Field Emission-Back Light Unit Fabricated Using Carbon Nanotube Emitter

H. S. Kim*, J. W. Lee, S. K. Lee, C. S. Lee, K. W. Jung, J. H. Lim, J. W. Moon, M. I. Hwang, I. H. Kim, Y. H. Kim, B. G. Lee, Y. C. Choi, H. R. Seon, S. J. Lee, J. H. Park
Display Lab, Corporate R&D Center, Samsung SDI, Yongin, Gyeonggi 446-577, Korea
TEL:82-31-288-4410, e-mail: hs88.kim@samsung.com
Keywords : Back light unit, Field emission, Carbon nanotube, Local dimming, Motion blur

Abstract

Field emission-back light unit (FE-BLU) was fabricated using carbon nanotube (CNT) emitter. Local dimming and local brightening techniques were achieved, which results in very high contrast ratio. In addition, the motion blur phenomenon, one of the serious problems of liquid crystal display (LCD) with cold cathode fluorescent lamp (CCFL)-BLU, was removed from LCD-TV by using FE-BLU.

1. Introduction

Cold cathode fluorescent lamp (CCFL) has long been used as a back light unit (BLU) for liquid crystal display (LCD) [1]. However, the LCD with CCFL-BLU has suffered from a few serious disadvantages. Since CCFL is illuminating the whole area of LCD, it is very difficult to represent the true black color, resulting in low contrast ratio. Another big problem of LCD with CCFL-BLU is motion blur phenomenon which occurs because the CCFL is a continuous lighting source [2]. To make things worse, CCFL has mercury which must be removed in all devices in the near future. To represent the black color with very low gray scale for the high contrast ratio of LCD, the BLU with a function of local dimming is required. The motion blur could be eliminated by using impulsive driving technique. In order to overcome such drawbacks of CCFL-BLU, we have fabricated field emission (FE)-BLU since the local dimming and impulsive driving techniques could easily be achieved using FE devices. Furthermore, FE-BLU does not have mercury. Conclusively speaking, the FE-device is an ideal BLU for the high quality LCD.

The carbon nanotube (CNT) was used as an emitter, since it is well known that the CNT is an excellent field emitter due to its high aspect ratio, small tip-radius of curvature, and high chemical inertness [3]. The screen-printing technology of CNT paste was chosen for the fabrication of the emitter because of its low fabrication cost but also easy scalability to a large size [4]. Finally, the LCD-TV with FE-BLU was fabricated and characterized with viewpoints of local dimming and motion blur.

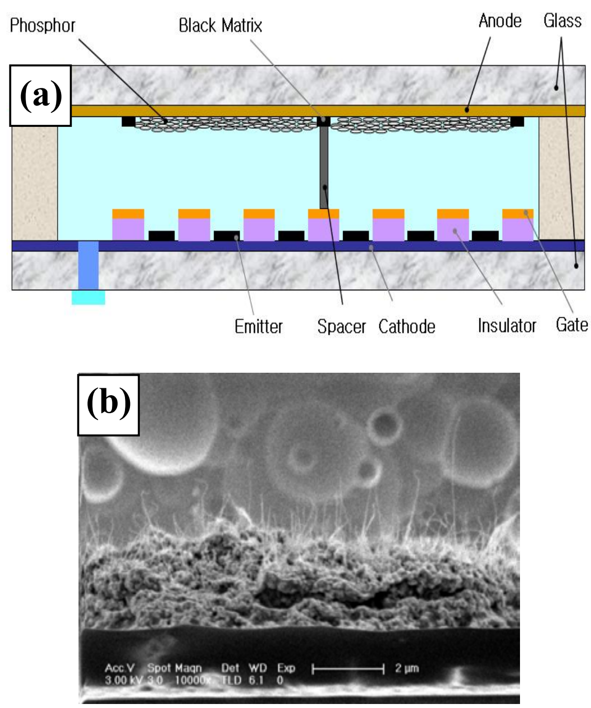

Fig. 1. (a) Schematic diagram of FE-BLU panel structure and (b) SEM image of a CNT paste emitter.

2. Experimental

Figure 1(a) shows the schematic diagram of the structure of FE-BLU with CNT emitters. A top-gated cathode with CNT emitters and a phosphor-coated anode was independently fabricated, followed by sealing process. The distance between cathode and anode is 1 cm, kept by spacers. The cathode structure is similar to the Spindt-type structure [5] other than CNT emitters. The diameters of a gate hole and a CNT emitter dot are 50 μm and 20 μm, respectively. The white phosphor was prepared by mixing red, green, and blue phosphors with a proper ratio, and then screen-printed on the anode plate.

The emitters were formed by screen-printing of CNT paste inside gate holes. Thin multiwalled (MW) CNTs with diameters ranging from 3 nm to 5 nm were used to prepare CNT paste. The paste was made by mixing the thin MWCNT powders, organic vehicles, negative-type photoimageable resins, and inorganic powders in a solvent. Glass frit was also included for the purpose of giving an adhesion between the substrate and the paste. After the screen-printing of the paste on the cathode plate, the back side of the cathode was exposed to ultraviolet (UV), followed by development process. Then, the cathode was fired at 450 ^{o}C in nitrogen atmosphere. Finally, the physical surface treatment was carried out using liquid elastomer to form vertically aligned CNT emitters, as can be seen in Fig. 1(b).

3. Results and discussion

Figure 2 shows the emission pattern of 32 inch diagonal FE-BLU panel. The BLU panel is composed of 2,800 blocks (70 columns x 40 rows). Each block (1 cm x 1 cm) has approximately 10,000 gate holes inside which CNT emitters are formed.

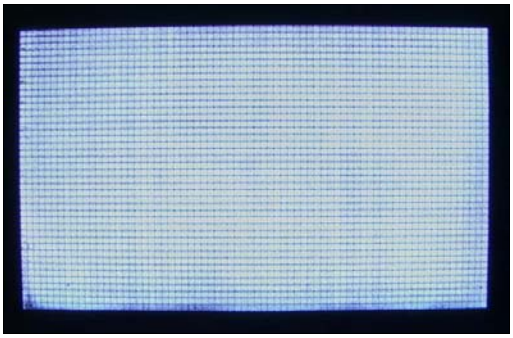

Fig. 2. Emission image of FE-BLU using CNT emitter.

The brightness of each pixel is controlled with 8 bit gray scale. As shown in the figure, very bright and uniform emission image was observed. The brightness of 6,000 cd/m^2 was obtained at anode voltage (V_a) and anode current density (J_a) of 15 kV and 5 μA/cm^2, respectively.

Assuming the transmittance of liquid crystal to be 5 %, the brightness of LCD with our FE-BLU would be 300 cd/m^2. The J_a of 5 μA/cm^2 was obtained by applying gate voltage (V_g) of 80 V with a duty cycle of 0.72 %. The emission was turned-on at around V_g = 50 V, and then the current increased steeply to 5 μA/cm^2 at around V_g = 80 V. Therefore, the difference between V_g for turn-on and V_g for the emission current density of 5 μA/cm^2 needed for the brightness of LCD of 300 cd/m^2 is as small as less than 30 V, which is advantageous for the operation of field emission devices. Such a small difference in two different gate voltages is attributed to high field enhancement factor (β) of CNT emitters. The β of the thin MWCNTs used in this study were as high as 2,860 that had been measured previously [6].

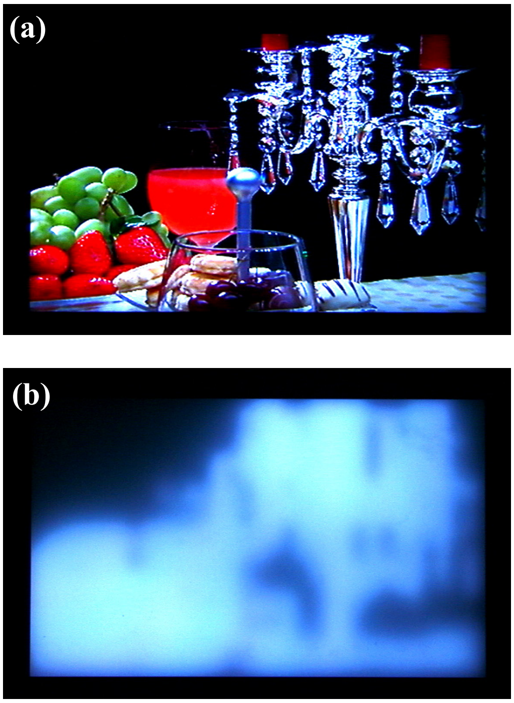

Fig. 3. (a) Image of LCD with FE-BLU with CNT emitters. (b) Corresponding BLU image showing local dimming.

Figures 3(a) and (b) show LCD-TV having FE-BLU with CNT emitters and the corresponding FE-BLU image, respectively. The diffusion plate is placed in front of FE-BLU panel, which prevents us from seeing discrete block image, as shown in Fig. 3(b).

It is clearly seen that the local dimming is achieved using FE-BLU. Furthermore, since the block size is as small as 1 cm x 1 cm, a precision local dimming is observed. As a result, the LCD-TV with a function of local dimming shows high contrast ratio since the true black color with extremely low gray scale was achieved, as can be seen in Fig. 3(a).

In addition to the local dimming technique, our panel has also the function of local brightening, which results from the use of automatic power control (APC) circuit. The local brightening achieved using the APC circuit has been used in plasma display panel (PDP). However, the conventional LCD could not have APC circuit due to the limitation of CCFL-BLU. Figure 4 represents the brightness of LCD-TV and the relative power consumption of FE-BLU with APC circuit as a function of load ratio. Also shown in Fig. 4 is the schematic illustration of load ratio of a display. The load ratio is defined as the relative area of illuminating the light compared with whole display area. As mentioned previously in Fig. 2, the LCD-TV with our FE-BLU panel showed the brightness of 300 cd/m^2 at a load ratio of 100 %, so called full white.

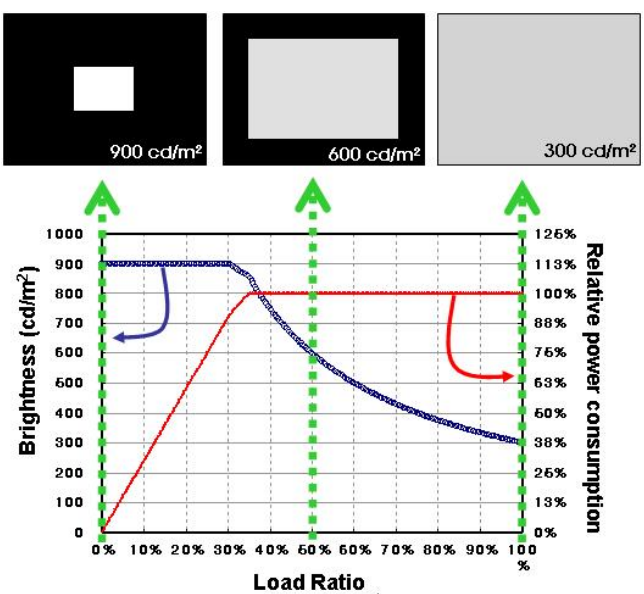

Fig. 4. The brightness of LCD-TV and the relative power consumption of FE-BLU using APC circuit as a function of load ratio.

The graph in Fig. 4 is divided into three regions according to the load ratio. First, with decreasing the load ratio from 100 % to 35 %, the brightness is increased from 300 cd/m^2 to 850 cd/m^2 while the power consumption is kept constant. This is possible because the power saved in the dark area is added on the bright area. Second, as the load ratio is decreased from 35 % to 30 %, the brightness is improved from 850 cd/m^2 to 900 cd/m^2 and the relative power consumption is decreased to 90 %. Third, in the range of load ratio from 30 % to 0 %, while the brightness is kept constant at 900 cd/m^2, the power consumption is linearly decreased from 90 % to 0 %. At a load ratio of 10 %, three times higher brightness was obtained using only 30 % of power consumption. It can be therefore said that through the application of APC circuit into the FE-BLU panel, the local brightening of LCD-TV is achieved with less power consumption. The local dimming technique together with the local brightening achieved using APC circuit enables LCD-TV to have very high contrast ratio.

We have also found that the motion blur phenomenon that is one of the most serious problems in conventional LCD-TV owing to the limitation of CCFL-BLU was completely removed by using our FE-BLU since the FE display device is operated with impulsive driving technique. Unfortunately, the pictures showing the elimination of motion blur could not be included in this paper due to the limitation of camera-resolution.

4. Summary

The FE-BLU was fabricated using CNT emitters. The screen-printing of CNT paste was carried out for the formation of the emitter. A top-gated cathode and a phosphor-coated anode were independently prepared, followed by sealing process. Then, the LCD-TV with FE-BLU panel was fabricated. Since FE-BLU is composed of with small blocks, precision local dimming is achieved. Furthermore, through the application of APC circuit into BLU panel, the LCD with a function of local brightening was also realized. The cooperation of local dimming and local brightening results in very high contrast ratio. The motion blur was not observed in the LCD-TV with FE-BLU since the field emission device is operated with impulsive driving technique.

5. References

1. Y. J. Jung, G. H. Son, J. H. Park, Y. W. Kim, A. S. Berdinsky, J. B. Yoo, and C. Y. Park, *Diamond Relat. Mater.*, **14**, 2109 (2005).

2. J. Miseli, *J. of the Soc. Information Display*, **14**, 987 (2006).
3. Y. C. Choi, K. S. Jeong, I. T. Han, H. J. Kim, Y. W. Jin, J. M. Kim, B. G. Lee, J. H. Park, and D. H. Choe, *Appl. Phys. Lett.,* **88**, 263054 (2006).
4. J. W. Nam, S. H. Cho, Y. C. Choi, J. S. Ha, J. H. Park, D. H. Choe, and J. H. Park, *Diamond Relat. Mater.,* **14**, 2089 (2005).
5. C. A. Spindt, I. Brodie, L. Humphrey, and E. R. Westerberg, *J. Appl. Phys*., **47**, 5248 (1976).
6. Y. C. Choi, E. M. Lee, J. W. Nam, S. H. Cho, J. S. Ha, J. H. Park, D. H. Choe, Field Emission Workshop ’05, (2005).