Fabrication and Driving of Active-Matrix Field Emission Display

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Abstract

The active-matrix field emission display (AMFED) was fabricated by integrating carbon nanotube emitters on a-Si thin-film transistors. Also, the tapered macro-gate was adopted for high immunity to a high anode voltage and strong electron beam focusing. The fabricated AMFED was successfully driven with a low voltage of below 15 V.

1. Introduction

We proposed that an active-matrix (AM) cathode with thin-film transistor (TFT) could be a good choice for field emission display (FED), and demonstrated a variety of AMFEDs [1-4]. In case of AM driven display panel, the control or switching device is integrated into each pixel. The addressing voltage for the panel is the operation voltage of control device, which is usually low enough to use general driving ICs for display panel. Also, the AM architecture gives a good solution for the uniformity problem in field emitter cathode, especially, carbon nanotube (CNT) emitters. In recent, the tapered macro-gate (TMG) structure with AM cathode was proposed for CNT field emitters [5]. We showed the ideal triode CNT emitters using the TMG, including high immunity to the high anode voltage and a strong electron beam focusing effect.

In this paper, we will report the recent progress in AMFED technology along with the detailed properties of CNT emitters and TMG structure.

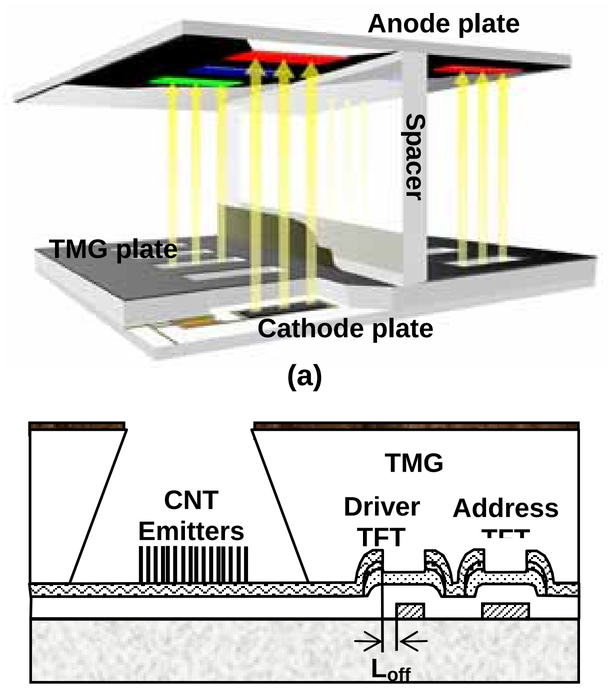
2. Experimental

Fig. 1 shows the schematics of AMFED, and AM cathode with cascade-connected address and driver TFTs, CNT emitters, and TMG. The AM cathode pixel was designed in a dynamic mode without any memory device. In the AM cathode, the address TFT, addressing the display signals, and the driver TFT, driving the CNT emitters directly, are series-connected. The address TFT has the normal gate structure meanwhile the driver one has the offset gate with an offset length (L_{off}) to endure a high voltage needed for field emission through the TMG. Conventional inverted-staggered process was applied. The deposition conditions for the active and dielectric layers were adjusted to endure a high-temperature vacuum sealing process.

The multi-walled CNTs grown by thermal CVD were mixed with binders based on acrylate, nano-scale metal particles, monomers and photo-initiators using a high speed homogenizer and then these were sufficiently milled to produce the CNT paste. The CNT pastes were patterned by a photolithography process and then fired at a proper ambient to remove the organic vehicles. Finally, a surface treatment using physical and electrical method was applied to protrude and align CNTs vertically.

The TMG has relatively tall and tapered holes compared with CNT emitters, protecting the CNT emitters from the anode field perfectly. To make the TMG plate, the tapered hole arrays were formed on a photosensitive glass substrate by using a novel method of UV exposure, annealing and etching processes, or on a sodalime glass substrate by using a sand blaster.

The anode was made of P22 color phosphors using a slurry-coating and lithography. The anode, cathode, TMG plates were vacuum-sealed with spacers by using a frit glass in a high vacuum chamber. 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 TFTs.



(a)

(b)

Fig. 1. Schematics of AMFED (a), and AM cathode with cascade-connected address and driver TFTs, CNT emitters, and TMG (b).

3. Results and discussion

Fig. 2 shows a SEM image of the developed CNT emitters with nano-scale metal particles that are melted during the CNT emitter process. The developed CNT paste and emitter process had so many vertical aligned CNT emitters and an improved adhesion to the cathode. During the field emission measurements, we could not observe any detachment of CNT emitters invoking arc damage. The field emission properties of the developed CNT emitters, applied anode field versus anode current characteristics in a diode configuration and its Fowler-Nordheim (F-N) plot, are shown in Fig. 3. The developed CNT emitter was observed to have a sufficient emission current under an apparent electric field of below 2.0 V/µm along with good reliability. The large field emission current resulted from the optimization in compositional and morphological properties of the CNT paste. The field emission current was very stable over long periods of time, about 100 h, under a severe environment such as a high level DC bias. It is noted that the field emission properties strongly depends on the CNT paste and emitter process as well as its raw material properties. In order to ensure a high field emission current and good reliability, a clean surface should be preserved after the CNT emitter fabrication.

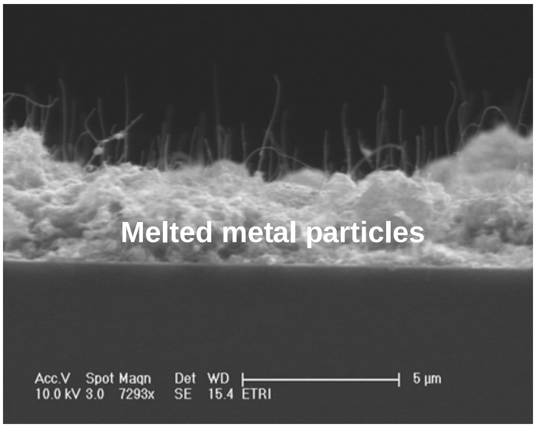


Fig. 2. SEM image of the developed CNT emitters with enhanced adhesion to the cathode electrode.

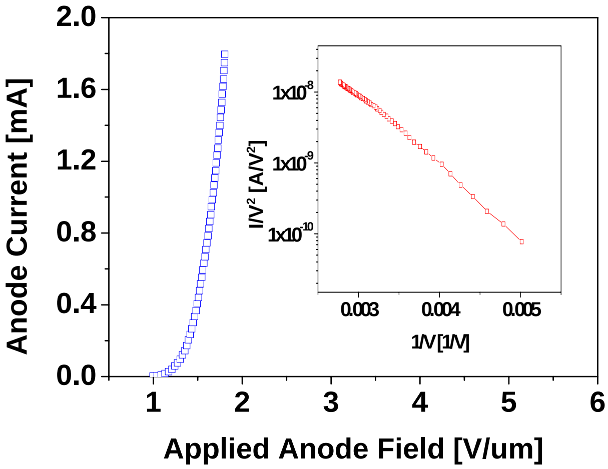


Fig. 3. Applied anode field vs. anode current characteristics of the developed CNT emitters in a diode mode. The inset shows the F-N plot of the measured current-voltage characteristics.

On the other hand, our TMG had relatively tall and tapered holes compared with CNT emitter. The thickness of the gate insulator was much larger than the height of CNT emitters. The large distance between the extraction gate electrode and emitters assures us of successful shielding the CNT emitters from the electric field induced by the anode voltage. The simulation results of electric field shielding effect are shown in Fig. 4 for a TMG-to-anode distance of 2.0mm. The characteristics of TMG structure were investigated by using the commercial OPERA simulator. In the case of ideal triode operation, the electric field at the cathode surface should not be influenced by the anode voltage under a constant gate voltage. But according to the simulation results, the cathode surface field was increased with anode voltages for the TMGs having a lower aspect ratio, α, defined as the gate insulator thickness (H) over the gate hole diameter (D). The higher aspect-ratio, the more shielding of anode field, showing that α larger than 1, at least nearly equal to 1, guarantees an ideal triode operation with perfect shielding.

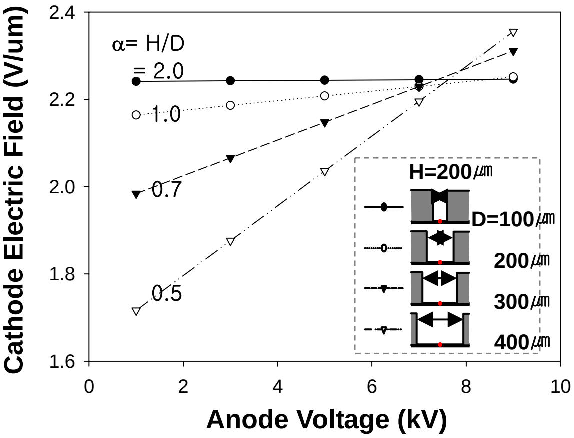


Fig. 4. Simulated electric field at the cathode surface as a function of anode voltage for various aspect ratios (α) of TMG holes.

Fig. 5 exhibits a still image from the vacuum-packaged 5-inch, QQVGA FED with the AM cathode, TMG, anode plates. The image was obtained with a scan pulse of 15 V and data pulses of 7.5 V. During the measurements, the anode and TMG were biased to DC voltages of 7000 V and 350 V, respectively. Some defective lines in the image were due to short failures of a-Si TFTs, and imperfect connections between the panel and driver board. The operation of color AMFED panel was very successful.

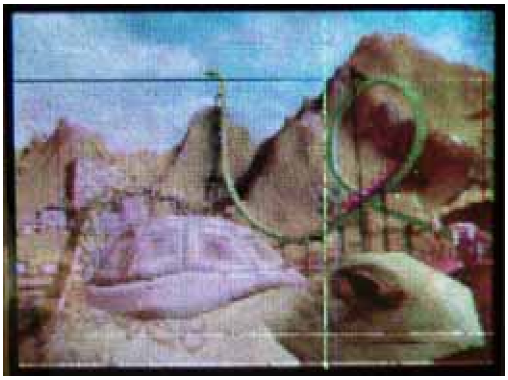


Fig. 5. Still image from the vacuum-packaged 5-inch AMFED.

4. Summary

The AMFED panel using the AM cathode of a-Si TFT and CNT emitters, TMG, and anode with an Al backing layer demonstrated a color moving image with a low-voltage addressing of below 15 V. Our AM cathode technology with the TMG can solve many problems in the FED commercialization and be an alternative to the passive matrix array.

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6. References

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