Actively Addressable Carbon NanoTube Emitters for Field Emission Display

Yoon-Ho Song, Chi-Sun Hwang and Kwang-Bok Kim
Basic Research Lab., ETRI, 161 Gajeong-dong, Yuseong-gu, Daejon 305-350, Korea
Phone : +82-42-860-5295, E-mail : yhsong@etri.re.kr

Abstract

The actively addressable carbon nanotube (CNT) emitters have been studied for stable and low-voltage driving field emission display (FED). The a-Si TFT and screen-printed CNT emitters were successfully integrated to fabricate the diode type active-matrix cathode and FED panel. Also, we propose a new FED architecture based on the actively controlled triode CNT emitters showing the properties of ideal triode type cathode with electron beam focusing effect.

1. Introduction

Since the first application of carbon nanotube (CNT) as an electron source, there were many attempts to make CNT-field emission display (FED) [1-4]. To construct reliable and low-voltage driving CNT emitters was one of the critical issues. The distance between the extraction gate electrode and CNT emitters must be small enough to induce field emission at a low voltage. In the case of CNT emitters, it is very difficult to make self-aligned emitter tips to the extraction gate electrode. Therefore, the extraction gate electrode should be electrically isolated for reduction of leakage currents that are originated from the asymmetric position of emitter tips. Furthermore, the electric field induced by the anode voltage should be shielded for the reduction of off-currents. These constraints require very complicate and expensive processes for CNT emitter cathode. So, for the application in large size display panel, another approach should be done.

We suggest that active-matrix CNT emitters controlled by thin-film transistor (TFT) can be a good choice for FED. For the case of active-matrix driven display panel, the control device is integrated into each pixel. The driving voltage for the panel is the operation voltage of control device, which is usually low enough to use general driving ICs for display panel. The off-currents are also suppressed by the off-characteristics of TFT. Up to now, there is no known method to control the emission characteristics of each CNT. In general the variation of emission currents from CNT emitters is larger than that of on-currents in TFT. So, the uniformity of the emission currents can be greatly improved through the TFT-controlled emission currents.

The reduction of power consumption is another advantage of the active-matrix driven FED. The large portion of driving power was wasted in charging and discharging the capacitance elements in the panel. The small distance between the electrodes and large overlapping area make the overlap capacitance very large. But for the case of active-matrix driven FED the overlap capacitance is isolated from one another by control TFT, so the wasted power for charging and discharging is greatly reduced.

We have already shown that incorporation of amorphous silicon (a-Si) TFT into the emitter cathode greatly improves the operation characteristics of Spindt-type emitter [5]. Fully vacuum-sealed active-matrix driven Mo-tip FED was demonstrated [6].

In this work, we present the prototype active-matrix FED panel with diode type CNT emitters. Also, we propose a new FED architecture based on the actively controlled triode CNT emitters showing the properties of ideal triode type cathode with electron beam focusing effect.

2. Active-matrix cathode with diode type CNT emitters

We have developed an active-matrix (AM) cathode in which an a-Si TFT and diode type CNT emitters are integrated within each pixel. The diode type CNT emitters are very simple and are suitable for manufacturing large size panel. Figure 1 shows the unit pixel consisting of an a-Si TFT and diode type CNT emitters. The CNT paste was screen-printed on the drain region of TFT.

The low soda-lime glass was used as a substrate. Conventional inverted-staggered type a-Si TFT was formed on the glass substrate. The deposition conditions for the active and dielectric layers were adjusted to endure the high-temperature sealing process. A special electrode, Light Focusing Grid (LFG), was added to the conventional a-Si TFT structure. The LFG was a metal layer and was formed on the back channel of a-Si TFT and around the CNT emitters. The LFG layer shielded a stray light and strong electric fields from the anode electrode to reduce off-leakage currents of a-Si TFT. Another role of the LFG was focusing the electron beams. The LFG layer may be connected to ground level or negatively biased for these effects.

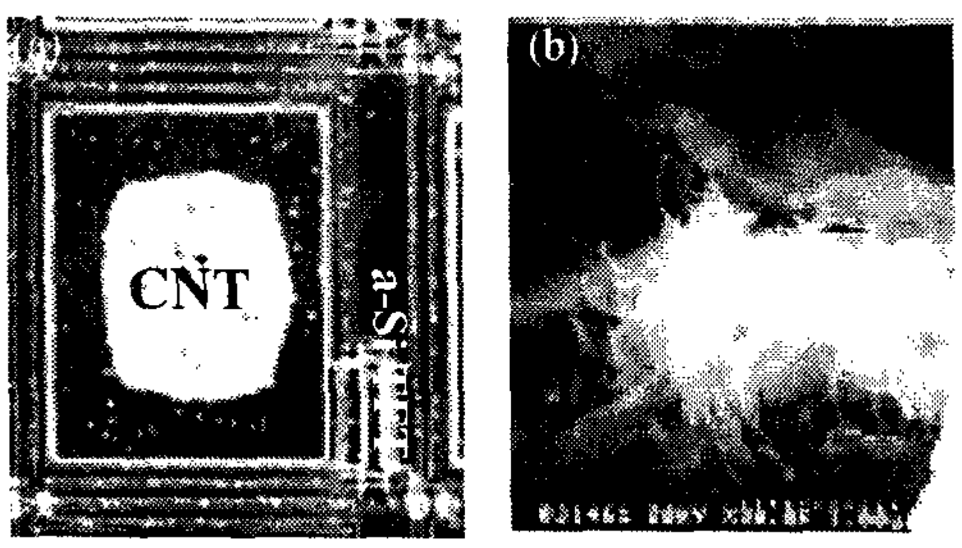

Figure 1 (a) Micrograph of unit pixel with a-Si TFT and CNT, (b) SEM image of CNT emitters

An as-prepared single-wall CNT powder was mixed with some binder and conducting particles. The mixed CNT paste was printed onto the drain of TFT using screen print mask. After the screen-printing of CNT paste, the cathode panel was fired and surface-treated for the enhancement of electron emission from the CNT emitters. The surface treatment gave rise to protrude and to vertically align CNT emitters to the surface, as shown in Fig. 1 (b). So, it was an essential process in the printed CNT technology.

Figure 2 shows the TFT-gate controlled electron emission from the active-matrix cathode with diode type CNT emitters. The emission currents were well controlled by the TFT-gate. The switching voltage is under 30 V. The on/off ratio of emission currents was above 200. The off-current should be reduced to achieve a good contrast.

The fully vacuum-sealed AM-CNT FED panel was shown in Fig. 3. The panel was 3-inch in diagonal and had 64x96 pixels. Commercial green phosphor was patterned in the anode plate for mono chromatic-display. To minimize the degradation of TFT characteristics, the process temperature of sealing sequence was lowered by using in-line vacuum sealing in an ultra high vacuum chamber. The in-line vacuum sealing and optimization of frit glass made the sealing temperature as low as 330 ℃. The laser-induced getter activation or direct-current-heating activation was done after sealing process to eliminate residual gases. In Fig. 3, the getter activation electrode for direct-current heating was shown.

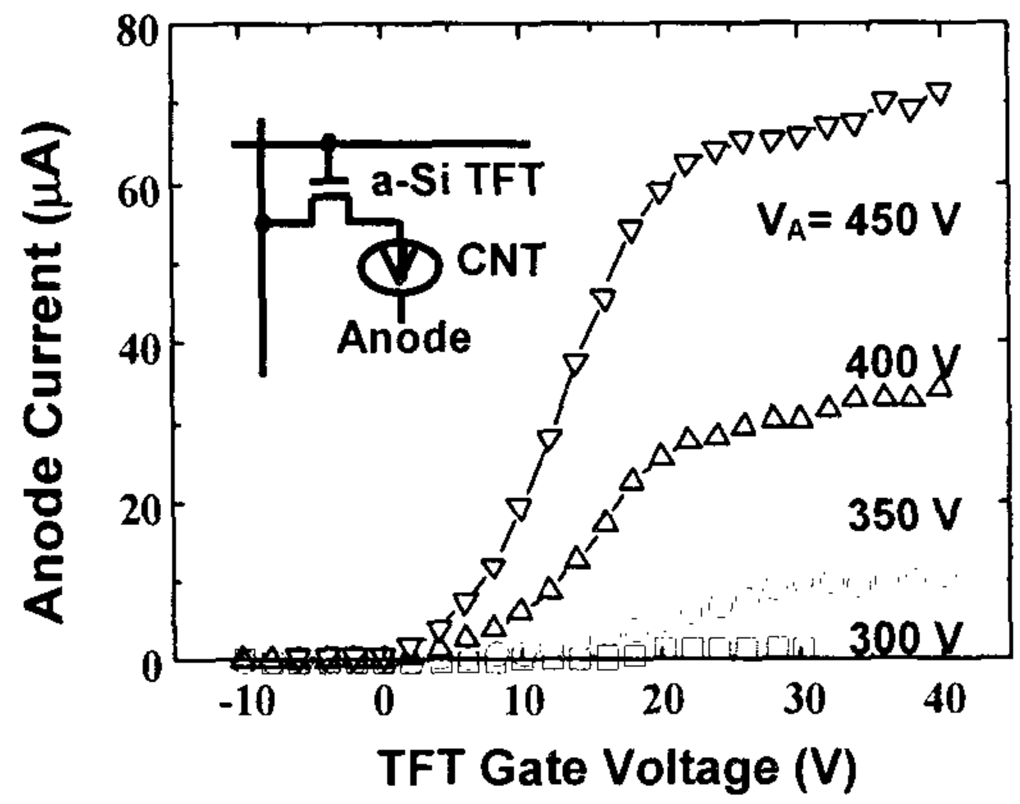

Figure 2 Anode current as a function of TFT gate voltage at various anode voltages (V_A)

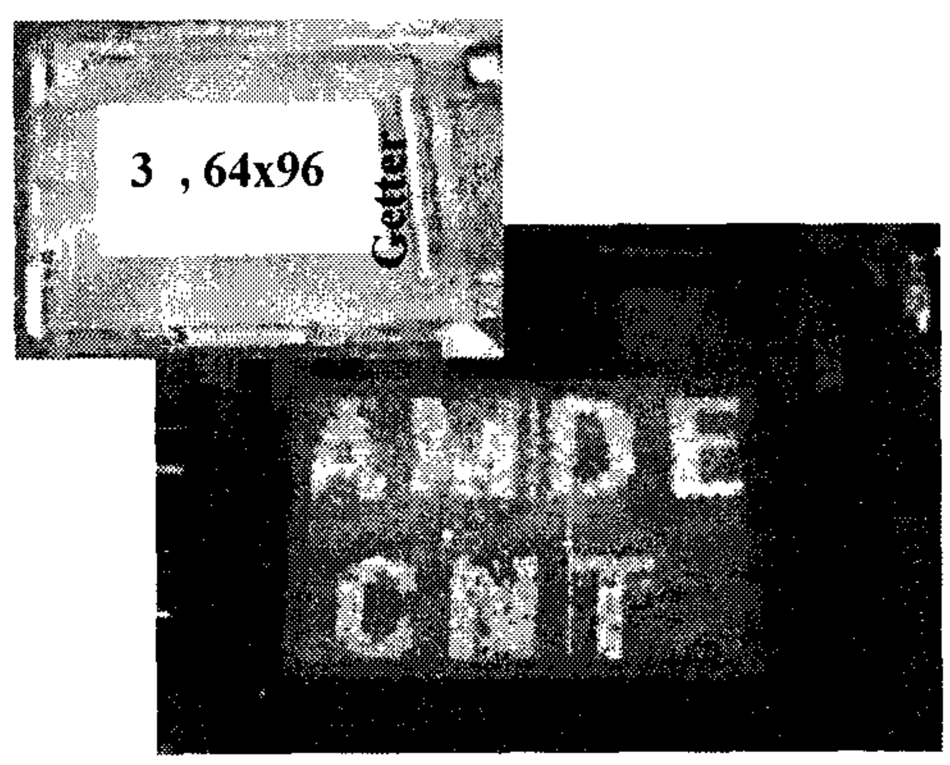

Figure 3 Packaged diode-type AM-CNT FED panel and display image

Good images were observed with a scan signal of 25 V, a data signal of 10 V, and an anode voltage of 490 V. The scan signal was applied to each TFT-gate electrode sequentially. As shown in Fig. 2, the bias voltage of scan signal was larger than the saturation voltage of TFT to stabilize the operation of the AM-CNT FED panel. We adjust the bias of scan signal according to the applied anode voltage. The pixel was turned-on only if the scan signal was on a high state and the data signal was on a low state. The data signal that was applied to the source electrode of control TFT in each pixel was should be large enough to turn-off the pixel. Therefore the difference between the scan and data signals was smaller than the threshold voltage of TFT. Due to the large threshold voltage of TFT, a 10 V bias is enough to turn-off the pixel in this panel. The addressing voltages of 25 V and 10 V are low enough to use low cost driver ICs as in TFT-LCD. The addressing biases can be further lowered if the characteristics of TFT are improved.

To get a brighter panel, the acceleration voltage applied to the anode electrode must be increased. But the increase of anode voltage induces a large voltage across the drain-to-source electrode in the off-state of TFT. At a high drain bias, the a-Si TFT gave leakage currents, which deteriorates the contrast ratio of the panel. The diode type field emitter limits the anode voltage even in the AM cathode architecture.

3. Active-matrix cathode with mesh gated CNT emitters

We propose a new FED architecture based on the actively controlled triode CNT emitters to achieve a highly bright display. Figure 4 shows our device structure consisting of a cathode plate and a mesh plate. Each pixel in the cathode plate has an a-Si TFT with CNT emitters on its drain electrode as mentioned in the previous section. The mesh plate made of an insulating substrate like glass has large gate holes with a tapered inner surface. The gate hole is aligned to the CNT emitters in each pixel. A metal layer was formed on the upper surface of the mesh plate as the extraction gate electrode for field emission. The size of gate holes was designed to be comparable to the thickness of the mesh plate, ensuring to shield the CNT emitter from the electric field induced by the anode voltage. Therefore, we can increase the anode voltage without any high voltage damage upon a-Si TFT in the cathode plate and then achieve a highly bright FED panel.

Figure 5 shows a preliminary study for our new AM cathode structure with a mesh plate gate. In the experiment, the mesh was made of glass with a thickness of 0.4 mm. The upper and lower hole sizes were about 0.3 mm and 0.4 mm in diameter, respectively. As a result, its inner surface was declined negatively. The anode plate was placed above 1.0 mm from the mesh plate. The field emission measurements were done in an ultra high vacuum system. As shown in Fig. 5, the anode emission currents extracted by the mesh-gate biases of 450 V and 500 V were controlled by the TFT-gate bias in the range of 20 V. Furthermore, the mesh-gate leakage current was hardly detected and the anode bias voltage did not affect the emission current, showing the ideal triode behaviors like Spindt-type emitters.

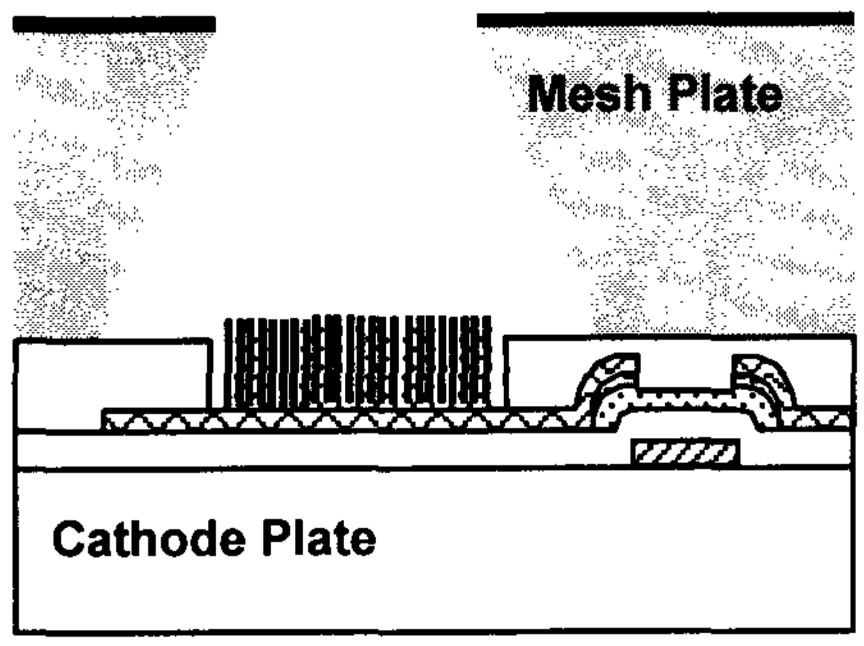

Figure 4 Actively controlled triode CNT emitters with a mesh plate gate

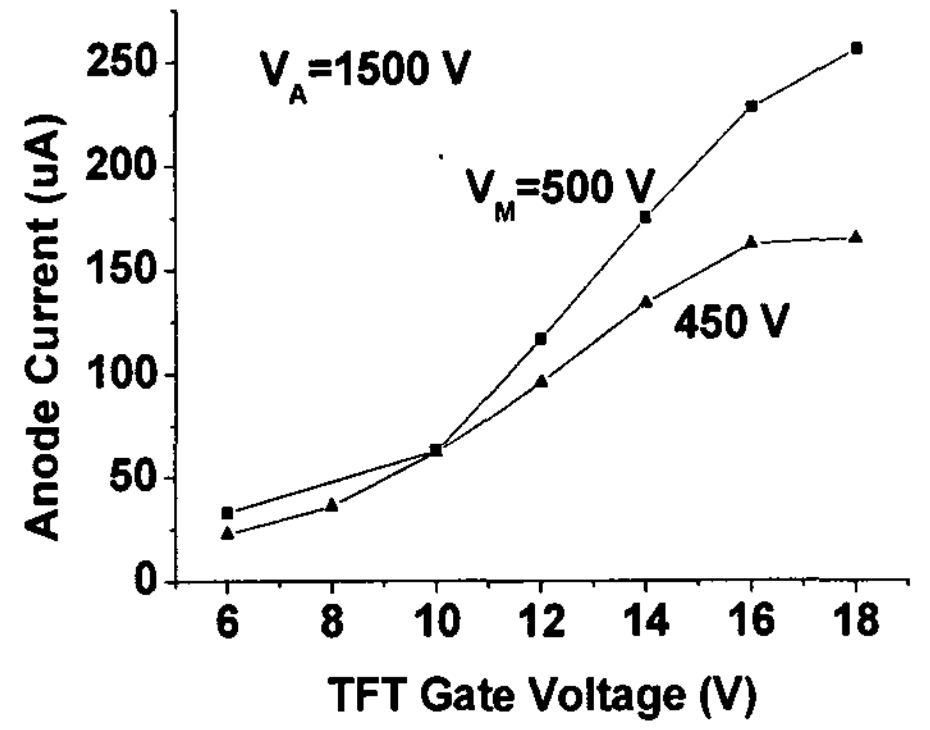

Figure 5 Anode current as a function of TFT gate voltage at two mesh gate voltages (V_M)

In the AM cathode with a mesh gated CNT emitters, we specially designed the gate hole to have a tapered inner surface. This hole structure can affect the electron beam trajectory due to a long traveling in the hole region. The simulation results of potential contours and electron beam trajectories for mesh gated CNT emitters are shown in Fig. 6. The simulation showed that the electrons extracted from the CNT emitters even at the hole edge region were traveling toward the center of the hole and so the beam divergence was very small. In reality, we have measured the electron beam divergence to be below

0.1 mm at 0.5 V/μm, which is very smaller than that of Spindt-type emitters. The mesh gated CNT emitters was found to have the beam focusing effect itself, enabling us to fabricate a high resolution FED panel without any additional focusing grid.

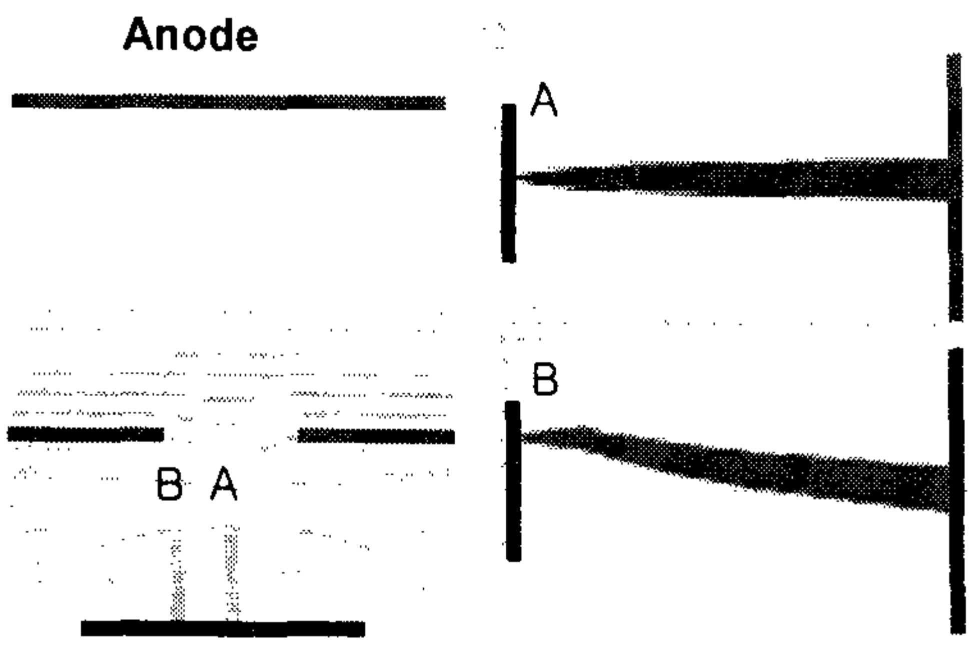

Figure 6 Potential contours and electron beam trajectories of mesh gated CNT emitters

4. Summary

We fabricated the prototype 3? AM-CNT FED panel by integration of a-Si TFT and diode type CNT emitters. By adopting TFT-controlled field emission, the display addressing voltage was greatly reduced below 25 V. The fully vacuum-sealed AM-CNT FED panel with 64x96 pixels was addressed to show relatively good images. Also, we proposed the AM cathode with mesh gated CNT emitters and confirmed its possibility through the preliminary study. The results showed that it has the properties of ideal triode type cathode including the electron beam focusing effect.

5. Acknowledgements

This work was financially supported by the Korea Ministry of Information and Communication. The authors would like to thank President J.-H. Park and Mr. I.-S. Choi of Epion Co. for the vacuum packaging of FED panel.

6. References

[1] W.B. Choi et. al., Appl. Phys. Lett. 75, p3129 (1999).
[2] C.G. Lee et. al., Proceedings of the ninth International Display Workshiops, p1021 (2002).
[3] W.I. Milne et. al., Proceedings of the Society for Information Display 2002 International Symposium, p 1120 (2002).
[4] J.C. Ho et. al., Proceedings of the Society for Information Display 2002 International Symposium, p 372 (2002).
[5] Y.-H. Song et. al., ETRI Journal, 24, p290 (2002).
[6] C.-S. Hwang et. al., Proceedings of the Society for Information Display 2002 International Symposium, p 361