Field Emission Display and Backlight for LCD using Printed Carbon Nanotubes

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Abstract

We mainly report recent progress in backlight unit (BLU) for liquid crystal display (LCD) using printed carbon nanotubes (CNTs) including top-gate and lateral gate structures. Lighting performances of CNT-BLU and longevity of printed CNT emitters are intensively discussed. Selected issues related with field emission display (FED) using the same emitters also are presented.

1. Introduction

Although various FEDs using surface-conduction electron-emitter (SCE), Spindt-type and CNT emitter have come into the spotlight owing to their superior display performances, Field emission technology should answer the question from the market of whether the technology are going to be limited to high-performance niche products. FED is obviously a dark horse in flat panel display race, but the future is not clear due to the tremendous decay in manufacturing cost and fast improvement in visual quality of other winning displays such as liquid crystal display (LCD) and plasma display panel (PDP). Of course, we have already seen the surprising FED performances based on Spindt (21-inch by Sony), SCE (55-inch by Canon-Toshiba) and printed CNT (38-inch by Samsung SDI) emitters at various exhibitions and conferences.

Screen printing of carbon nanotubes (CNTs) for electron field emitters has advantages over other technologies in cost and easy scalability to large-size. In spite of their excellent properties, CNT emitters still have couple of serious problems to be challenged for commercialization such as uniformity of electron emission over large area and longevity of emitter life time. Roughly, Fowler-Nordheim theory tells 10% difference of field enhancement factor (~same difference in tube length at vertical morphology) results in 90% difference in emission current. In other words, only a small portion of CNTs out of prepared tips participate in electron field emission due to the irregularity of tip morphology especially in printed CNTs as shown in Fig. 1. Such problems lead to lack of emission site density and its uniform distribution over large area. Also the emitter life time problem, we expect, can be solved by same approach. The current estimated emission site density of CNT emitters is still 1~2 order lower than that of the required value for the TV application. To challenge this issue with low cost, there are strong demands for technology breakthroughs in post-activation of printed CNTs and tube length control in CNT raw material.

Under this technological limit, in Samsung, we focus on development of CNT field emission based BLU for the high performance LCD with fast MPRT (motion picture response time ≤ 3 ms), high dynamic contrast ratio (≥ 100,000:1) and eco-design by not using Hg.

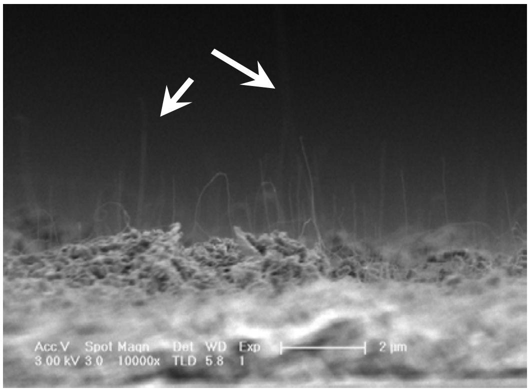

Fig. 1. Typical morphology of printed CNTs after activation and electric field aging process shows irregular tip distribution: Arrows indicate long CNTs, which are expected to emit electrons dominantly.

2. Experiments and Results

CNT-FED with double-gate structure has been developed using CNT paste.[1] Fig. 2 (a) shows the typical printed CNT emitter arrays for a sub-color pixel. Enlarged electron microscope image is shown in fig. 2 (b). We have optimized this structure to have average pixel uniformity (a-PU) of brightness over 90% through developing *a*-Si:H resistive layer, focusing gate and black matrix.

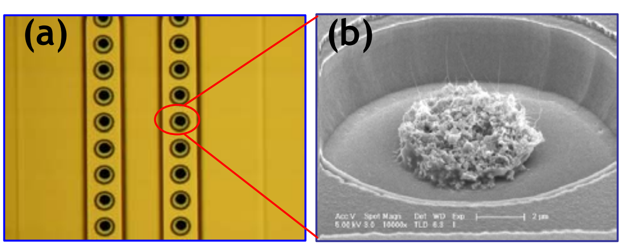

Fig. 2. (a) Top-view image of a sub-pixel structure for double-gate FED. (b) An enlarged CNT-dot image in a gate-hole structure, where the gate hole and CNT-dot dimension are 15 μm and 6 μm in width, respectively.

The demonstrated 15-inch diagonal CNT-FED is shown in Fig. 3. The gap between anode and cathode is maintained by ceramic spacers at 2 mm and P-22 based RGB phosphors are used for individual color representation. Applied bias on the anode is 7 kV from which we acquired brightness of 400 cd/m^2.

Fig. 3. Captured image of a 15-inch diagonal CNT-FED with double-gate structure.

Unlike FED, it is desirable for electron beam to be far much divergent for the BLU application. Therefore, a back plate with single-gate structure has been constructed for BLU as illustrated in Fig. 4. All other parts are similar with FED except for using mixed white phosphors, higher anode voltage over 10 kV and larger vacuum gap over 5 mm to extract white light over 10,000 cd/m^2.

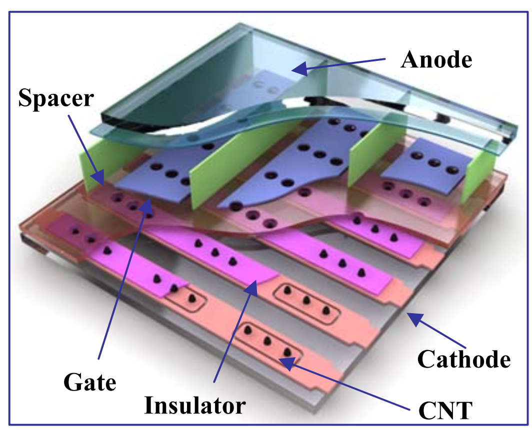

Fig. 4. An illustration of CNT-BLU having single-gate back-plate: Scanning pulses under 100 V at 1 kHz are applied for driving.

Using this structure shown in Fig. 4, we fabricated 7-inch diagonal BLU showing brightness over 12,000 cd/m^2 under anode voltage 12 kV. Through equipment of LCD panel and light diffuser sheet over BLU at ~ 5 mm clearance to ensure light uniformity, 600 cd/m^2 of full white brightness was accomplished.

The estimated light efficiency[2] is ~ 27 lm/W and the color temperature of the light was ~ 10,000 K measured after passing through LCD panel. The demonstrated 7-inch diagonal CNT-BLU is shown in (a) of Fig. 5 and captured LCD image is in (b) of Fig. 5.

Fig. 5. (a) A Light image captured from 7-inch diagonal CNT-BLU with diffuser sheet: the gap between diffuser and BLU is maintained at 5 mm. (b) LCD picture image backlighted by (a).

3. Discussion

For commercialization of CNT FED, it is critical to solve the uniformity issue. Here we report an observation obviously shows the current situation. In Fig. 6, the upper is enlarged capture image of recently manufactured 15-inch CNT-FED and we measured brightness of each emitting pixels along a scan line under full white mode.

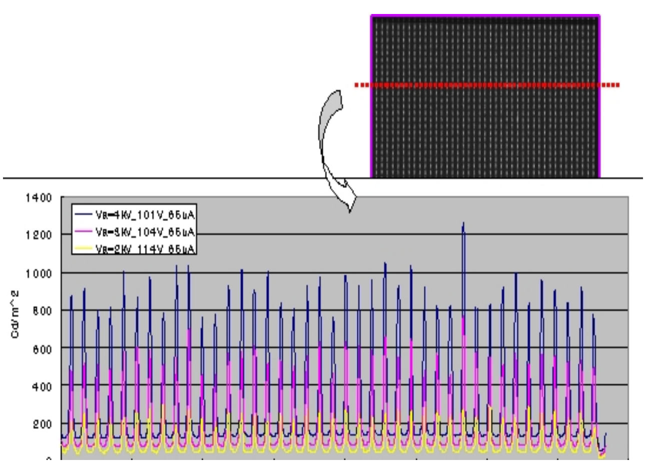

Fig. 6. Upper: A part of enlarged pixel image of CNT-FED. Lower: Brightness data over every single pixel along the scan line.

The lower peak-type data are the results with respect to the anode voltage varying from 2 to 4 kV. At 4 kV, the brightness variance is from 750 to 1250 cd/m^2. This brightness difference reflects emission current difference from pixel to pixel. Due to the brightness of cathode-luminescent phosphors tend to saturate with Coulomb dose especially at low or medium voltage, the expected emission current difference is still larger than this result. This non-uniformity stems from non-uniform CNT array and lack of emission site density.[3]

The estimated emission site density from I-V analysis is not more than 10^5/cm^2, which is far lower than that of the required for HDTV application ($\geq 10^6 \sim 10^7$/cm^2). Moreover, this non-uniform emission current, in other words, local high Coulombic load on specific phosphor pixel leads to possible non-uniform phosphor degradation during device life time. This problem can easily be observed at low anode voltage less than 5 kV owing to the shallow penetration depth (~ 0.1 μm) of electron into the phosphor.

Fig. 7 apparently proves this speculation in which the initial uniform image of the panel seriously deteriorated after life time test.

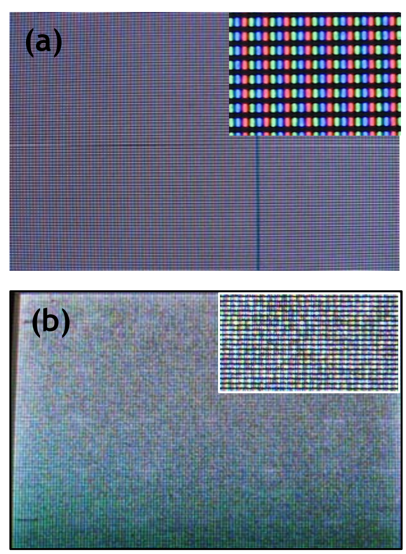

Fig. 7. Initial capture image (a) of CNT-FED is showing good emission uniformity, which is degraded after life time test (b): Non-uniform phosphor pixel degradation is supposed to be from non-uniform emission current from pixel to pixel.

Another possible cause for this uniformity degradation is the wrong choice of phosphor material for example $SrGa_2S_4$:Eu (SGS for green), which is sulfur rich compound and is apt to be degraded under high dose of electron bombardment. We are under investigation of phosphor-originated uniformity deterioration of our CNT-FED panel.

4. Conclusion

We introduced recent results of FED and BLU for LCD using CNT paste. The emission site density of printed CNT emitters should be much improved to meet the HDTV standard of uniformity.

5. References

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