Active-Matrix Field Emission Display Based on CNT Emitter and a-Si TFT

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Abstract

Active-matrix field emission display (AMFED) based on carbon nanotube (CNT) emitter and amorphous silicon thin-film transistor (a-Si TFT) is reviewed. The AMFED pixels consisted of a high-voltage a-Si TFT and mesh-gated CNT emitters. The developed AMFED panel showed a high performance with a driving voltage of below 15 V. The low-cost and large-area AMFED approach with a metal mesh technology will be discussed.

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 driven 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. So far, therefore, the extraction gate electrode has relatively large leakage currents that are originated from the asymmetric position of emitter tips. Furthermore, the extraction gate could not shield CNT emitters from the electric field induced by the anode voltage perfectly, which resulted in an imperfect triode device. Also, the electron beam from CNT emitters was dispersed largely so that an additional focusing grid is needed for FED application.

We suggested that an active-matrix (AM) cathode controlled by thin-film transistor (TFT) could be a good choice for FED [5-7]. For the case of AM 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. In general, the variation of emission currents from field 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 AMFED. 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 AMFED the overlap capacitance is isolated from one another by control TFT, so the wasted power for charging and discharging is greatly reduced.

In this paper, we review AMFED technology including design, fabrication, driving method of the panel. The AMFED with mesh-gated CNT emitters showed the properties of ideal triode type cathode along with the electron beam focusing effect, giving the solution to a very high acceleration voltage to the anode needed for commercial-grade high brightness and high life time.

2. Design and Fabrication of AMFED

Figure 1 shows the core structure of AMFED pixel finally developed. The cathode pixel consisted of a high-voltage a-Si TFT and printed CNT emitters meanwhile the mesh plate was made of glass with tapered holes.

The low soda-lime glass was used as a cathode substrate. The a-Si TFT was designed to have an offset length (L_{off}) at the drain region, ensuring the high- voltage endurance required for field emission from the CNT emitters. Conventional invertedstaggered process could be applied to the fabrication of a-Si TFT with a 4-mask lithography, which is at least 1 less mask than the TFT-LCD process. The deposition conditions for the active and dielectric layers were adjusted to endure the high-temperature vacuum sealing process. An as-prepared single-wall or multi-wall CNT powder was mixed with some binder and conducting particles. The mixed CNT paste was printed onto the drain of TFT using a 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 [8]. The surface treatment gave rise to protrude and to vertically align CNT emitters to the surface. So, it was an essential process in the printed CNT technology.

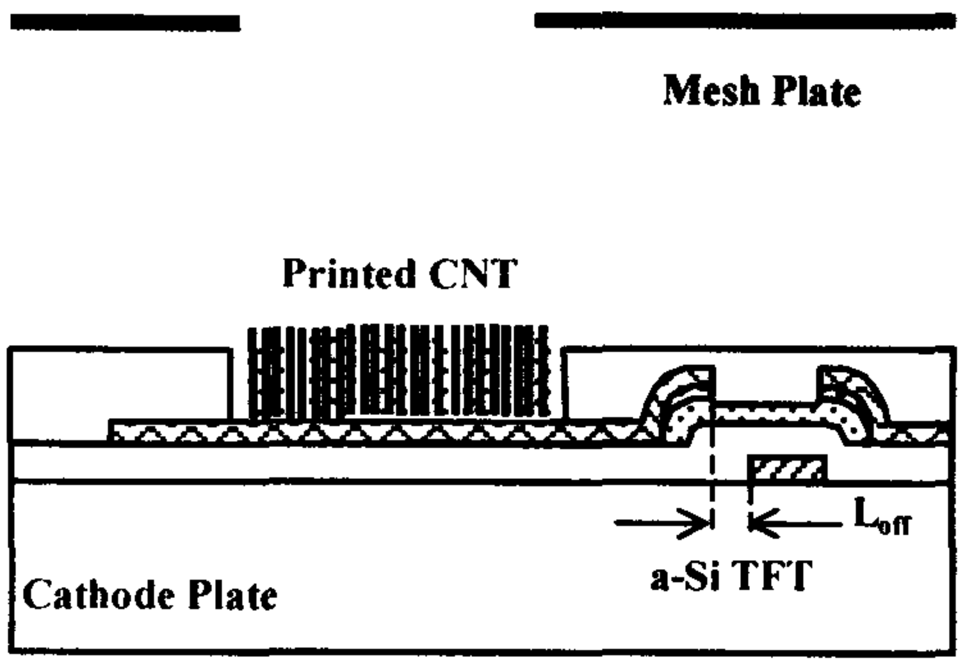


Figure 1. Schematic diagram of the cathode and mesh plates for AMFED

The mesh plate made of glass had relatively tall and tapered holes compared with CNT emitters. The size of gate holes was designed to be very large comparable to that of pixel in FED applications. The thickness of mesh plate was much larger than the height of CNT emitters. This design scheme was based on that the macro-symmetry of the gate holes could neglect the micro-irregularity of CNT emitters. The tapered hole generates electric fields parallel to the inner wall near the corner of the holes. Also, the electron beam at the position of gate hole outlet has a moderately high energy due to a large gate voltage for field emission, ensuring to guide the electron beam to the anode electrode directly.

Another approach to the mesh fabrication instead of glass is using a metal plate for low-cost and large-area FED. We have tried to simulate the electron trajectory in the mesh-gated CNT emitters using a metal gate, as shown in Fig. 2. The thickness of the metal plate was 200 μm. Also, the metal mesh had the same tapered holes as the glass mesh and a 20-μm thick dielectric layer was coated on the wider side and inner wall of the hole. The simulation of the beam trajectories showed that the electrons emitted from the corners of hole traveled along the tapered wall of the holes. As a result, the electron beam dispersion in the metal mesh was strongly suppressed as in the glass-mesh structure. We confirmed that the metal mesh can give the same focusing effect as the glass mesh if it was properly designed including the hole shape and the dielectric layer.

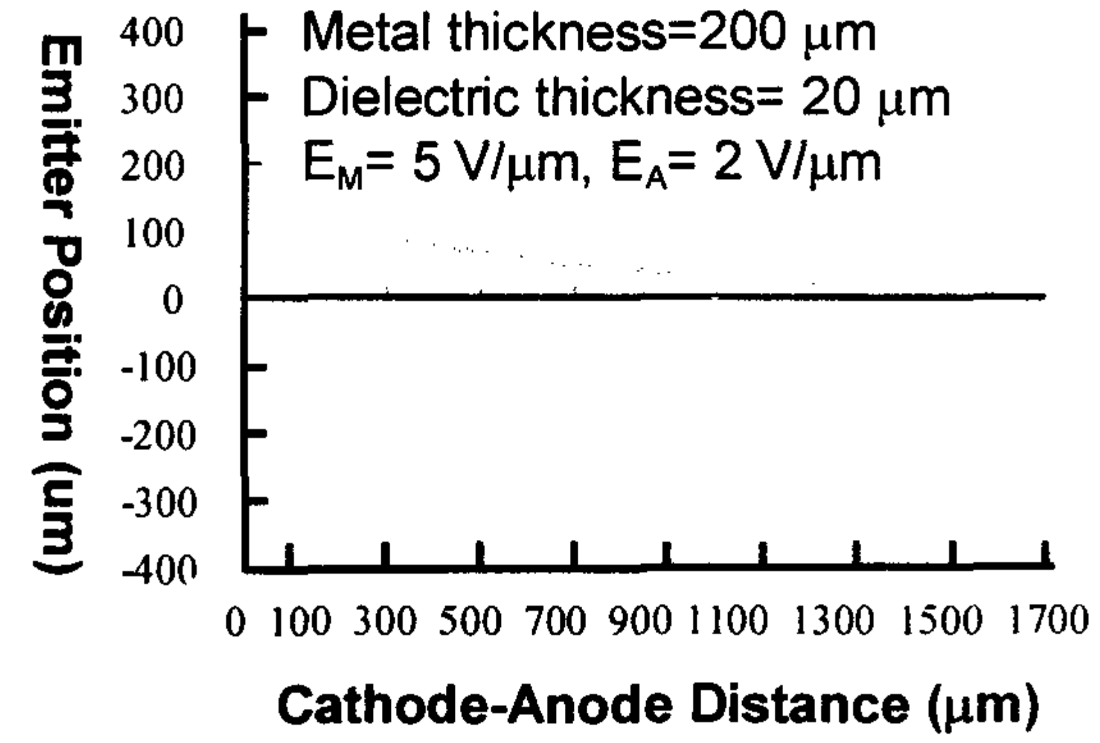


Figure 2. Electron beam trajectory from a CNT emitter at 100 μm apart from the center of hole in the metal mesh. The E_M and E_A designate the electric fields by the metal mesh and anode electrode, respectively.

3. Operation of AMFED Panel

The vacuum-packaged AMFED panel is shown in Fig. 3. The panel was 5-in. in diagonal and had 160x3x120 sub-pixels. The anode, cathode, mesh-gate plates were vacuum-sealed with spacers by using a frit glass in a high vacuum chamber. The gate hole of the glass-mesh plate was aligned to the CNT emitters in each pixel. The spacing between the mesh gate and anode plates was 0.3~1.1 mm. We used a seal-cap method to obtain high-vacuum, real-flat FED panel. After the sealing process, non-evaporable getters in the panel were activated. The thermal budget of vacuum packaging process was critically adjusted to minimize any influences on the a-Si TFT performances.

Figure 4 shows an anode emission characteristic as a function of TFT gate voltage and a moving picture from the 5" AMFED. The average anode currents were obtained with a mesh voltage (V_M) of 500 V, an anode voltage (V_A) of 800 V and a duty of 0.2. The a-Si TFT was observed to control the emission currents from the mesh-gated CNT emitters perfectly.

The moving picture was obtained with a scan pulse of 15 V and a data pulse of 7.5 V. During the measurements, the anode and mesh-gate were biased to dc voltages of 4000 V and 350 V, respectively. The operation of AMFED panel was very successful and very uniform images were achieved without any cross-talks. The pixel was turned-on only if the scan signal was on high and the data signal is 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 when both scan and data signals were on high states. Therefore, the difference between the scan and the data signals was smaller than the turn-on voltage of TFT. The signal voltages of 15 V and 7.5 V are low enough to use low-cost display drivers such as LCD driver ICs.

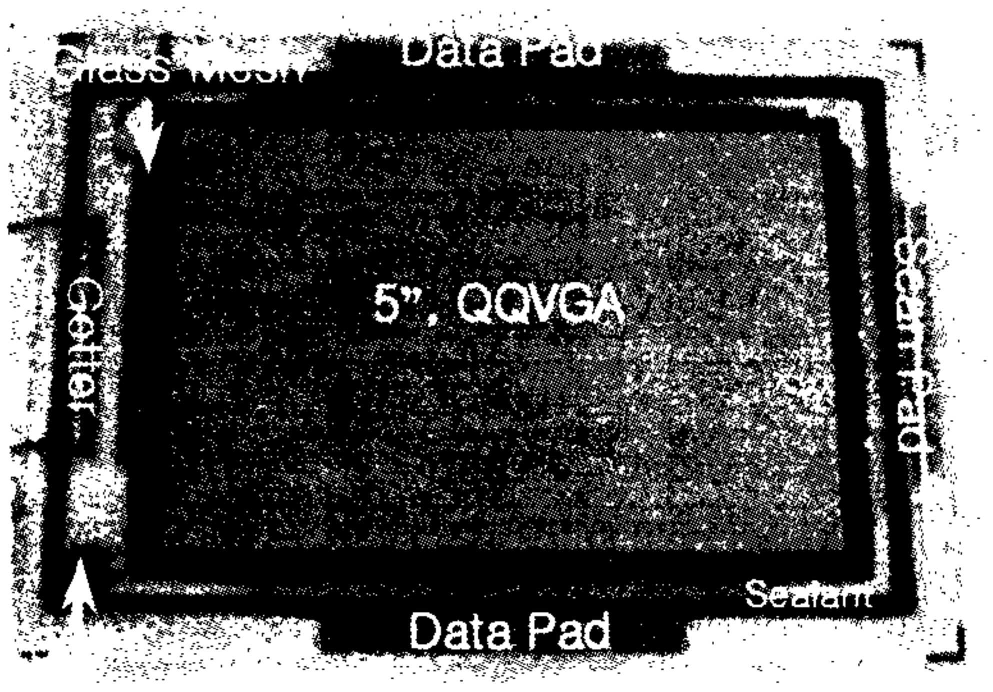
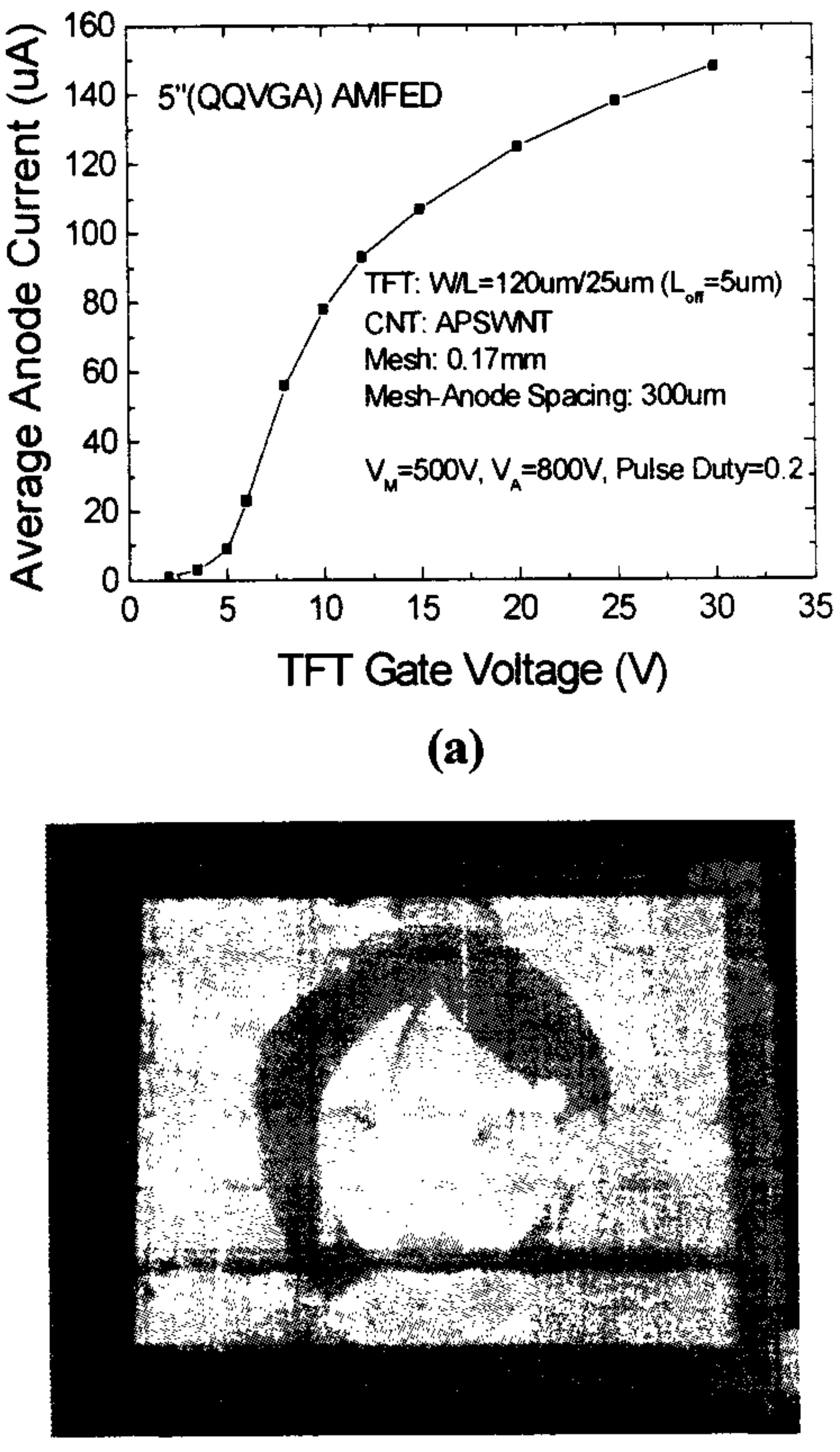


Figure 3. Photographic image of vacuum-packaged AMFED panel with 5-in., QQVGA resolution.

The electron beam dispersion of the fabricated AMFED panel was measured to be negligible, and it could be controlled by the geometry of the mesh-gate holes. So, we can achieve a high-resolution FED with a proper fabrication of the mesh-gate plates using a thick film technology. Furthermore, we have found that the anode field of above 4.5 V/μm did not induce any electron emissions from the CNT emitters in the hole of the mesh gate, even though the mesh gate field of 2.0 V/μm induced electron emissions enough to drive the images of AMFED. This implies that the mesh gate perfectly shield the anode field into the CNT emitters, enabling us to increase the anode voltage sufficiently and so to fabricate a high brightness FED panel along with its electron beam focusing effect mentioned above.



(a)

(b)

Figure 4. Anode currents as a function of TFT gate voltage, (a), and a moving picture, (b) from vacuum-packaged AMFED panel with 5-in., QQVGA resolution.

4. Summary

The AMFED technology with mesh-gated CNT emitters and a-Si TFT was reviewed, and its possibility was confirmed through the successful fabrication and operation of 5-in., QQVGA panel. Combining the TFT-controlled CNT emitters and the mesh gate, we can achieve the ideal triode properties including electron beam focusing effect. The proposed AMFED architecture can be a good candidate for solving the problems in the FED commercialization.

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6. References

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