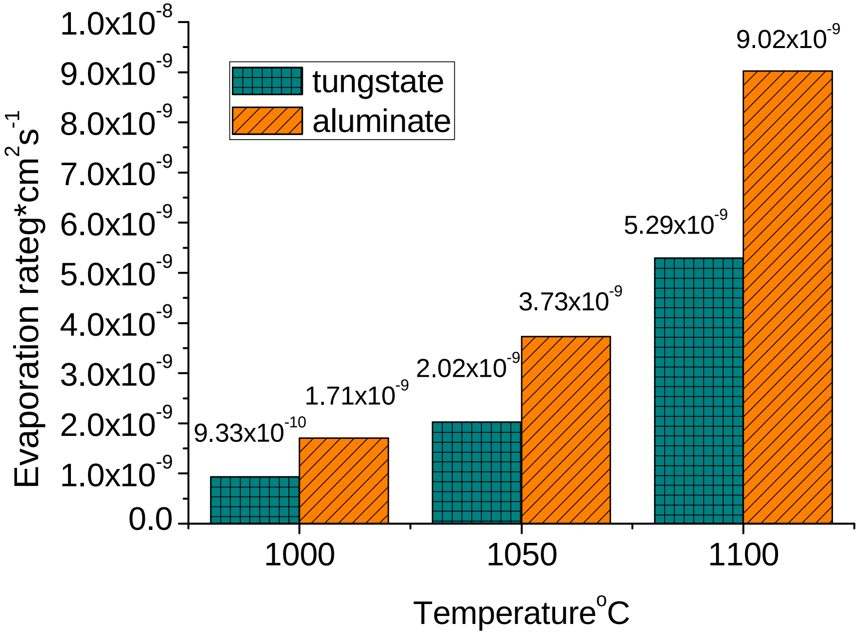


Fig.27 XRD analysis of the tungstate   Fig.28 Evaporation rate of the cathode

- The synthesis of tungstate form Nanometer WO_3 has lower sintering temperature compared with conventional WO_3 .
- $Ba_{11}Sr(WO_6)_4$ and Ba_2SrWO_6 increased from 13% and 9% to 30% and 13% respectively.
- The evaporation rate of the nanometer tungstate cathode is lower than that of 612 aluminate cathode.

■ Nanometer tungstate cathodes

Emission Characteristics of the cathode

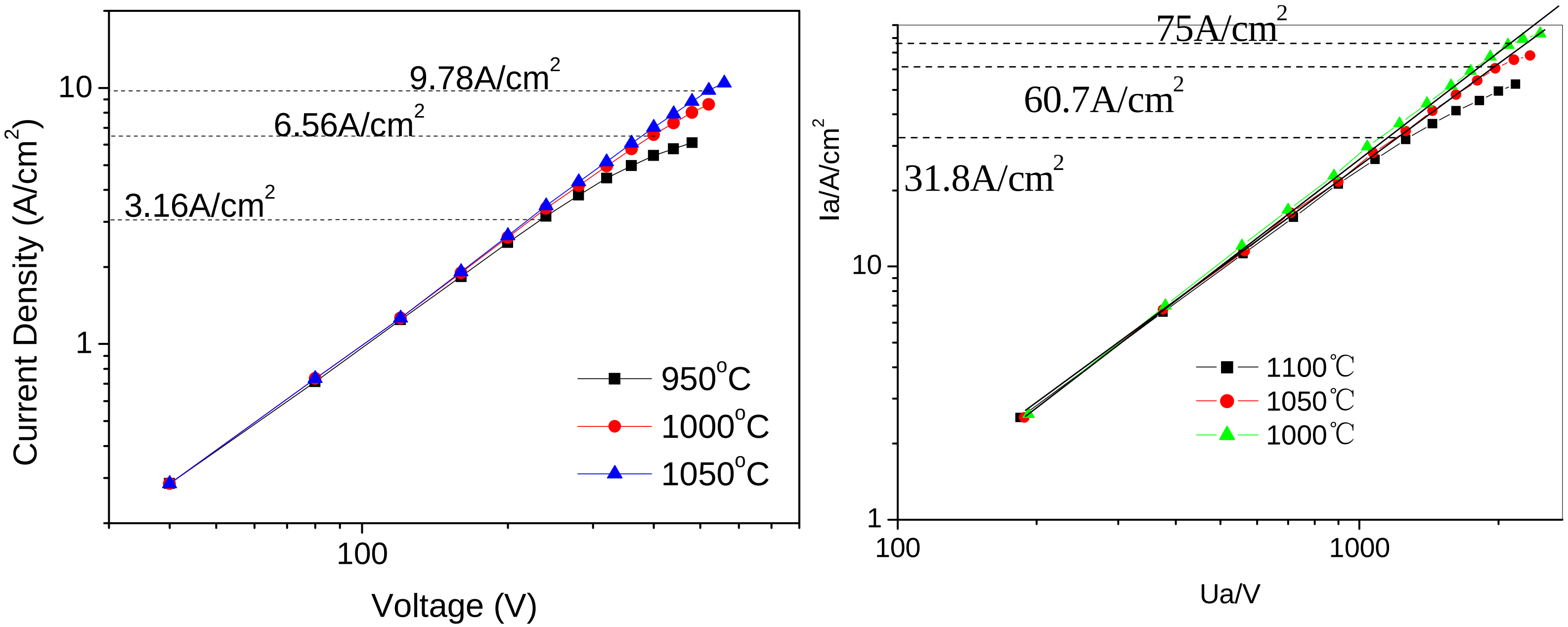


Fig.29 I-V DC/PC emission characteristics of the cathode.

- There is no significant improvement in the emission performance of the tungstate cathode by doping Sc.
- After coating, the emission performance the tungstate cathode has not been improved , but it can improve the emission uniformity and anti-poisoning ability of the cathode.

■ Summary

● Directly heated cathodes

◆ W-Re alloy cathode:

The emission current density is 0.4A/cm^2 at 1800 ℃, the SEEY reaches 1.8, lifetime is 6000 hours.

◆ ThO_2 -W cathode :

The emission current density is 0.4A/cm^2 at 1600 ℃, lifetime reaches 9000 hours. The lifetime of 20kW continuous wave magnetron is beyond 6200 hours.

◆ Y-Gd-Hf-O W base cathode:

The emission current density of the 5%wt Sc_2O_3 doped Y-Gd-Hf-O cathode is beyond 5.0 A/cm^2 at 1500 ºCbr. The SEEY of W doping Y-Gd-Hf-O W base cathode reaches 3.1 at room temperature.

The lifetime is reached 6000 hours with 1.5 A/cm^2 at 1600 ºCbr.Ant-electron-bombing capability of the 5%wt Sc_2O_3 doped Y-Gd-Hf-O W based cathode is better than that of the conventional cathode.

Summary

- **Plasma spraying coating oxide cathode :**

The plasma spraying oxide cathode has better coating eletricity conductance and heat conductance compere with the conventional spraying oxide cathode. The pc emission current density of the plasma spraying coating oxide cathode is reached 118A/cm^2 at 850 ºCbr.

- **Ammonium perrhenate impregnated W matrix Ba-W cathode :**

The DC emission current density is 9.30 A/cm^2 , and the pulsed emission current density reaches 24.5A/cm^2 with 10μs pulse width at 1000 °Cbr. The PWFD is narrow and the average practice work function of the cathode is about 1.75eV.

- **Nanometer tungstate cathode :**

The synthesis of tungstate form Nanometer WO_3 has lower sintering temperature compared with conventional WO_3 . The pulsed emission current density reaches 60A/cm^2 with 10μs pulse width at 1050 °Cbr. The evaporation rate of the nanometer tungstate cathode is lower than that of 612 aluminate cathode.

■ Acknowledgements

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Thank you！

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