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A Field-Emission Device with Novel Self-Focus Gate Structure

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Abstract

A field-emission device (FED) with self-focus gate structure using carbon nanotubes (CNTs) as cold cathode materials is fabricated. The non-symmetric gate electrode can be employed to extract electrons; meanwhile, it can be a focus lens. According to the simulation results and luminescent images, this self-focus gate structure has a well controllability on the trajectory of electrons emitted from CNTs, and therefore represents a smaller luminescent spot size than conventional structure, that is, it shows an excellent focusing effect. The novel gate structure which employs a simple fabrication process has advantages of low-cost manufacturing and scalability, and is promising for the application of FED.

1. Introduction

Carbon nanotubes (CNTs) have attracted much attention for the application of field emission due to their high geometric aspect ratios, chemical inertness, and large emission capacity.[1–2] In most of field emission device (FED) panels the phosphor materials used in CRT screens are still used. These phosphors provide high efficiency into light by bombardments of electrons at enough high voltages of the anode plate. The high-anode voltage improves the qualities of FEDs in color purity and high brightness. The high-anode voltage requires a large vacuum gap between the cathode and anode plates. The large vacuum gap may cause a problem of beam spreading. Therefore, a focusing structure which could well control the trajectory of electrons and reduce the cross-talk noisy is necessary. Several focusing structures of FED have been announced to overcome the issue of electron spreading, such as planar-electrode type,[3] double-gate type,[4] and mesh-electrode type.[5] Those structures have some issues, such as the complication of the manufacturing process and difficulty in formation of CNTs or other emitters within gate apertures.

In the papers, a self-focus gate structure is fabricated with simple fabrication processes, and the results of the simulation and luminescent images shows a good controllability in electron trajectory. This novel triode structure with simple processes is promising for the application of FED.

2. Fabrication and Simulation

2.1 Devices Design and Simulation

The conventional device has a surrounding gate so that electrons are emitted from the peripheral area of the extraction gate. In the contrary, the self-focusing gate structure has a non-symmetric extraction gate area, which consists of a pair of linear electrodes closed to the emission region of CNTs. The top and cross-section views of conventional and self-focus gate structures are shown in Fig. 1(a) and 1(b), respectively.

Simulations were performed to investigate the beam spreading of emission electrons with commercial software (SIMION-3D) using the finite element method. Simulations of electron beam trajectories of the conventional gate structure and the self-focus gate structure are shown in Fig. 2(a) and 2(b), respectively. The thickness of silicon oxide layer formed by plasma-enhanced chemical vapor deposition (PECVD) is 1 μm. In simulations, emission of electrons is assumed on a flat surface of CNT emitters. The voltage between the cathode and anode plates is applied with 1 kV with the spacing of 550 μm, while the gate voltage is applied at 80 V. Simulation results show that the self-focus structure has a spot size of 232 μm in length on the anodic plate, while conventional one has 622 um in length. It's clear that the novel structure could effectively reduce the spot size on the anodic palate, therefore achieving a better focusing effect.

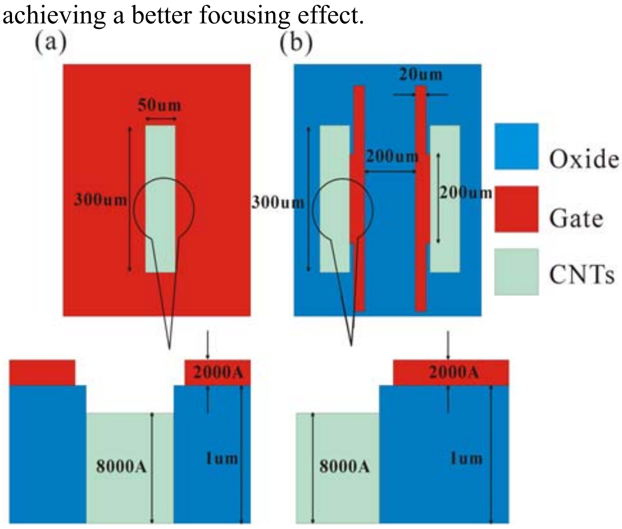

Fig. 1. The top view (up) and its' cross-section view (under) of design of the conventional structure is shown in (a) and the self-focus gate one is shown in (b).

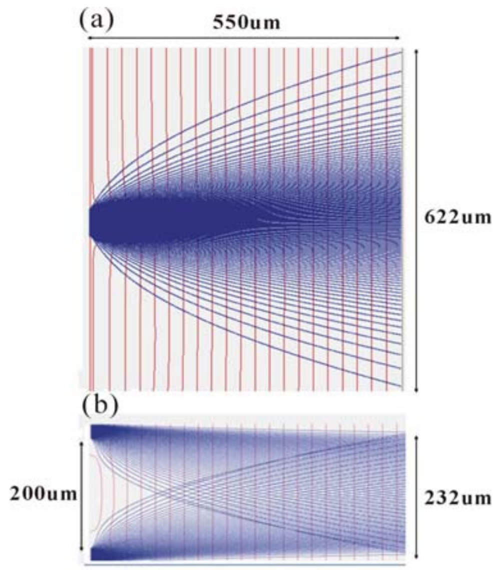

Fig. 2. Simulate electron beam trajectories of the conventional gate structure (a) and self-focus gate structure (b).

2.2 Fabrication and Measurement

CNTs are synthesized with a multilayered catalyst of Co/Ti/Al by thermal CVD at the temperature of 500℃. The SEM images of the self-focus gate structure are shown in Fig. 3. The field emission characteristics of devices with conventional and self-focusing gate structures are measured in a high-vacuum chamber with the pressure below 5×10^{-6} Torr. The field emission curve of current density versus extraction gate voltage is shown in Fig. 4, and the inset represents the corresponding FN plot. Although conventional structure has a high emission current density than novel one, there is no enormous difference between them. The photo-luminescent images taken via CCD camera are shown in Fig. 5. The spot sizes are consistent with the simulation results, indicating that the self-focus structure has good functionality in controlling the spot size of electron beams.

(a) (b)

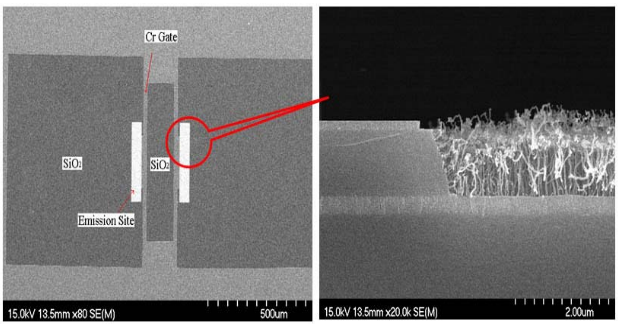

Fig. 3. The SEM images of the self-focus gate structure (a) top view (b) cross-section view.

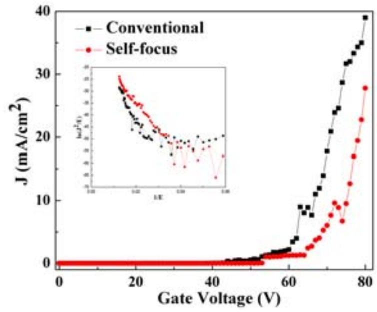

Fig. 4. I-V plots for self-focus gate structure (red curve) and conventional (black curve). The insert is F-N plot.

(a) (b)

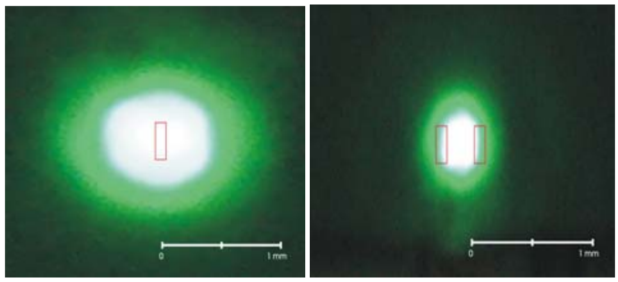

Fig. 5. The luminescent images of the conventional structure (a) and the novel self-focus one (b). (The red rectangles are emission sites.)

3. Conclusions

We successfully manufacture a novel self-focus gate structure with CNTs emitters, which shows a good controllability in luminescent spot size compared with conventional one. In addition to CNTs, the novel structure could be applied to all kind of emitter materials, such as ZnO rods, Silicon tips or nanoparticles. The simulations and luminescent images show the excellent focusing results. Therefore, the self-focus structure seems to be promising for large panel of FEDs.

4. Acknowledgements

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