Characteristics of a cold cathode electron source combined with secondary electron emission in a FED

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Abstract

In electron beam devices, the voltage applied to the cathode (w.r.t. grid voltage) provides the initial energy for the electrons. Based on the type of electron emission, the electron sources are (mainly) classified into thermionic cathodes and cold cathodes. The power consumption of a cold cathode is smaller than that of a thermionic cathode. The delay time of the electron emission from a cold cathode following the voltage rise is also smaller. In cathode ray tubes, field emission display (=FED) panels and other devices, the electron current emitted from the cathode needs to be modulated. Since the strong electric field, which is required to extract electrons from the cold cathode, accelerates the electrons to a high velocity near the gate electrode, the required voltage swing for the current modulation is also high. The design of the driving circuit becomes quite difficult and expensive for a high driving voltage.

In this paper, an insulator plate with holes is placed in front of a cold cathode. When the primary electrons hit the surface of the insulator tunnels, secondary electrons are generated. In this paper, the characteristics of the secondary electrons emitted from the gate structure are studied. Because the energies of the secondary electrons are smaller than that of the primary electron, the driving voltage for the current modulation is decreased by the introduction of the insulator tunnels, resulting in an improved energy uniformity of the electron beam. Triode structures with inclined insulator tunnels and with double insulator plates are also fabricated and lead to further improvements in the energy uniformity. The improved energy uniformity predicted by the simulation calculations is demonstrated by the improved brightness uniformity in the screen display images.

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1. Introduction

In an electron beam device, such as a RF amplifier [1], an electron microscope, a cathode ray tube, etc., a cathode is used for supplying the electrons.
The electron source can be either a thermionic cathode or a cold cathode.

The electrons are emitted from a cathode surface by field emission when a very strong electric field is applied on the cathode. To increase the field enhancement of the field emitters, microtip arrays and carbon nanotube arrays were proposed as cold cathodes. In some electron devices with cold cathodes, the electron beam has to be modulated with the input signal. Because of the high electric field required for the field emitter array, the high swing of the modulation voltage makes the driving circuit design difficult and expensive.

In this paper, an insulator tunnel array is introduced above the cold cathode. When the primary electrons hit the surface of the insulator tunnels, secondary electrons are generated. Because the energies of the secondary electrons are smaller than that of the primary electrons, the driving voltage can be decreased by the introduction of the insulator tunnel array [2,3].

2. Triode with a cone-shaped insulator tunnel

In Refs. [4–6], an insulator plate was inserted in the field emission display panel. When the primary electrons bombard the surface of the insulator tunnels, secondary electrons are generated. Because the energies of the secondary electrons are smaller than that of the primary electrons, the driving voltage can be decreased by the introduction of the insulator tunnel array [2,3].

In this paper, the yield function $\delta$ is expressed by the following equation:

$$\frac{\delta}{\delta_m} = 1.85 F \left( \frac{0.92 eV_p}{eV_{pm}} \right)$$  \hspace{1cm} (1)

$$F(r) = \exp \left( -r^2 \right) \int_0^r \exp(Y^2) \, dY$$  \hspace{1cm} (2)

where $\delta_m$ is the maximum value of $\delta$, and the parameter $eV_{pm}$ the energy of the primary electron when the yield function is at the maximum value $\delta_m$.

As shown in Eq. (1), the material property of the insulator and the energy of the primary electrons affect the secondary electron yield. In Ref. [3], an insulator plate was used in the field emission panel. The structure of the insulator tunnels is shown in Fig. 2. Because the energies of the secondary electrons are
small, the driving voltage can be decreased when only the secondary electrons are modulated. In this paper, the trajectories of the electrons are calculated, including the primary electrons, the secondary electrons and the back-scattered electrons. The potential distribution and the trajectories are shown in Fig. 3.

As shown in Fig. 3, most of the electrons that reached the anode are the secondary electrons generated inside the insulator tunnel. However, some primary electrons and the back-scattered electrons also hit the screen. Because the energy of the primary electrons and of the back-scattered electrons are larger than that of the secondary electrons, the energy uniformity of the electron beam is also poor. Consequently, the wide energy distribution of the electrons increases the required driving voltage of the gate electrode. In this paper, a practical carbon nanotube cathode is fabricated with the screen-printing method. A triode structure described in Fig. 2 is constructed and the anode current is measured with different driving voltages. The driving curve of this triode is shown in Fig. 4.

Fig. 4. The gate structure with one insulator layers.

Fig. 5. The characters display with the one insulator layers.
From the measurement it can be seen that the anode current is larger than 90% of the cathode current. In Fig. 4 the driving electric field is about 3.0 V/μm. We use the triode structure to display several Chinese characters. The displayed image is shown in Fig. 5.

Because some primary electrons and back-scattered electrons can also pass through the insulator tunnel in Fig. 3, the energy uniformity of the electrons that reach the screen is poor, as demonstrated by the poor brightness uniformity in Fig. 5.

Fig. 6. Insulator plate with incline holes.

Fig. 7. The electron trajectories inside an inclined hole (a) incline angle is about 20.8°; (b) incline angle is about 37.2°.

Fig. 8. The driving voltage of the triode with incline holes.
3. Triode with the inclined holes

To improve the energy uniformity of the electron beam, inclined tunnels are used in this study. The structure is shown in Fig. 6.

In the triode structure shown in Fig. 6, the inclined tunnels shield the primary electrons. Fig. 7 gives the trajectories of the electrons inside the inclined holes. The trajectories show that the larger the inclined angle $\theta$ is, the more primary electrons the insulator plate shields.

Table 1 gives the relative amount of the secondary electrons on the screen w.r.t. primary electrons.

As shown in Table 1, the percentage of the secondary electrons is only about 80% if we use a cone-shaped insulator hole shown in Fig. 3. Therefore, the required driving electric field in Fig. 4 is still high. When the angle of inclination increases to 37.2°, the percentage of the secondary electrons is over 98%.

Normally, the inclined hole can be fabricated by etching or by the powder blasting method. The present manufacture technology limits the size of the inclined angle of the insulator. In this study, an insulator plate with inclined holes at an inclination angle of less than 20° was fabricated. The anode currents were also...
measured with different driving voltages. The driving curve is shown in Fig. 8.

Because some primary electrons still bombard the anode, the driving electric field is almost the same as that shown in Fig. 4. However, the energy uniformity of the electron beam reaching the screen has improved. Fig. 9 shows the character display image with this structure.

From the comparison between Figs. 5 and 9 it can be seen, that the uniformity of the brightness has been obviously improved.

4. Triode with double insulator plates

To improve the driving characteristic further, a double insulator plate structure is proposed. The structure is shown in Fig. 10. With the effect of the double insulator plates, more primary electrons can be shielded. Fig. 11 shows the driving curve measured in the experiment.

Because the percentage of the secondary electrons on the anode is increased with the double insulator layers, the driving electric field has been decreased to 1.5 V/μm in Fig. 11. Fig. 12 shows the character display image with the double insulator layers structure.

With the double insulator layers, the energy uniformity of the electron beam at the exit of the insulator plate has been improved. In Fig. 12, it can be seen that the uniformity of the brightness on the screen has been improved significantly with the double insulator plates.

5. Conclusion

In electron devices, such as cathode ray tubes, field emission display panels, RF amplifiers, etc., the electron beam has to be modulated. Because of the high electric field applied on the cold cathode, the driving voltage for the cold cathode is also high.

In this paper, a cold cathode with an additional insulator tunnel structure is studied. With this insulator tunnel structure, the secondary electrons are the main electron source. Because the energy of the secondary electron is smaller than that of the primary electron, the driving performance and the uniformity in the brightness on the screen can be improved. Simulations and experiments are performed to verify this conclusion.

In order to improve the driving characteristic of the triode further, a double insulator plate with inclined holes is proposed. With the shielding effect of the double insulator plate, the percentage of the secondary electrons among the electrons that reached the anode increases further. Therefore, the required driving electric field decreases. Apart from this, the energy uniformity of the electron beam at the exit of the insulator plate has improved. The uniformity in the brightness on the screen is better than that with only one insulator plate.

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