Study of the movement of electron groups near a field emission cathode

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Abstract

Because the cold cathode, such as carbon nanotubes array, diamond film, etc., has good field emission performance, it has been used in the field emission display panel and microwave amplifier as an electron source. In a field emission based device, a few dielectric layers are used to separate different electrodes. This paper studies the secondary electron generation on these dielectric layers, and analyses the movement of electron groups near the cathode.

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1. Introduction

Compared with the thermionic cathode, the field emission cathode has a low power consumption, short response time and high stability. Therefore, it has been used as a cold cathode in the field emission display panel and microwave amplifier [1,2]. Many research works are focused on the improvement of the emission current density and the emission stability.

In a field emission based device, a few dielectric layers have been used to separate different electrodes. The primary electrons are emitted from a cold cathode, such as carbon nanotube array, micro-tip array and diamond film. When these primary electrons bombard on the dielectric layer, some secondary electrons will be generated. In this paper, the influence of the secondary electrons on the uniformity of the electron beam is analysed. The movement of electrons groups near the cathode is also calculated.

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2. Generation of secondary electrons in a field emission based device

In a conventional electron optical system, the electrons are emitted from the thermionic cathode. These electrons are focused and accelerated by the electron optical system and then bombard the anode with high energy. However, in a field emission based device, the different electrodes, such as cathode, gate and anode, as shown in Fig. 1, are separated by a dielectric layer. Some of the electrons emitted from the cold cathode may bombard on the insulator layer between the cathode and the gate electrode. As a result of this, some secondary electrons and backscatters are generated. These secondary emission electrons join the electron beam. Because the energy of the secondary electron is quite different from the primary electron, the electrons are grouped seriously in the triode with a cold cathode.

![Fig. 1. The electron trajectories in a triode structure.](image)

It is well known that the electrons emitted from the cathode should have the same velocities in a field emission based device to get a good device performance. If the electron beam has already been grouped near the cathode, the amplification characteristics at high frequencies may be influenced. This paper studies the charge deposition and the secondary electron emission on the insulator wall.

In this paper, equation (1) is used to estimate the secondary electron yield approximately [3]

\[
\frac{\delta}{\delta_m} = 1.85 F \left( \frac{0.92 eV_p}{eV_{pm}} \right),
\]

where \( F(r) = \exp(-r') \int_0^{r'} \exp(-y^2) \, dy \) (1)

where \( \delta \) is the secondary electron yield, \( \delta_m \) is the maximum value of \( \delta \), \( eV_p \) is the energy of the incident primary electron and \( eV_{pm} \) is the maximum primary electron energy related to \( \delta_m \).

When the incident angle of the primary electrons changes, the variation of the secondary electron yield is calculated with equation (2)

\[
\delta_\theta = \delta_0 \exp[P(1 - \cos \theta)]
\]

where \( \delta_\theta \) is the secondary electron yield with an incident angle \( \theta \), \( \delta_0 \) is the value when the incident angle is zero, and \( P \) is a coefficient determined by the energy of the primary electron.
3. Movement of electron groups caused by the secondary electrons

As discussed above, the energy of the secondary electron is smaller than that of the primary electron, so some electron groups will be formed in a field emission based device. The movement of these electron groups influences the performance.

This paper calculates the movement of electron groups. In the calculation, the structure of a field emission triode is shown in Fig. 1. The thickness of the dielectric layer is 20 μm, the diameter of the cathode is 200 μm and the diameter of the gate electrode is 100 μm. In this paper, carbon nanotubes are used as the field emitters. Fig. 2 gives the J-E curve of CNTs cathode obtained by measurement.

![J-E curve of a CNTs cathode.](image)

The initial status of the primary electrons can be defined according to Fig. 2. It is suggested that there are 1000 electrons emitted from a CNTs cathode when time parameter $t$ is zero. Fig. 3 gives the movement of the electron group after the electron emission from the cathode.

As shown in Fig. 3(a), the electrons have just been emitted from the CNTs cathode, and the number of secondary electrons is quite small in the electron group. Therefore, most electrons move with the same velocity. However, more secondary electrons are generated while the primary electrons move towards the gate electrode. In Fig. 3(b), the primary electrons have moved about 0.25mm from the cathode surface after 40 ps. Thus, the primary electrons have passed the gate electrode. However, these primary electrons generate a few secondary electrons and backscatters in the dielectric funnel. Because the initial energy of the secondary electrons are smaller than that of the primary electrons, the secondary electrons move much more slowly. The length of the electron group is about 0.2 mm in Fig. 3(b). With the increment of time, the distances between primary electrons and secondary electrons become large. As shown in Fig. 3(c), some electrons have reached the anode which is 0.7 mm from the cathode, and some electrons are still in the dielectric funnel.

To decrease the driving voltage, a high secondary electron emission material is often coated on the inner surface of the dielectric funnel [4,5]. The movement of electron group when a MgO layer is coated on the inner surface of a dielectric funnel is also simulated, and the results are shown in Fig. 4.

From the comparison of Fig. 3 and Fig. 4, it can be seen that the profile of the electron group is almost the same at the beginning of the emission. However, more secondary electrons are generated in the dielectric funnel when a MgO layer is coated. Therefore, the density of electrons with slow velocity is larger in Fig. 4(b) and Fig. 4(c) than that in Fig. 3.
Fig. 3. The electron group at different time intervals.

(a) Electron group, 1 ps after its emission.
(b) Electron group, 40 ps after its emission.
(c) Electron group, 100 ps after its emission.

Fig. 3. The electron group at different time intervals.
Fig. 4. The electron group, with a MgO layer coated on the inner surface of the dielectric funnel, at different time intervals.

(a) Electron group, 40 ps after its emission, with MgO layer inside dielectric funnel.

(b) Electron group, 40 ps after its emission, with MgO layer inside dielectric funnel.

(c) Electron group, 100 ps after its emission, with MgO layer inside dielectric funnel.

Fig. 4. The electron group, with a MgO layer coated on the inner surface of the dielectric funnel, at different time intervals.
4. Conclusion

The generation of secondary electrons in a field emission based device has been analysed. Because the velocity of secondary electrons is often smaller than that of the primary electrons, some electrons move fast and some electrons move slow in a field emission triode.

As the simulation results have shown, the electrons move with almost the same velocity near the cathode surface. However, a few secondary electrons are generated in the dielectric funnel, so the length of the electron group becomes large when the primary electrons pass the gate electrode. Finally, the primary electrons reach the anode while some secondary electrons are still in the dielectric funnel.

If a high secondary electron emission material is coated in the inner surface of the dielectric funnel, more secondary electrons are generated. Therefore, the profile of the electron group has a small change. The density of electrons with slow velocity increases.

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