A New Structure of Triode-type CNT-FEAs for Enhanced Electron Emission and Beam Focusing

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Abstract

We proposed a novel triode-type carbon nanotube field emitter arrays in which extracted gate is surrounded by CNT emitters. We carried out 3-dimensional numerical calculations of electrostatic potential for the proposed CNT-FEAs using the finite element method and compared the results with those obtained from the structure of conventional CNT-FEAs. It was found that the proposed structure could reduce the turn-on voltage for electron emission and improve beam focusing.

1. Objectives and Background

Since the discovery of carbon nanotubes (CNTs)[1], CNTs have drawn much attention owing to their unique physical properties and various applications. Especially, CNTs have been applied to field emitters and a lot of experiments and investigation have been carried out[2-3]. The advantages of CNTs as field emitters include a small radius of curvature, high aspect ratio, high chemical inertness and mechanical strength[4,5]. For the application to field emission display, a triode-type CNT-FEAs with under gate structure was developed and has been improved in various ways[6]. Although the structure showed a lot of advantages such as low gate leakage current, it was difficult to realize uniform distribution of emission current because the large part of the electron emission was occurred on the edge of CNT layer.

In this paper, we propose a new structure of triode-type CNT-FEAs whose extracted gate is surrounded by CNT emitters. The emission properties of proposed CNT-FEAs are investigated and compared with those of conventional ones by using 3-dimensional electrostatic simulator of Opera-3D.

2. Experiment

Simulation was performed with commercial simulator of Opera-3D. The simulator uses the finite element method to solve the electrostatic Poisson's equation, and calculate the electric scalar potential[7]. The space charge density which is included in the Poisson's equation is found by calculating the trajectories of a set of charged particles from the emitters under the influence of the electrostatic field. Electron emission from emitter surface and trajectories of field-emitted electrons are calculated using the following Fowler-Nordheim equation[8].

where J_e is the emission current density in A/cm^2, E is the electric field in V/m applied to the emitter surface, and E_f and ϕ_w are the Fermi energy of electrons in the cathode and the work function in eV, respectively.

Fig. 1 shows schematics of the conventional and the proposed triode-type CNT-FEAs used in the simulation. From the fitting of the simulated data with measured ones in our previous works, field

$$J_e = 6.2\times10^2\left(\frac{E_f}{\phi_w}\right)^{\frac{1}{2}}\frac{E^2}{E_f+\phi_w}e^{\frac{-6.83\times10^7\phi_w^{\frac{3}{2}}}{E}} \quad (1)$$

enhancement factor(β) and work function(ϕ_w) were assumed to be 710 and 5 eV, respectively[9-10].

3. Results and Discussion

The electrical characteristics were obtained at various gate voltages. Fig. 2(a) shows the simulated trajectories of emitted electrons from conventional structure at gate voltage of 30 V and Fig. 2(b) from new structure at a gate voltage of 21V. From the figures, it is apparent that the emitted electrons in the proposed structure are well focused compared with conventional structure.

Fig. 3 and Fig.4 show the positional distribution of emission current density obtained from the conventional and the new structure, respectively. In Fig. 3 and Fig. 4, the calculation was carried out in cartesian and in circular cylindrical coordinates considering the real structure of CNT-FEAs. In the conventional structure, the peak point of emission current density moves along the gate electrode by about 65 μm to 110 μm from the edge of CNT layer as gate voltage increases from 20 V to 50 V. Therefore, emitted electrons may be diversified outside a pixel. On the other hand, in the proposed structure, the peak point exists within 90 μm at the gate voltage of 50 V, which implies that the emitted electrons can be collected inside circular CNT layers around center of extracted gate.

Fig. 5 shows the simulated I-V characteristics. Since the proposed structure has the CNT emitter layer and the extracted gate in the shapes of circle, the electric field is converged around CNT emitters. Hence, the new structure has a higher electric field at the edge of CNT than the conventional structure in condition of the same gate voltages, which can lead to lower turn-on voltage. While electron emission occurs at 45 V and reaches 15 μA at 52 V in the conventional structure, the emission in the proposed structure occurs at 22 V and reaches 16 μA. In fact, the measured data obtained from fabricated conventional structure revealed that the emission started at 38 V and reached the level of 14 μA at the gate voltage of 55 V[10].

4. Conclusion

In conclusion, we proposed a novel triode-type CNT-FEAs with lower turn-on voltage and better beam focusing. With the help of the 3-dimensional electrostatic simulation, it is confirmed that the proposed structure may reduce the turn-on voltage by half compared with the conventional under gated CNT-FEAs. Proposed structure is also effective in beam focusing. We expect that the new structure can be a promising candidate for high-resolution field emission displays.

5. References

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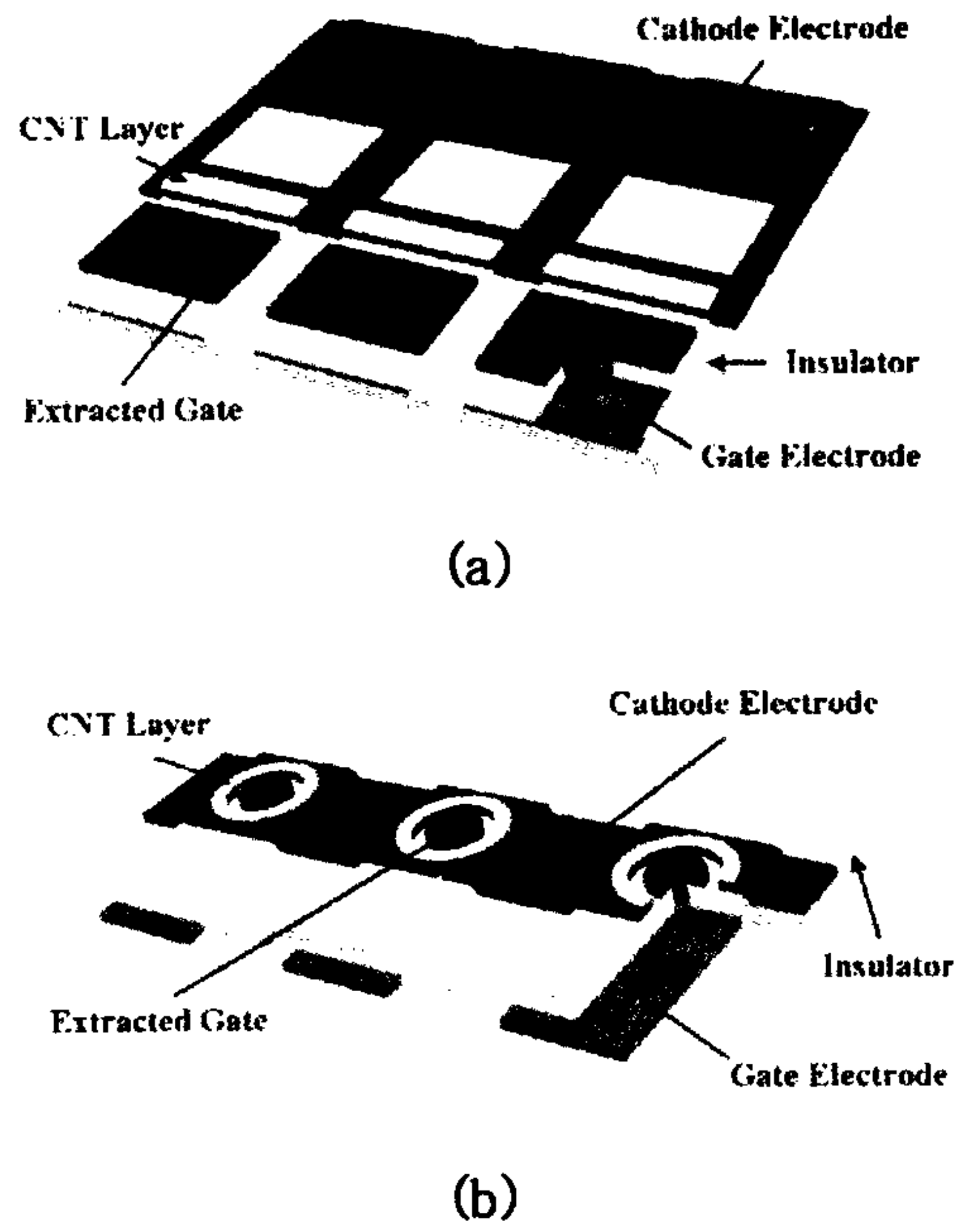


Fig. 1. Schematic diagram of triode-type CNT-FEAs. (a) conventional structure, (b) proposed structure.

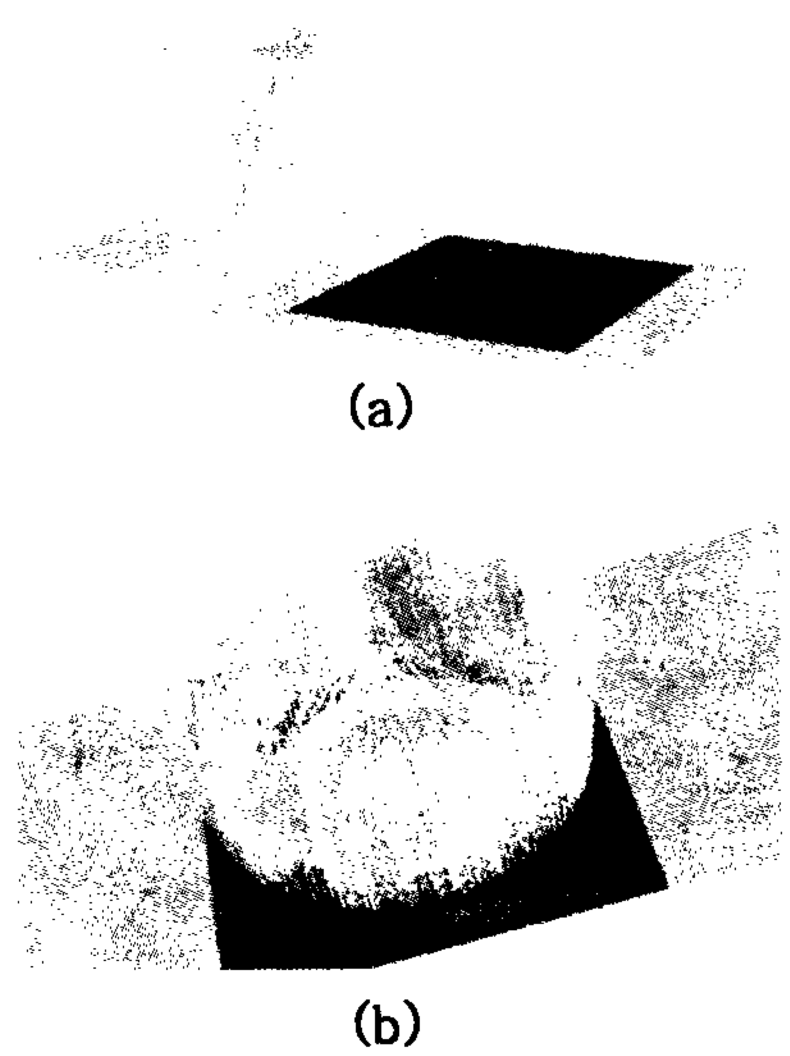
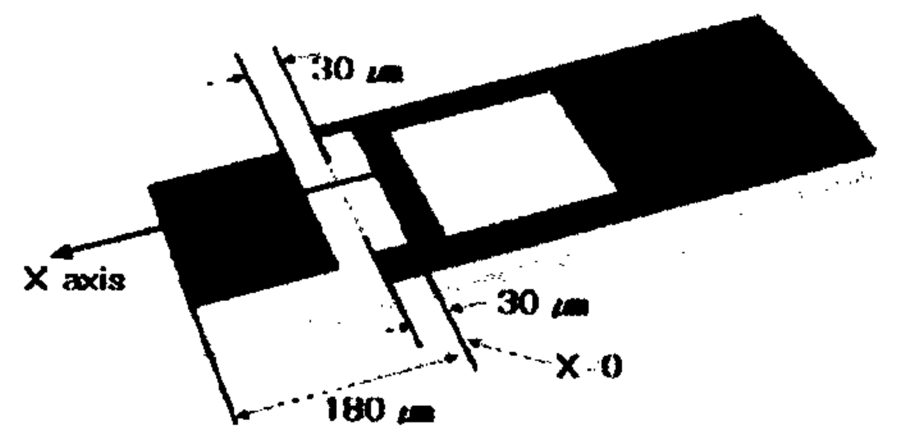
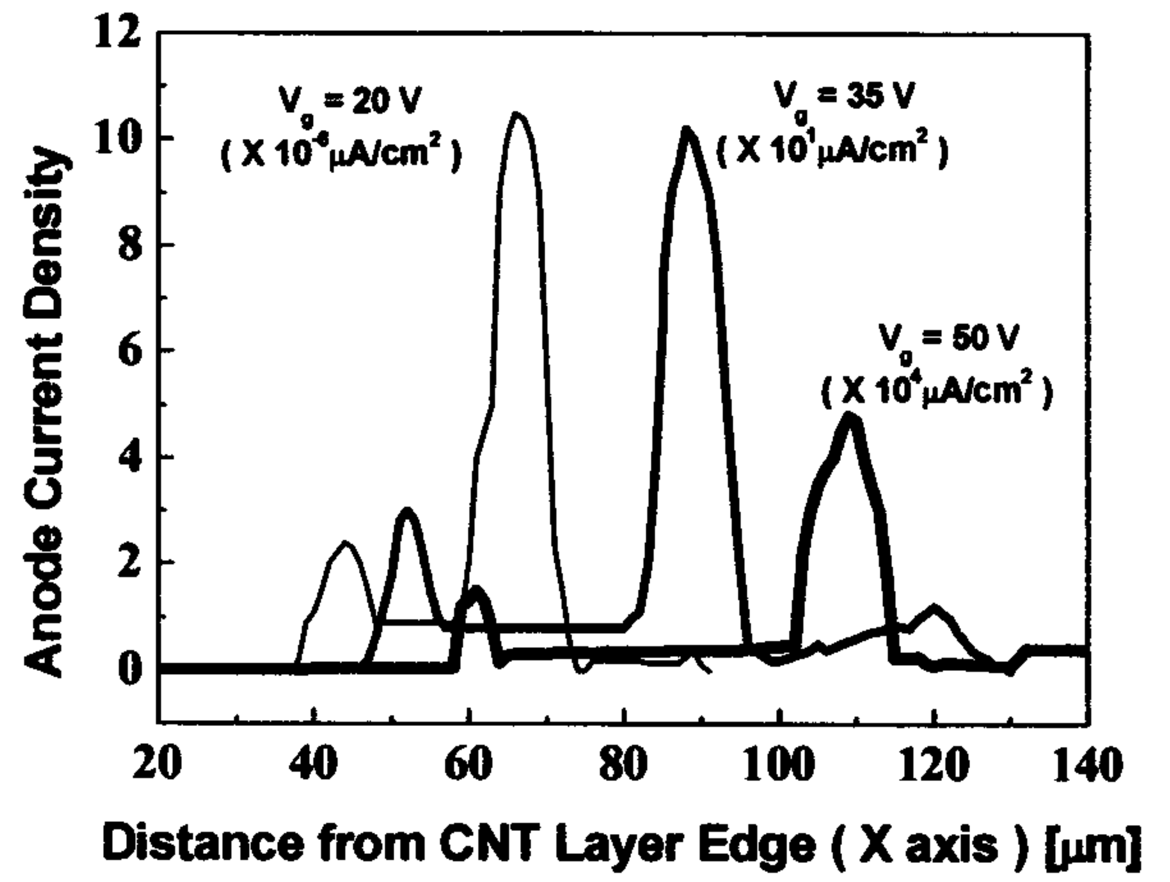


Fig. 2. Simulated trajectories of emitted electrons from (a) the conventional and (b) proposed CNT-FEAs.

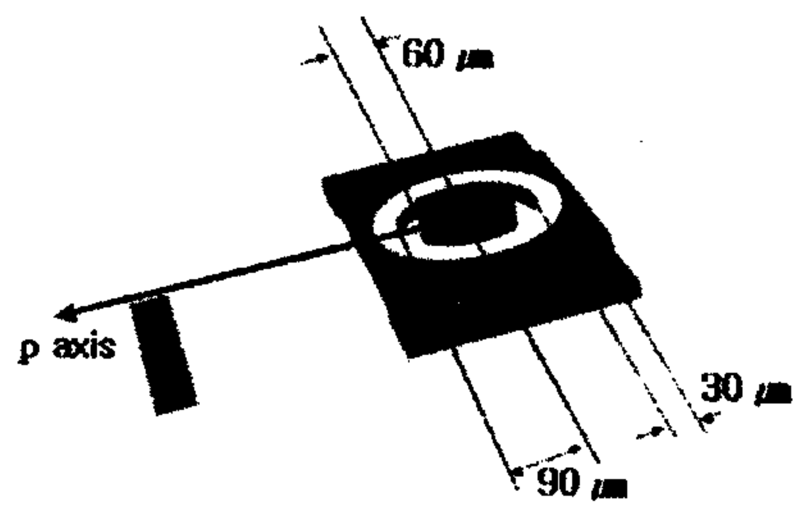


(a)

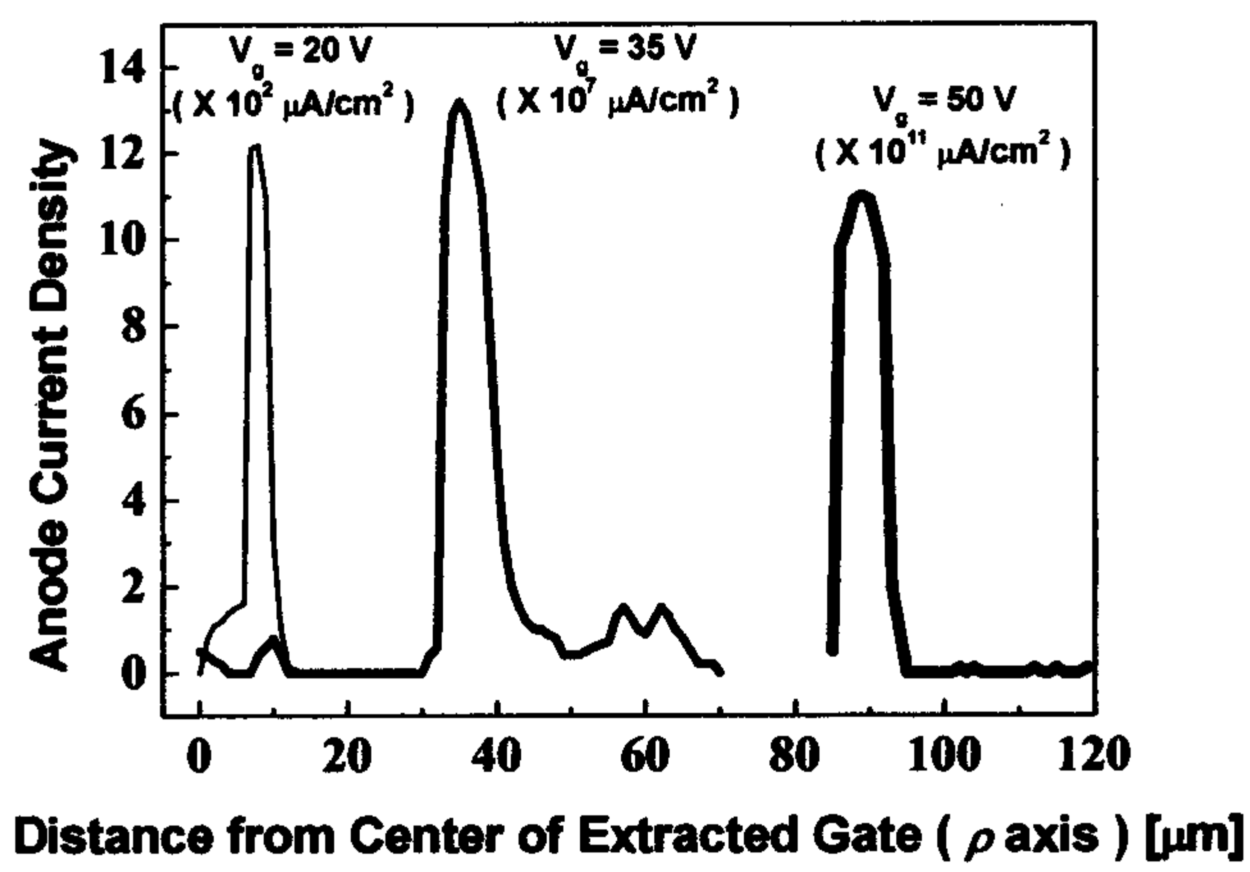


(b)

Fig. 3. (a) Schematic diagram showing the geometry used in the simulation and emission current density calculated from the conventional structure at the gate voltage of (b) 20V, 35V and 50V. The calculation was carried out in cartesian coordinates.



(a)



(b)

Fig. 4. (a) Schematic diagram showing the geometry used in the simulation and emission current density calculated from the proposed structure at the gate voltage of (b) 20V, 35V and 50V. The calculation was carried out in cylindrical coordinates.

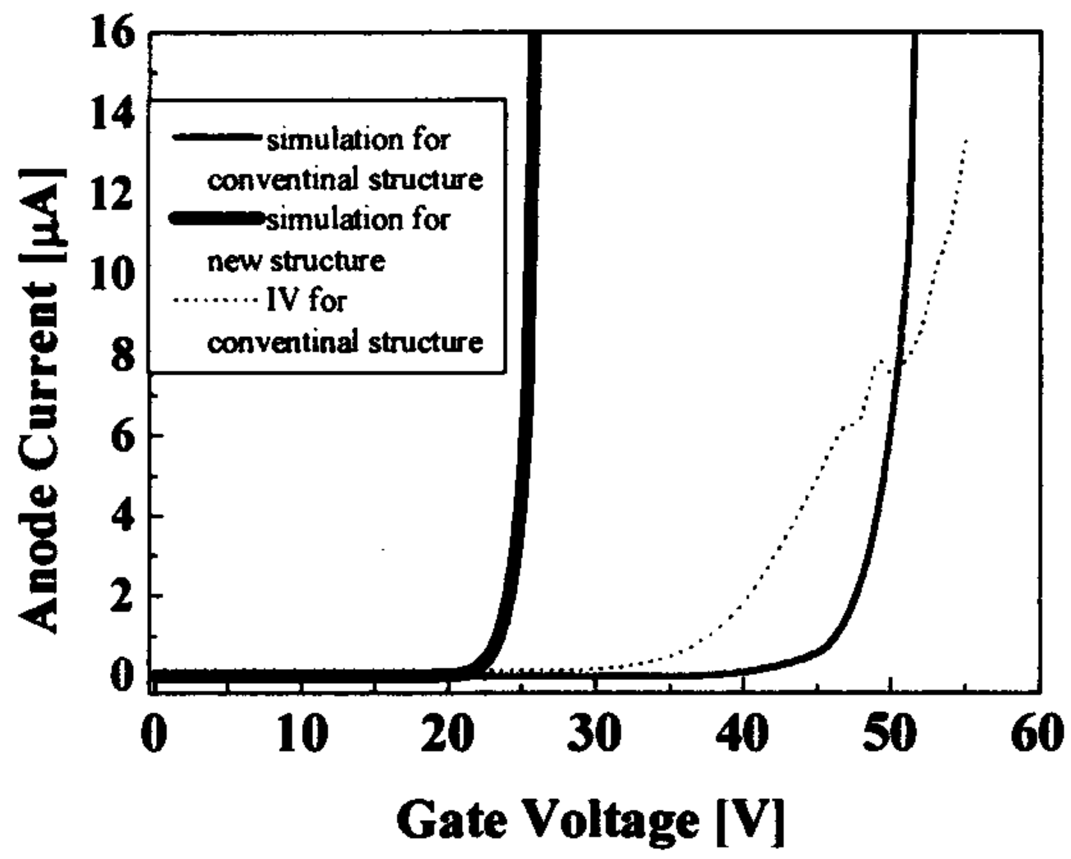


Fig. 5. Calculated I-V characteristics of the conventional and the proposed triode-type CNT-FEAs.