Recent improvements in display image qualities of CNT FEDs

Eung Joon Chi*, Cheol Hyeon Chang, Chun Gyoo Lee, and Deok Hyeon Choe
CTO) Display 3 Team, Samsung SDI, Cheonan 330-300, Korea
Phone: +82-41-560-3046, E-mail: ejchi@samsung.com

Abstract

The prototype of the field emission display with carbon nanotube emitter is developed in this study. To improve the brightness and color gamut of the prototype, new phosphor material, $SrGa_2S_4$:Eu, is adopted instead of conventional CRT-green phosphor. By replacing the green phosphor, the prototype shows significant improvements in the brightness and color gamut. At the anode voltage of 7 kV and the anode current of 2~3 ㎂/㎠, the brightness is higher than 600 cd/㎡. The luminous efficiency of the prototype is about 7.7 lm/Watt.

1. Introduction

As liquid crystal and plasma displays make great progress in their technology and cost down, the market of large flat panel display is increasing rapidly. On the other hand, field emission display (FED) has been considered as one of the most competitive devices for the HDTV application.

In principle, FED shows display quality that is very similar to CRT. Another advantage of FED is low power consumption owing to its simple driving scheme. As FED does not require many expensive facilities, the capital investment for the FED manufacturing line is expected to be small compared with other large flat panel displays.

In the FED system, many of the display performances are dependent on the electron emitting material and cathode structure. For the electron emitting material, carbon nanotube (CNT) has been widely investigated since it was recommended [1-6]. CNT has inherent advantages for the electron emitter, that is, it conducts electrons and has very large aspect ratio. In addition, CNT can be mixed with other organic and/or inorganic materials and formed to the printable paste. By screen-printing and firing processes, the electron emitting layer is easily manufactured from the paste on a large substrate. For the cathode structure, various structures have been developed and investigated from the viewpoint of emission efficiency and large-size manufacturing.

An important and effective way to improve the display qualities is to enhance the screen efficiency of the prototype. In this study, new green phosphor material, $SrGa_2S_4$:Eu, is adopted to improve the brightness and color gamut of the CNT-FED. Some properties of $SrGa_2S_4$:Eu phosphor are introduced and compared with conventional CRT-green phosphor. The effects of changing green phosphor on the improvements in the display performance are discussed. The images from color video operation of the prototype are also shown.

2. Results and Discussion

2-1 Structure of CNT FED

Figure 1 shows the schematic cross section of the CNT FED structure investigated in this study. The structure is based on the typical top-gate structure. In the top-gate cathode structure, the gate electrode is located above the cathode electrode and these two electrodes are electrically insulated. In the matrix driving system, scan and data signals are applied to the gate and cathode electrodes, respectively.

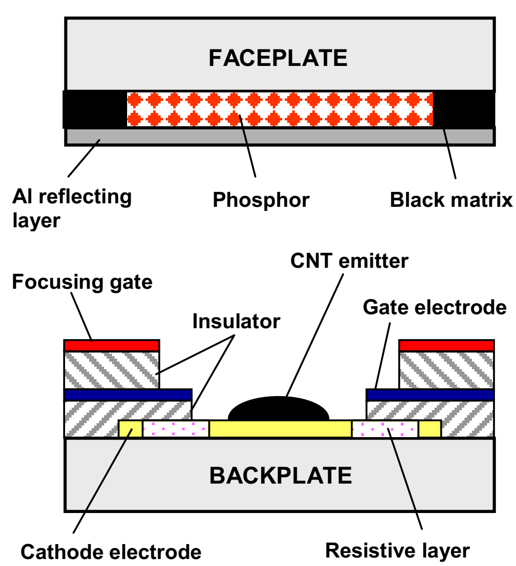

Figure 1 Schematic cross section of faceplate and backplate of CNT FED.

On the cathode electrode, CNT emitter is formed from the CNT paste by printing and photolithography processes. The CNT paste is composed of many ingredients such as CNT powder, polymer binder, photosensitive resin, and other functional additives. After firing the CNT paste, some special treatment on the CNT emitter is needed to activate its emitting property.

The TV application requires high brightness and good color representation. To achieve both properties, high anode voltage has to be applied and emitted electrons should be focused sufficiently. Therefore, electron focusing structure is needed in addition to the basic components including gate, cathode, and insulator. In general, the electrons are emitted from the cathode with some angles to the perpendicular direction, and then focused by the focusing structure to reach the corresponding phosphor.

In Figure 1, focusing gate structure is made on the top-gate cathode. So, this system is generally called the double-gate structure; one for extracting electrons from the emitter and the other for focusing the emitted electrons. As the focusing gate and insulating layer beneath are formed by the photolithography process, the dimension and location can be precisely controlled. The structure investigated in this study, therefore, is favorable to the high resolution display.

To improve the uniformity in the emission current and hence the brightness of each pixel, resistive layer is applied. The resistive layer is made of amorphous silicon grown by plasma enhanced chemical vapor deposition. The layer is doped with phosphine to adjust the resistivity. It connects the cathode electrode to the CNT emitter dot and acts as a lateral-type resistor. The resistive layer increases the driving voltage but levels the various emitters, that is, improves emission uniformity. There is always some trade-off between the uniformity improvement and the driving voltage increase.

The faceplate consists of phosphor dots, black matrix, and aluminum reflecting layer. The reflecting layer is coated on the whole of the phosphor dots. It acts as a mirror for the light emission and reflects the backward light from the phosphor. So, the light directing forward increases and higher brightness is obtained. This process is effective only when the Al layer does not obstruct the electron penetration and the electrons passing through the layer reach the phosphor dot with sufficient energy to activate it. Therefore, the effectiveness of the reflecting layer is related to the thickness of the aluminum.

2-2 Characteristics of $SrGa_2S_4$:Eu Green Phosphor

In general, conventional P22 CRT phosphors are widely used for FED application. To represent wider color gamut than P22 phosphors, however, green color should be improved. After reviewing various phosphor materials for green color, a new green phosphor, $SrGa_2S_4$:Eu, was adopted to obtain deeper green color in CIE chromaticity diagram. In Figure 2 and Table 1, the color coordinates and luminous efficiency of some green phosphor materials are shown respectively.

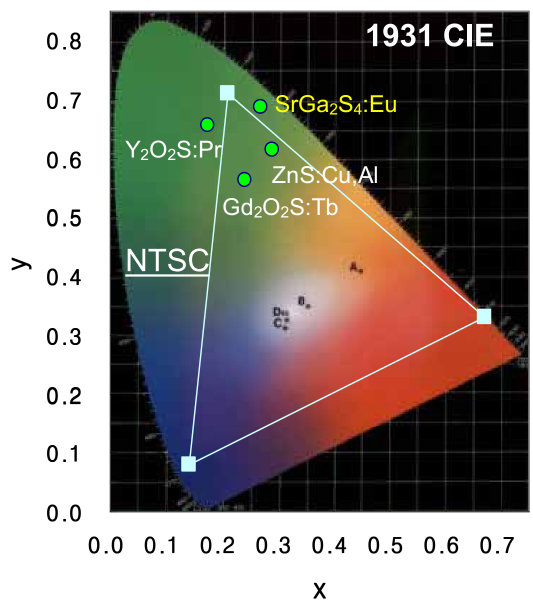

Figure 2 Color coordinates of various green phosphor materials in CIE 1931 diagram.

Table 1 Luminous efficiencies of green phosphors.

Phosphor	Efficiency (lm/W @1kV)
$SrGa_2S_4$:Eu	16.5
ZnS:Cu,Al	15.1
Y_2O_2S:Pr	4.9
Gd_2O_2S:Tb	14.1

Figure 3 shows the luminescence spectra of P22 CRT-green phosphor (ZnS:Cu,Al) and $SrGa_2S_4$:Eu phosphor. Both phosphors show peak intensity at the same position of about 535 nm, but the $SrGa_2S_4$:Eu has sharper and higher relative intensity than ZnS:Cu,Al. The difference in these spectra can explain why the color coordinates of $SrGa_2S_4$:Eu phosphor reside in deep green area in the CIE chromaticity diagram of Figure 2. Thus, by replacing ZnS:Cu,Al with $SrGa_2S_4$:Eu as green color phosphor in the FED prototype, the color gamut could be significantly expanded.

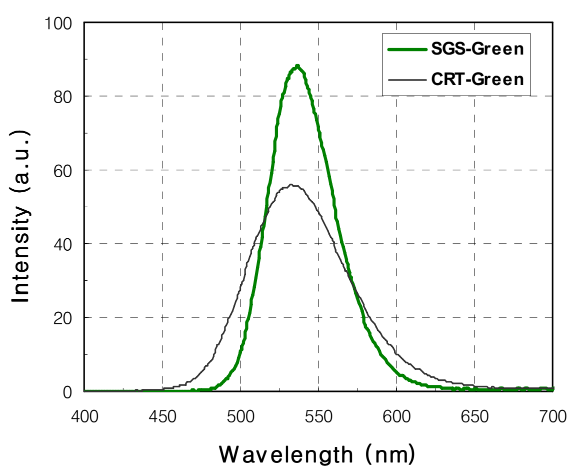

Figure 3 Luminescence spectra of P22 CRT-green phosphor and $SrGa_2S_4$:Eu phosphor.

In addition to the wide color gamut, $SrGa_2S_4$:Eu has the advantage of high luminous efficiency. In Table 1, $SrGa_2S_4$:Eu shows the highest efficiency among the green phosphor materials reviewed in this study. At the acceleration voltage of 4 kV, the luminous efficiency of $SrGa_2S_4$:Eu is 43 lm/Watt, which is about 10% higher than 39 lm/Watt for ZnS:Cu,Al at the same voltage[7].

2-3 Display Performance of FED panel

To evaluate the display performances such as brightness and color representation, the cathode substrate (backplate) is aligned and assembled with the faceplate. The faceplate consists of electrode, black matrix, phosphor dots, and aluminum reflecting layer. The assembly is enveloped with sealing frit at about 400 ℃ and then evacuated to low pressure. The gap between the two plates is sustained by the spacers.

For the measurement of color gamut, complete FED panel that is vacuum sealed is used under its normal operating condition. The prototype with $SrGa_2S_4$:Eu green phosphor shows 15 % wider gamut than P22 phosphors. The improvement is resulted from the enhancement of green color. The color gamut of the prototype is about 90 % of NTSC gamut area. The color representation implies several information such as phosphor characteristics, electron beam focusing, and alignment accuracy. In this point of view, the CNT FED developed in this study shows sufficiently competitive performance.

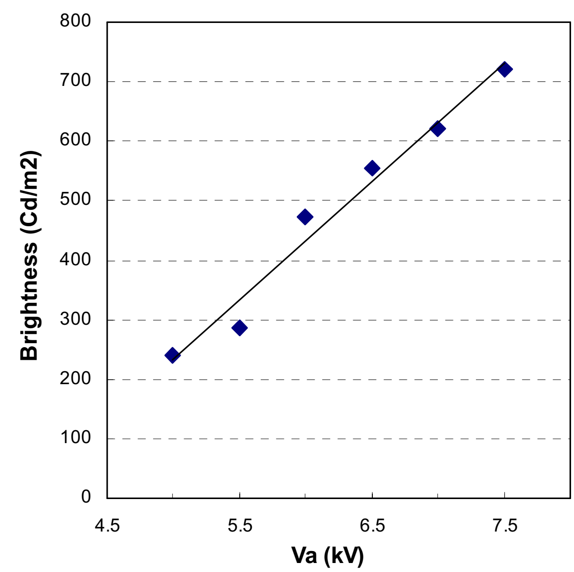

Figure 4 Brightness of CNT-FED prototype as a function of voltage applied to the faceplate.

Figure 4 shows the dependence of the brightness on the voltage applied to the faceplate. These data are obtained from the CNT FED prototype of double-gate cathode structure. During the brightness measurement, the anode current is set to the same value regardless of the applied voltage. In the range of the measurement, the brightness increases almost linearly with the anode voltage. As the current is fixed, it means that the brightness can be effectively increased by the anode voltage without increasing the cathode driving voltage. This fact is very desirable in respect of the lifetime of the device. The CNT emitter is known to deteriorate as the current it emits increases. Therefore, it is not recommended to increase the emission current to obtain higher brightness. To apply the anode voltage as high as possible is proper method for the high brightness, and it also improves the lifetime of the phosphor screen. At the anode voltage of 7kV and the anode current of 2~3 μA/cm², the brightness is higher than 600 cd/m². The luminous efficiency calculated from the data is about 7.7 lm/Watt.

For the color video operation, the prototype is driven by integrated electronics developed for the CNT FED including column drivers, row drivers, power supply and so on. The drivers control the grey scale through pulse width modulation. During operation, the row driver sequentially scans each row at turn-on voltage. A pixel is turned on when the row is scanned high and the column switches from certain voltage to ground. The grayscale value is defined by the length of the time that the column remains switched on.

The prototype in this study is a 15” diagonal which is a small section of large diagonal HDTV display. This prototype is operated with the same duty ratio that is needed for 1280x768 HD resolutions. It means that though the prototype has less row lines, the actual signal (on-time) of each scan line is identical to the signal at real HD resolution. In Figure 5, an image captured from video operation is shown. This picture is generated with 70 V on the row, 40 V on the column, and 5 kV on the anode. The voltages applied to the scan and data are low enough for the cost of the driver electronics. The anode voltage of 5 kV is much milder than the required and achievable in the prototype. The technologies for increasing the anode voltage up to 10 kV are under development.

Figure 5 Image from color video operation of Samsung’s CNT-FED prototype.

3. Conclusion

The prototype of the field emission display with carbon nanotube emitter is developed in this study. The cathode structure is based on the typical top-gate structure, and electron focusing gate and resistive layer are applied. To improve the brightness and color gamut of the prototype, new phosphor material, $SrGa_2S_4$:Eu, is adopted instead of conventional CRT-green phosphor. By replacing the green phosphor, the prototype shows significant improvements in the brightness and color gamut. At the anode voltage of 7 kV and the anode current of 2~3 μA/cm², the brightness is higher than 600 cd/m². The luminous efficiency of the prototype is about 7.7 lm/Watt. An image from color video operation of the prototype is shown.

4. References

[1] S. Iijima, “Helical Microtubules of Graphitic Carbon” Nature, Vol. **354**, pp. 56-58, (1991).

[2] E.J. Chi, C.G. Lee, J.S. Choi, C.H. Chang, J.H. Park, C.H. Lee, and D.H. Choe, “CNT FEDs for large area and HDTV applications”, Proceedings of the Society for Information Display 2005, pp. 1620-1623, (2005).

[3] C.G. Lee, et al., “Large Size Under-Gate CNT Cathode for HD-TV Applications”, Technical Digest of the 16th International Vacuum Microelectronics Conference, p. 39, (2003).

[4] B.F. Coll, K.A. Dean, J. Jaskie, S. Johnson, and C. Hagen, “Nano-Emitters for Big FEDs -The Carbon Nanotubes Solution-”, Proceedings of EURODISPLAY 2002, pp. 219-224, (2002).

[5] M. Ushirozawa, et al., “Feasibility Study on Graphite Nanofiber FED”, Proceedings of the 10th International Display Workshops, p. 1720, (2003).

[6] J.Yotani, et al., “Luminance Uniformity of a CNT-FED for Character Displays”, Proceedings of the 10th International Display Workshops, p. 1243, (2003).

[7] C.Stoffers, “Saturation Kinetics of Low Voltage Phosphors”, A Bell & Howell Company (1998).