The Possibility of AM-CNT FED

Yoon-Ho Song *, Jin-Woo Jeong, and Dae-Jun Kim, Kyoung-Ik Cho
IT Convergence & Components Lab., ETRI, 161 Gajeong-dong, Yuseong-gu, Daejeon 305-350, Korea
Phone: +82-42-860-5295, E-mail: yhsong@etri.re.kr

Abstract

The possibility of an active-matrix carbon nanotube field emission display (AM-CNT FED) is discussed from the view points of display performance and cost. The critical issues for FED commercialization such as anode acceleration voltage, uniformity, stability and reliability can be solved through our AM-CNT FED technologies.

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 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. Also, the AM architecture gives a good solution for the uniformity problem in field emitter cathode, especially, carbon nanotube (CNT) emitters. In general the variation of emission currents from CNT emitters is much larger than that of on-currents in TFT. 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 a high immunity to the anode voltage and a strong electron beam focusing effect.

In this paper, we will discuss the possibility of AM-CNT FED from the view points of display performance and cost. The proposed AM-CNT FED architecture can be a good candidate for solving the problems in FED commercialization.

2. AM-CNT FED Technology

Fig. 1 shows the schematics of AM-CNT FED, 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 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 AM-CNT FED panel can be easily driven by addressing the display signals to the a-Si TFTs in each pixel. The pixel was turned-on only if the scan signal was on high and the data signal is low state. The data signal which was addressed to the source electrode of address TFT in each pixel 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.

3. Results and Discussion

3. 1. Acceleration Voltage

A very high anode-accelerating voltage is essential in FED to guarantee commercial brightness, lifetime and efficiency in the absence of low voltage phosphors. The commercially available phosphors need very energetic electrons above 7 keV, which in turn requires high voltage architecture in FED.

Our TMG structure can meet the high voltage requirement for CNT-FED along with a focusing effect. The tapered gate hole was shown to protect the CNT emitters from the anode field of up to 5~6 V/μm perfectly, enabling us to apply a high anode voltage over 10 kV as shown in Fig. 2. Fig. 2 shows a luminance as a function of anode voltage for the TMG-CNT emitters with a spacing of 5 mm between the anode and TMG. We can apply a very high anode voltage enough to achieve a commercial luminance level. Additionally, the electron beams from CNT emitters in the TMG holes were strongly focused to the anode phosphors, which prevented the cross-talks between the sub-pixels and guaranteed good color purity without an additional focusing electrode [5].

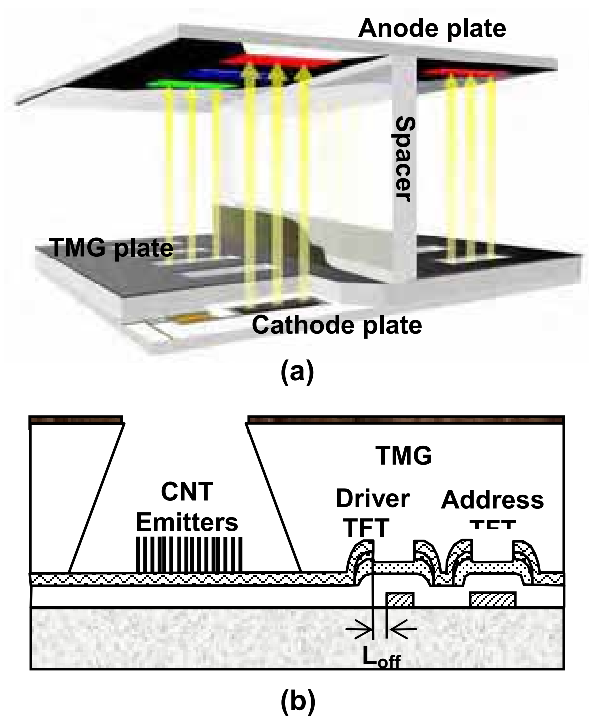

Fig. 1. Schematics of AM-CNT FED (a), and AM cathode with cascade-connected address and driver TFTs, CNT emitters, and TMG (b)

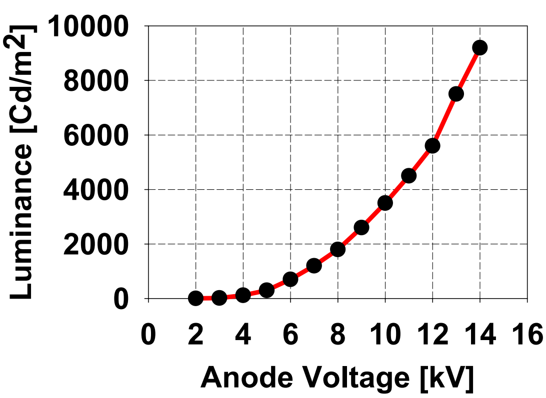

Fig. 2. Luminance as a function of anode voltage for TMG-CNT emitters

3. 2. Uniformity

Among the most critical points the uniformity of the electron emission from pixel to pixel is considered. This is due to the feeling that without individual control of the emitters a targeted uniformity around 1% would be very difficult to achieve and also to the fact that few reliable data are available for FED technology [7]. The AM cathode can be a good solution to the uniformity problem.

Fig. 3 shows the equivalent sub-pixel circuit of the AM cathode newly proposed to further improve the inter- and intra-pixel uniformity in recent [4]. A single address TFT and multiple driver TFTs have been incorporated in a sub-pixel in which each driver TFT had its own CNT emitters and controlled the CNT emitters separately.

Fig. 4 exhibits the transfer and output characteristics of cascade-connected TFTs with normal (address) and offset gates (driver) after thermal annealing at a vacuum sealing temperature. The driver TFT had an offset length of 5 μm while the address one had a gate-drain overlap of 4 μm. The cascade-connected address and driver TFTs exhibited high performances with a very low source-drain leakage current under high drain voltages (V_{ds}). The breakdown voltage was observed to be above 400 V. The developed cascade TFTs had a relatively large current of about 1-10 μA. Also, a perfect saturation behavior in the output characteristics was observed within a very wide drain-voltage range. The wide saturation range of above 150 V can results in a good uniformity to a commercial grade considering an applied voltage of 200 ~300 V to the TMG for field emission.

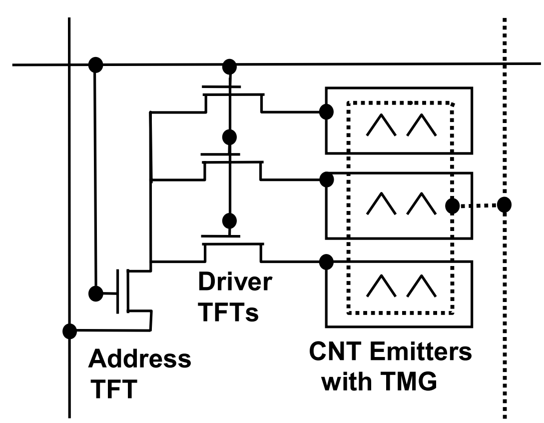

Fig. 3. Equivalent sub-pixel circuit of the AM cathode

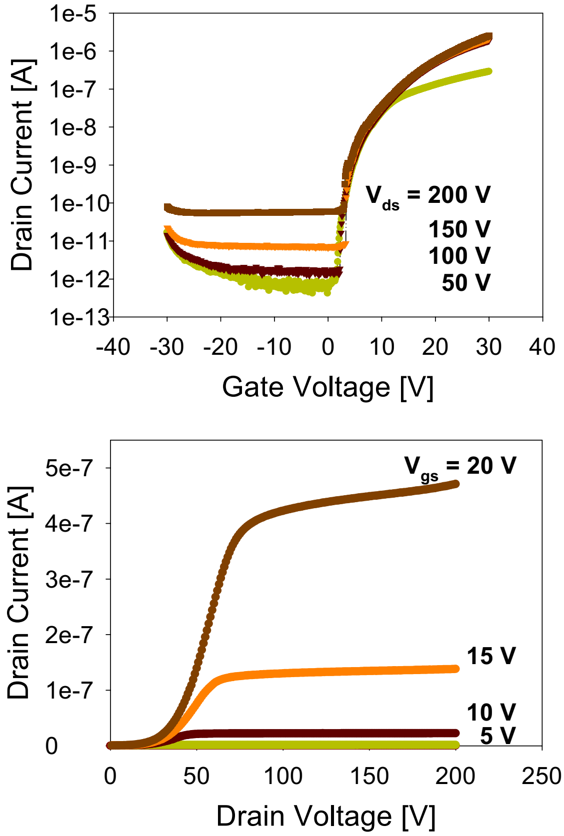

Fig. 4. Transfer and output characteristics of cascade-connected TFTs with normal and offset gates

Fig. 5 shows sub-pixel images with a single TFT and multiple cascade TFTs of 1 address and 12 drivers, and a still image from the vacuum-packaged 5-inch, QQVGA AM-CNT FED with multiple cascade TFTs. The image was obtained with a scan pulse of 15 V and a data pulse 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 bright lines in the image were due to imperfect connections between the AM-CNT FED panel and driver board. The newly developed AM pixels exhibited great improvement in both long and short range uniformities compared with conventional ones.

3. 3. Stability/Reliability

The stability and reliability issues are also critical in FED commercialization. The short-term fluctuation in field emission may give rise to some flickers in the display image. We have already confirmed that field emission can be strongly stabilized in the AM cathode architecture [1].

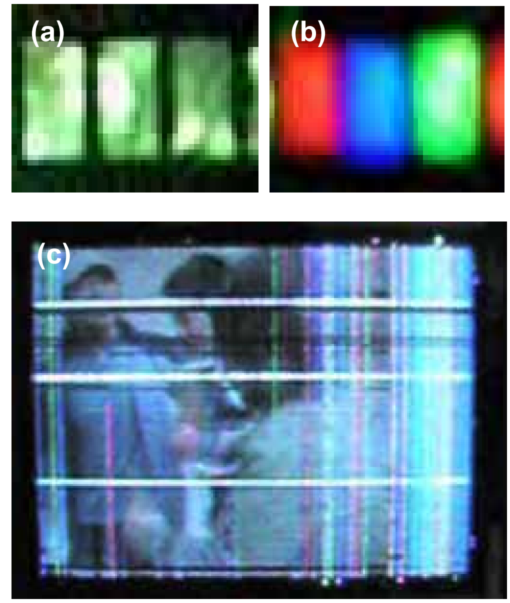

Fig. 5. Sub-pixel images with a single TFT (a) and multiple cascade TFTs of 1 address and 12 drivers (b), and still image (c) from the vacuum-packaged 5-inch AM-CNT FED

The reliability may be the last parameter to be checked in CNT-FED performances and mainly dependent on the degradation in CNT emitters. We have developed a very reliable CNT emitter using a nano-scale metal particle [8]. Fig. 6 shows a SEM image of the developed CNT emitters with enhanced adhesion to the cathode electrode. Fig. 7 shows the reliability test of CNT emitters from the optimized paste 4 shown in Fig. 6 to the other pastes under the DC operation. In case of paste 4 with the optimized paste composition and enhanced adhesion, the emission characteristic was observed to be very stable over long periods of time under a severe environment such as a high level DC bias. The initial anode current density (about 30 mA/cm^2) of paste 4 was nearly maintained with an only 5 % degradation upon a 2-h stress.

Of course, the AM cathode technology greatly enhances the reliability, especially, by the wide saturation range discussed in the previous section. In the AM cathode, if the CNT emitters degrade a much larger voltage is biased to the CNT emitters at a given voltage to the TMG, resulting in a constant field emission within the saturation range. As a result, we think that there is no problem concerning reliability in AM-CNT FED with the developed CNT paste.

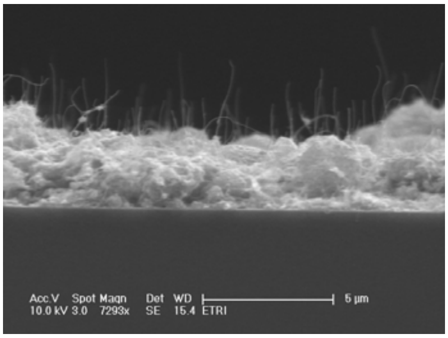

Fig. 6. SEM image of the developed CNT emitters with enhanced adhesion to the cathode electrode

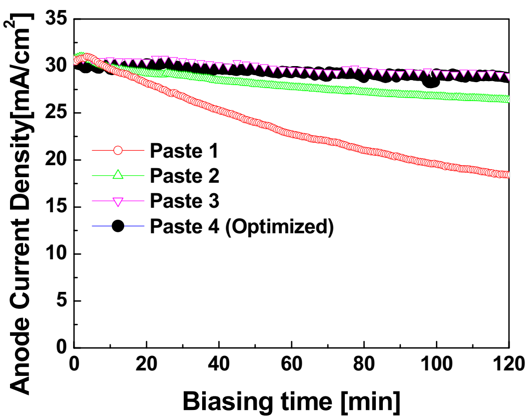

Fig. 7. Anode current density as a function of DC biasing time for various CNT emitters

3. 4. Cost

The market for large area 40-50-inch diagonal displays for digital television has not yet found an optimal technology meanwhile LCD now dominates the market below 20-inch diagonal sizes. Several technologies of PDP, projection displays, and large LCD including FED possibly are currently competing in this marketplace. Nowadays the cost, rather than the display performance, is the most crucial point to penetrate the market because nearly all types of display technologies meet the performance requirements. FED is compelling because it can be manufactured like a PDP along with using CRT's facility and process.

In case of the AM-CNT FED shown in Fig. 5, the driving voltage for the panel is very low enough to use low cost driver electronics. The driver cost becomes more important for true HDTV displays, such as the 1280 × 720 and the 1920 × 1080 pixel formats. In conjunction with the low driving voltage we expect another advantage of low power consumption. Furthermore the pixels in AM-CNT FED are isolated from one another by the switching TFT, so the driving power that occupies nearly 60 % in the total power consumption for passive-matrix array can be greatly reduced.

Our AM-CNT FED needed the a-Si TFT and novel TMG processes, which might increase the manufacturing cost. Since the a-Si TFTs for AM cathode can be fabricated with 4-mask lithography, which is at least 1 less mask than the TFT-LCD along with no ITO process, its fabrication cost may be low. For passive-matrix FED, a 4-mask process step is still required with the use of a-Si process for a resistive layer.

Until now the TMG has been mainly made of glass using the sand blaster or photosensitive glass and so its cost is relatively high. However, the TMG fabrication cost can decrease if it is made of metal mesh with a thick dielectric technology as in PDP. We already confirmed the TMG effect such as e-beam focusing even using the metal mesh [6]. This result means that the metal TMG can be used in AM-CNT FED with low cost.

4. Conclusion

Some critical issues in AM-CNT FED were discussed and its possibility was confirmed. The AM-CNT FED 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 driving 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.

5. Acknowledgements

The authors would like to thank Professor J. Jang at Kyung Hee Univ. for the TFT array, Principal Engineer T. Lee at LG.Philips Displays for the phosphor coating, and President J.-H. Park of Epion Co. for the vacuum packaging of FED panel.

6. References

[1] Y.-H. Song, C.-S. Hwang, Y.-R. Cho, B.-C Kim, S.-D. Ahn, C.-H. Chung D.-H. Kim, H.-S. Uhm, J. H. Lee and K.-I. Cho, ETRI Journal, **24**, p. 290, 2002.

[2] Y.-H. Song, K. -B Kim, C.-S. Hwang, S.- H. Lee, J.-H. Lee, I.-S. Choi, J.-H. Park, SID 2004, Digest of Technical Papers, p. 360 (2004).
[3] Y.-H. Song, K. –B. Kim, C.-S. Hwang, D.-J. Park, J. H. Lee and K.-Y. Kang, J. SID, **13**, p. 241, 2005.
[4] Y.-H. Song, J. –W. Jeong, D.-J.Kim, J. H. Lee, K.-Y. Kang, SID 2006, Digest of Technical Papers, p. 1849 (2006).
[5] J.-W. Jeong, Y.-H. Song, D.-J. Kim, S.-H. Lee, J. H. Lee, and K.-Y. Kang, IDW 2005, Proceedings of the 12th IDW, p.1683 (2005).
[6] Y.-H. Song, K.-B. Kim, C.-S. Hwang, S.-H. Lee, D.-J. Park, J. H. Lee, K.-Y. Kang, J. H. Hur, J. Jang, Asia Display/IMID 2004, Digest of Technical Papers, p. 923 (2004).
[7] J. Dijon, A. Fournier, T.G. De Monsabert, M. Levis, R. Meyer, C. Bridoux, B. Montmayeul, D. Sarrasin, SID 2006, Digest of Technical Papers, p. 1744 (2006).
[8] D.-J.Kim, Y.-H. Song, J. –W. Jeong, J. H. Lee, K.-Y. Kang, SID 2006, Digest of Technical Papers, p. 663 (2006).