

Carbon-Nanotube Based Field-Emission Displays for Large Area and Color Applications

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Abstract

The first 9-inch carbon nanotube based color field emission displays (FEDs) are integrated using a paste squeeze technique. The panel is composed of 576 x 242 lines with implementation of low voltage phosphors. The uniform and moving images are achieved only at 2 V/μm. This demonstrates a turning point of nanotube for large area and full color applications.

Keywords : Carbon nanofubes(CNTs), field emission displays(FEDs), full color

1. Introduction

Carbon nanotubes (CNTs) with extremely small diameters, hollowness, and chemical and mechanical strengths have provided a vast range of their applications such as electron field emitters, room-temperature transistors, and vehicles for hydrogen storage [1-3]. CNTs have a strong potential to be applied to field emitters for emissive devices including flat panel displays, cathode-ray tubes, backlights for liquid crystal displays, and outdoor displays. We have demonstrated 4.5-inch fully sealed CNT field emission display operating at low voltage with high brightness and high stability [4, 5]. Here we present the first 9-inch CNT-FED with diode- and triode-type geometry. The first moving image demonstrates the high potential of large area and full color display applications with very low cost fabrication and low power consumption.

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2. Results and Discussion

Here we report the first integration processes of fully sealed 9-inch color CNT-FEDs. The structure of CNT-FED is shown in Fig. 1. The panel structure consists of two glass plates: stripes of CNTs on the patterned cathode plate and phosphor-coated indium tin oxide (ITO) stripes on the anode plate. The gate electrode for the triode-type is inserted between two plates.

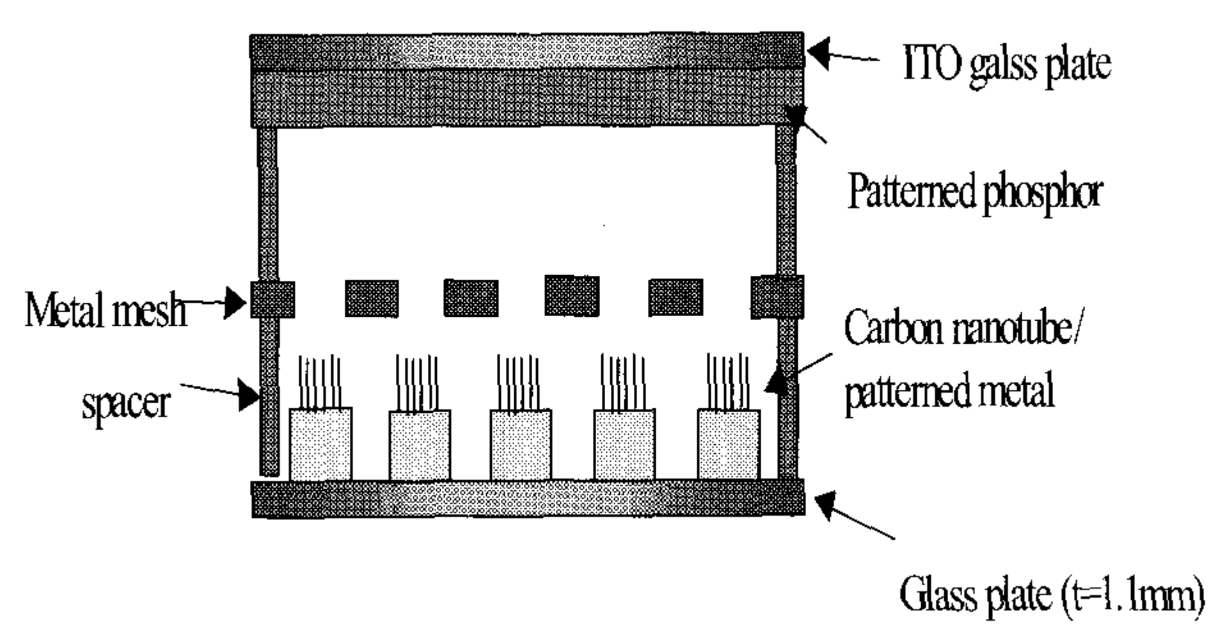
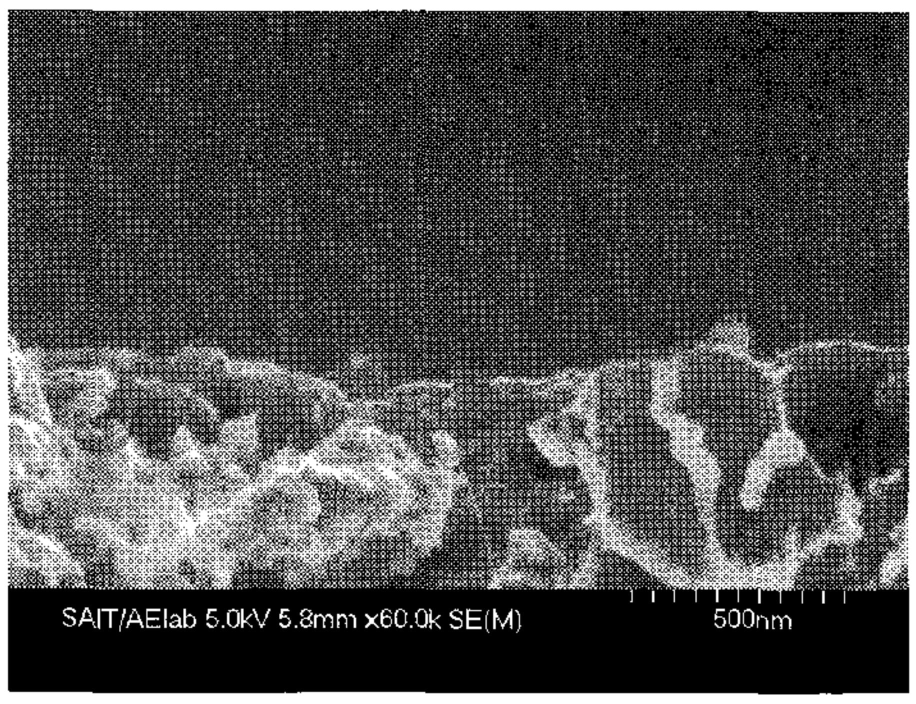
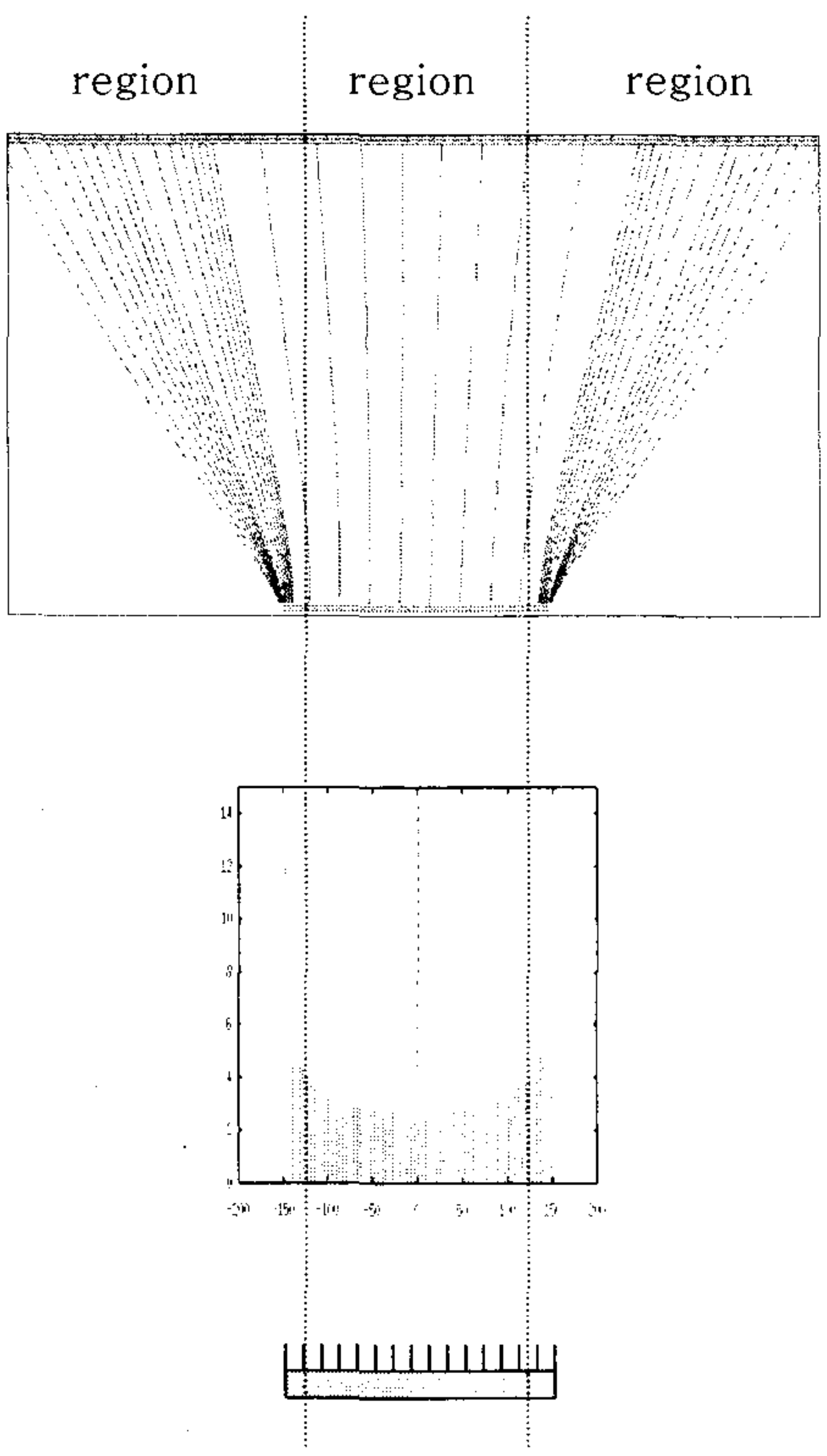


Fig. 1. Schematic geometry of a triode-type carbon nanotube-based field emission display.

Fig. 2(a) is a cross-sectional view of typical CNT based electron emitters. The CNTs were aligned and laid out on the all area in the cathode electrode. Fig. 2(b) shows the calculated electric field distribution and trajectory of emitted electrons on one of the cathode electrodes. However, as shown in Fig. 2(b), electric field distribution is strongly enhanced at the edge of the electrode. Due to the strong electric field enhancement of the edge, the emitted electrons are widely spread from the center of the electrode (Fig. 2(b)). This induces the color cross talk between pixels and color degradation on the pixel. These problems could be overcome if only one of the cathode-edge is used. Here, we propose unique edge field effect-based structure and layout. The fabricated device shows perfect color separation for FEDs.



(a)



(b)

Fig. 2. (a) A cross-sectional view of typical CNT-emitters (b) Electric field distribution and electron trajectories on an aligned CNT cathode. (aligned-CNT cathode (bottom), field distribution on the cathode (middle), and trajectories of emitted electrons from the cathode to the anode (top)).

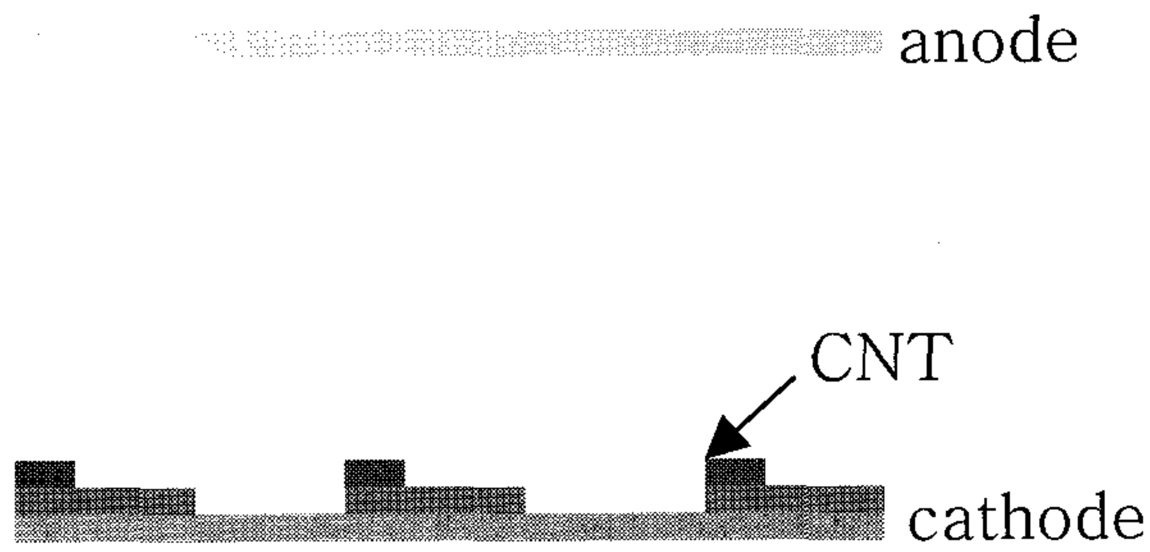


Fig. 3. Cross-sectional view of an edge-field CNT-FEDs

Fig. 3 shows the cross-sectional view of the layout. The edge-aligned CNT by the size of 120um shows the perfect color separation. The 200 μm x 120 μm pixel is formed. The magnified pixels of an emission images are shown in Fig. 4. Very uniform emitting-pixels of red, green and blue color were observed over the 9-inch panel, without cross talk between pixels. Brightness of green phosphor on the CNT-FED was measured and shown in Fig. 5. The brightness of 800 cd/m^2 was observed at 3 V/μm. Red and blue phosphors showed 200 cd/m^2 and 150 cd/m^2 respectively.

The field-emission energy distribution (FEED) has been investigated by using a hemispherical electron analyzer (VG Instruments CLAM IV). The FEED measurements were carried out at different extraction voltages for the single wall CNT-FEDs with and without ultra violet light (253.7 nm mercury light from $^3P_1 \rightarrow {}^1S_0$). The intensity of field emission increased anormalously and the full width at half maximum (FWHM) reduced from 1.05 eV to 0.68 eV at the extraction voltage of 100V by illuminating UV photon (Fig. 6). From the experimental results, it can be concluded that a large number of field emission electrons with mono-energetic character can be obtained with UV light.

Two glass plates of patterned CNT-cathode and phosphor-coated anode were integrated. The gate electrode for the triode type was inserted between two plates. For the anode plate, the Y_2O_2S:Eu, ZnS:Cu,Al, and ZnS:Ag,Cl phosphors were screen-printed with a thickness of 7 μm on 576 lines of red, green, and blue colors respectively. The panel was evacuated down to the pressure level of 1×10^{-6} Torr. Non-evaporable getters of a Ti-Zr-V-Fe alloy were activated during the final heat-exhausting procedure, finally leading to the complete fabrication of a 9-inch CNT-FEDs (Fig. 7). The fully sealed CNT-FED was operated in a matrix addressable

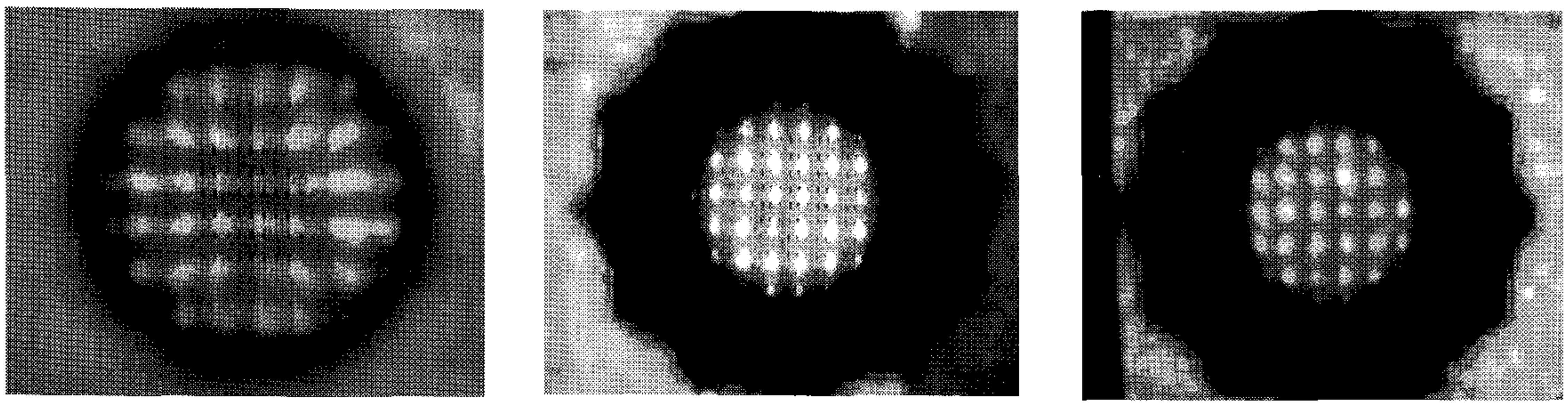


Fig. 4. Pixel images of an emitting carbon nanotube -FED: white, green and blue color respectively (magnified by x100, pixel size is 200 micron x 120 micron).

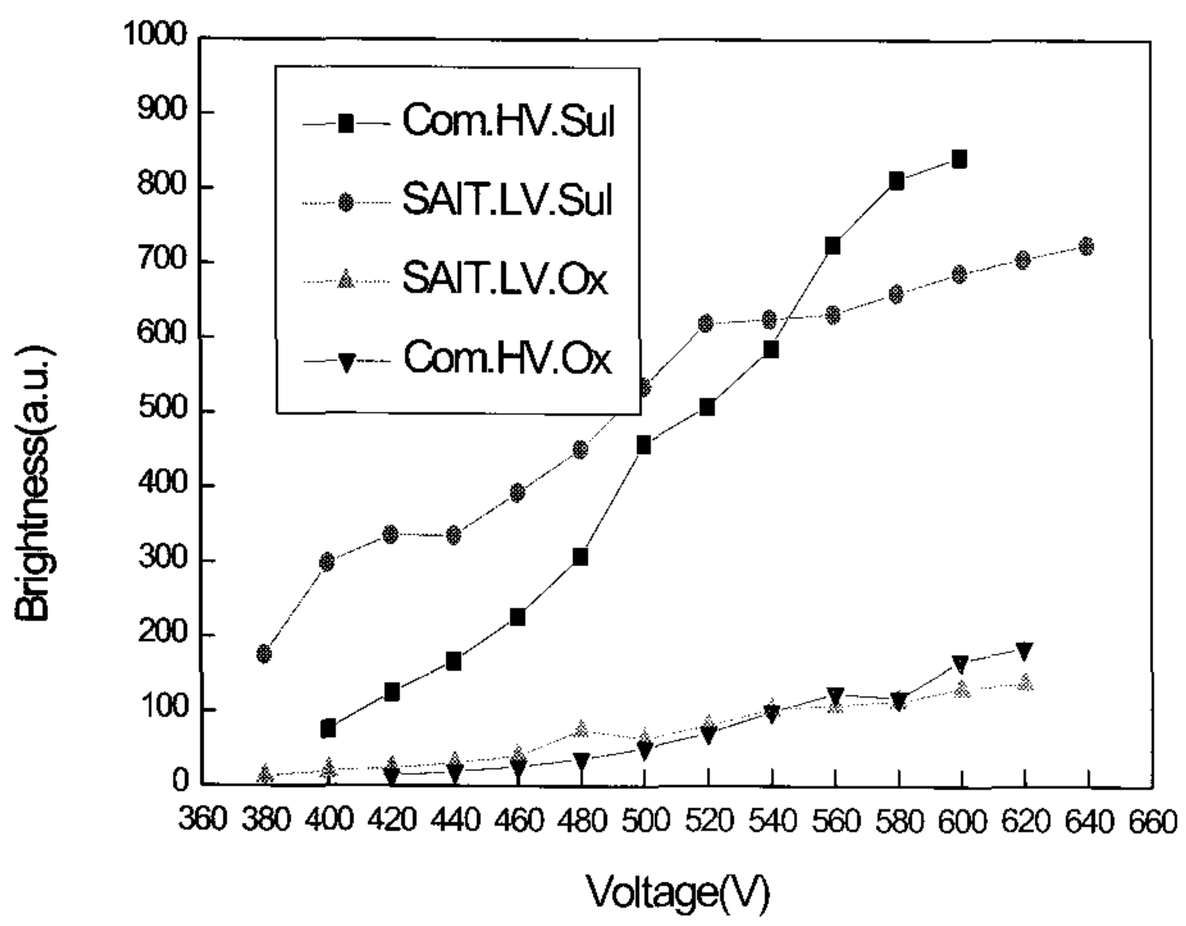


Fig. 5. Brightness of CNT-FEDs with anode voltages for various green color phosphors. The value of brightness was taken without con sidering emitting area. (Com.: commercial, SAIT: Samsung, Ox :oxide, Sul.: sulfide, LV: low voltage, HV: high voltage -phosphor).

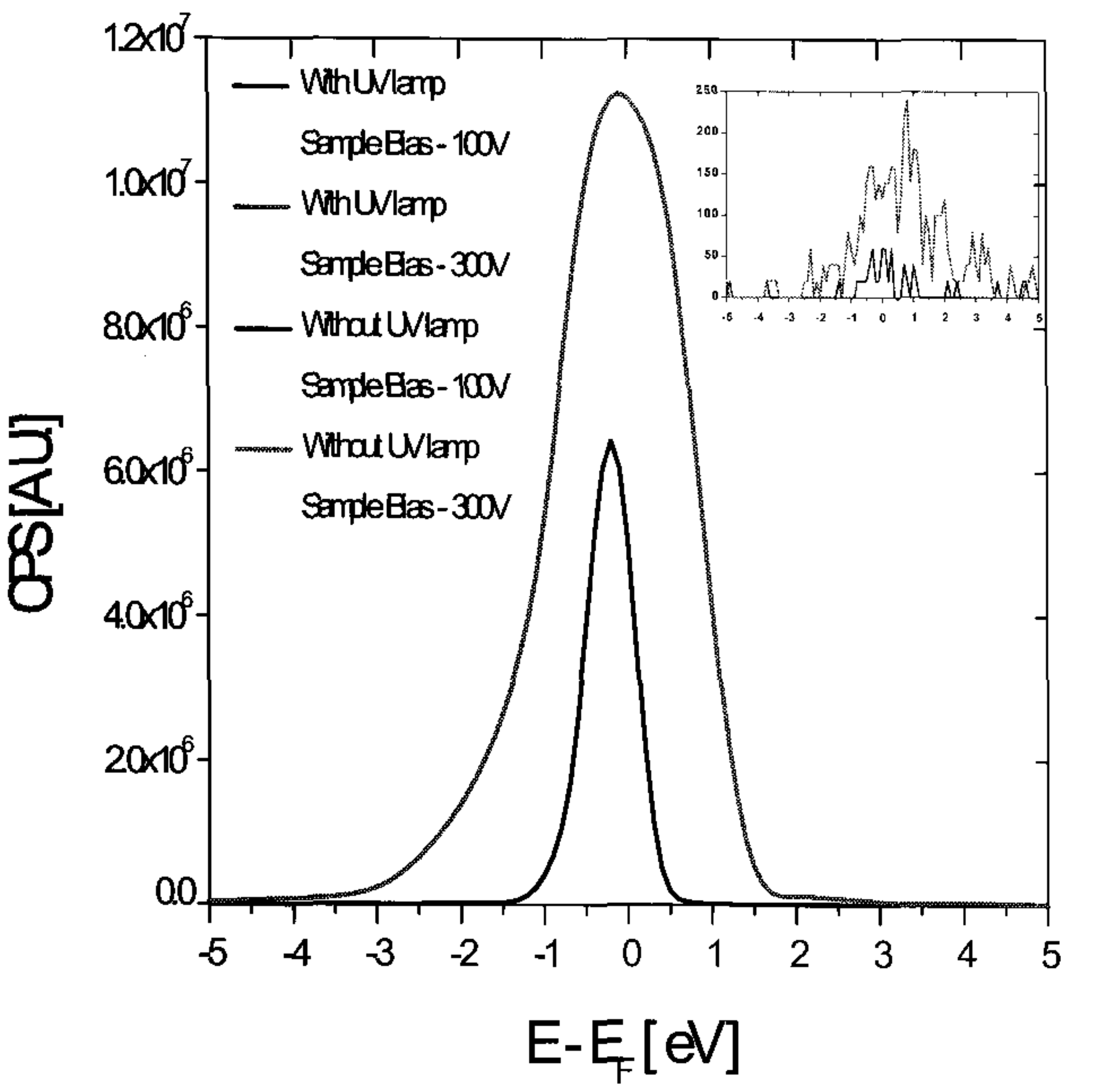


Fig. 6. Field emission energy distribution of a single walled carbon nanotubes at the extraction voltage of 100V – 300V with UV light (inset shows FEED without UV light).

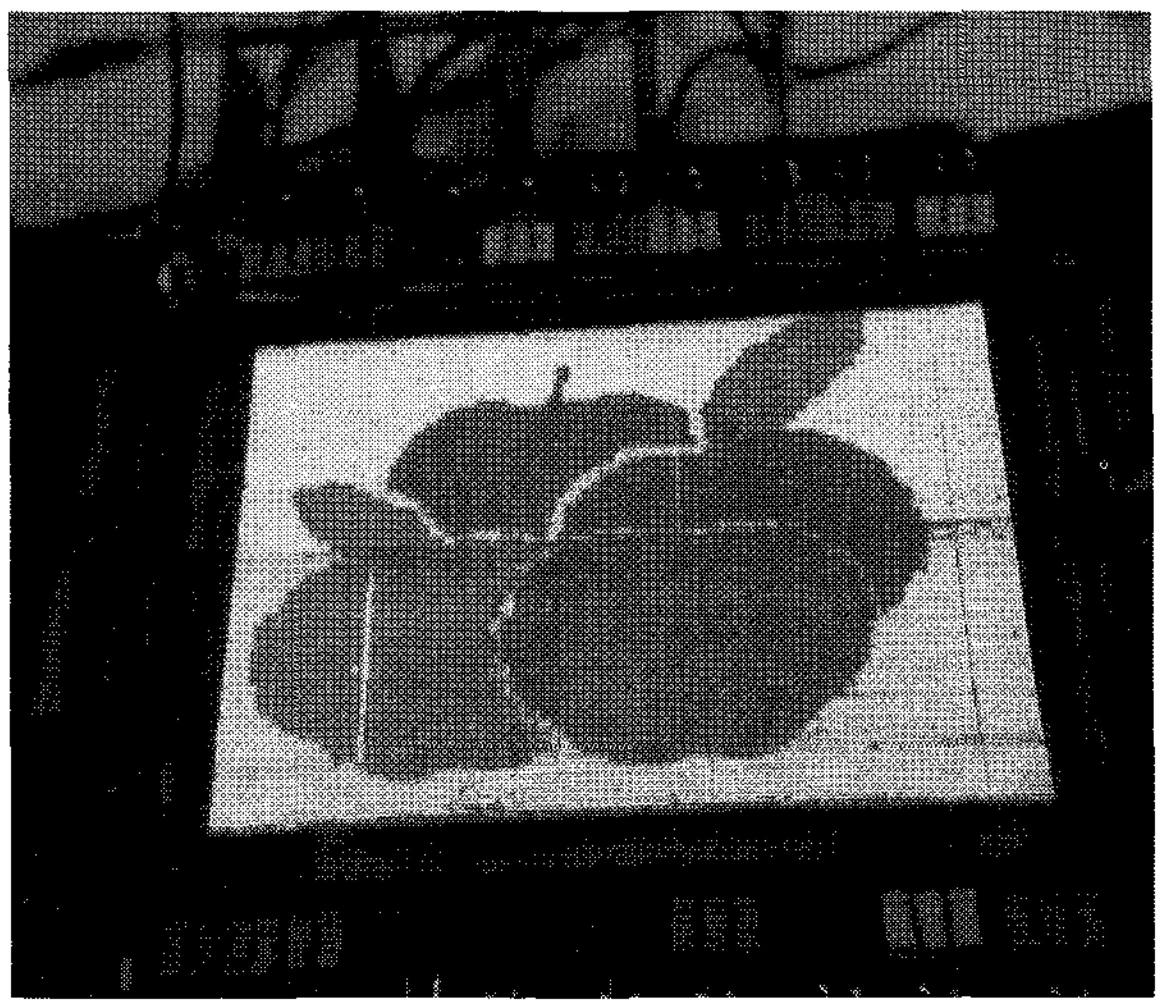


Fig. 7. Test image of a fully scaled 9-inch carbon nanotube-based field emission display.

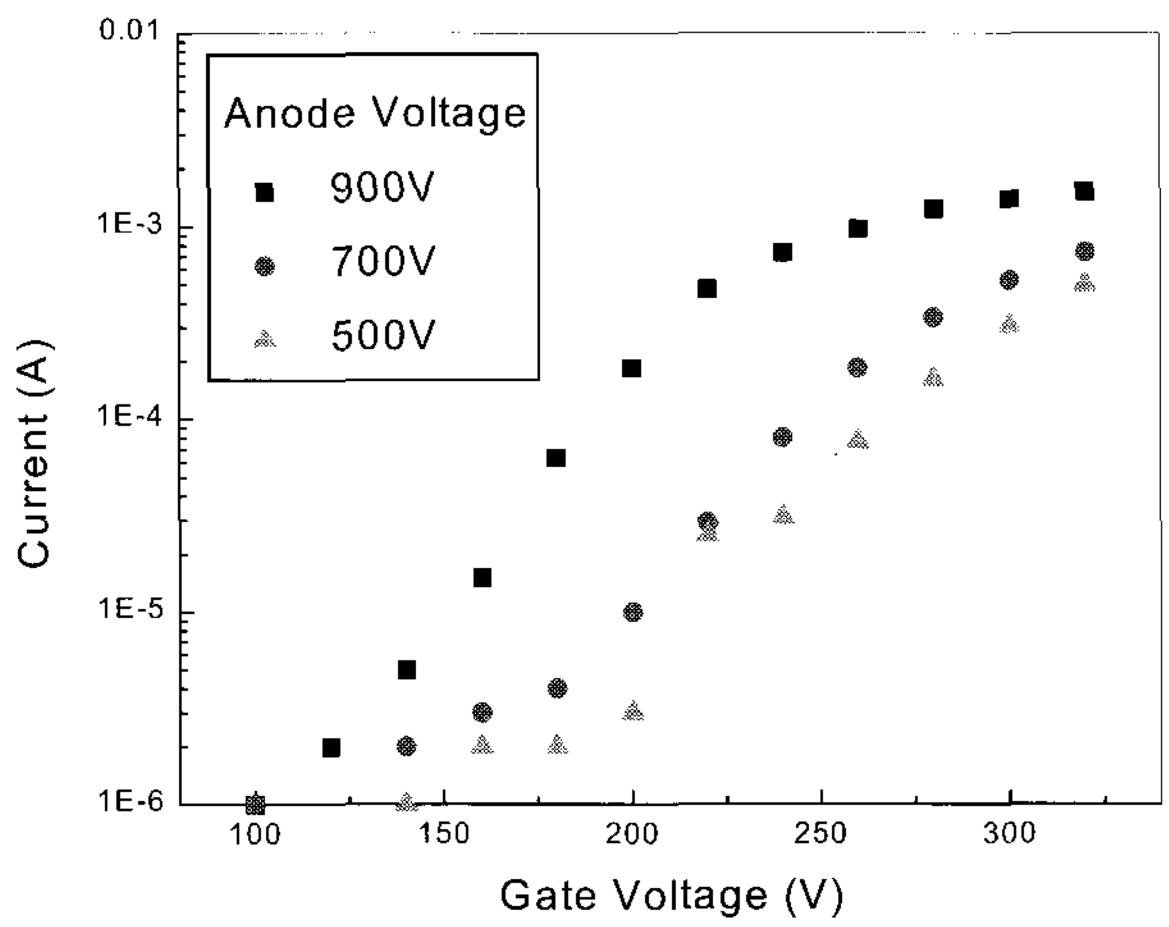


Fig. 8. Characteristics of field emission as a function of gate voltage in a triode-type CNT-FED.

mode with cathode-scan and anode-data input. Moving images were modulated at the peak amplitude of 200 – 400 V (1 – 2 V/μm). Triode-type CNT-FED was well modulated by changing gate bias. Emission image with high brightness was obtained at the gate-bias of 100-300 volts and the anode bias of 500–1000 volts. I-V characteristics of a triode-type CNT-FED are shown in Fig. 8.

Fig. 9 shows an image of a 9-inch CNT-FED with 240 x 576 lines matrix-addressable in a diode mode. A very uniform and stable moving image over the entire 9-inch panel was obtained at the operating field of 2 V/μm. Such high and uniform brightness over a large area implies that the CNTs are well aligned, uniformly distributed with a high number density, and highly efficient in emitting electrons. The whole fabrication processes were fully scalable and reproducible

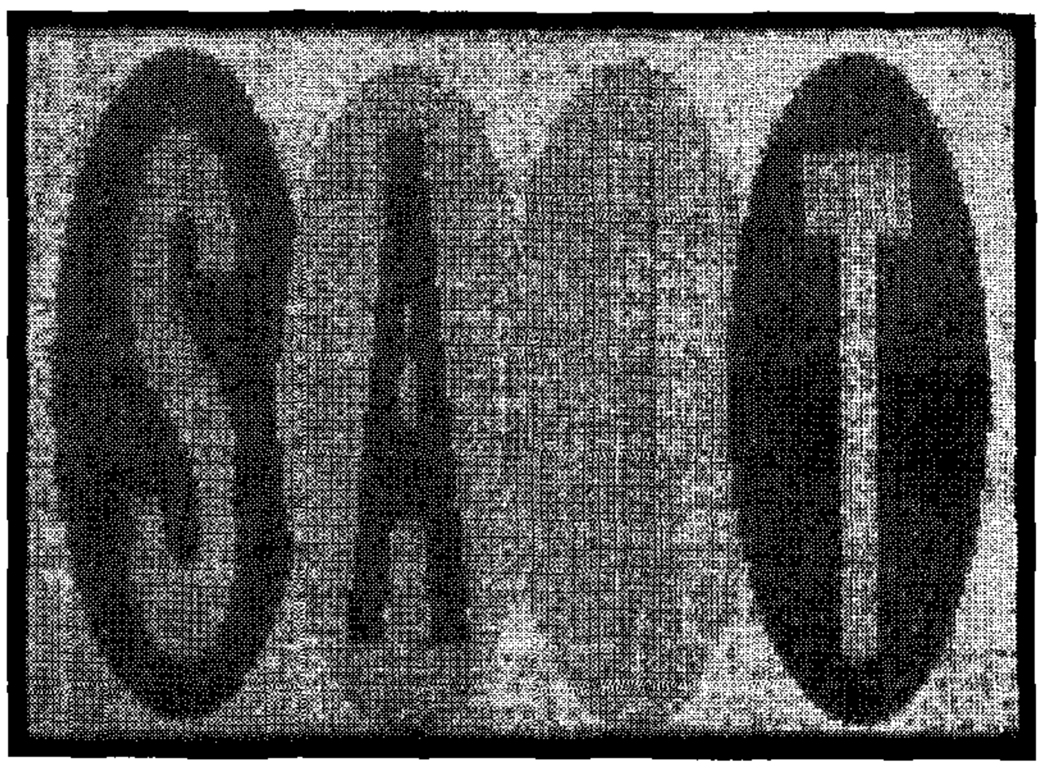


Fig. 9. A moving image of the fully sealed 9-inch carbon nanotube field emission displays.

3. Summary

The first 9-inch fully sealed CNT-FEDs with full color was fabricated. The fabricated displays were fully scalable and showed very uniform moving color images at operating field of 2 V/μm. The triode type CNT-FEDs was modulated less than 2V/μm with high brightness and uniform emission. The CNT-FEDs will be one of the very promising flat panel displays towards the new millenium.

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