CNT FEDs with Electron Focusing Structure for HDTV Application

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Abstract

In this study, the field emission display with carbon nanotube emitter is developed for the large size HDTV application. Two structures for electron beam focusing are developed on the typical top-gate cathode. The metal grid and focusing gate structure are proved to be effective for the focusing. The data switching voltage for the double gate structure is lower than 30V which is competitive value in respect of the cost for driver electronics. The brightness and color gamut are comparable to those of the commercial product such as CRT.

1. Introduction

Field emission display (FED) has been considered as one of the most competitive devices for the HDTV application. In principle, it 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 expensive facilities, the capital investment for the FED manufacturing line is expected to be small compared with other large flat panel display.

In the FED, most of the performances are determined by the electron emitting material and cathode structure. Various materials such as silicon, molybdenum, carbon, etc. were studied for the electron emitter. In particular, carbon nanotube (CNT) has been widely investigated since it was recommended [1-5]. 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 CNT FED to be more competitive in the large area flat display market, it is necessary to reduce the cost of driver electronics. The cost is mostly decided by the switching voltage that can be, in turn, lowered by optimizing the cathode structure. In this study, some experimental results are given for the low voltage operation in the CNT FED. Other display qualities such as brightness and color gamut are also shown for the CNT FED with the focusing structure.

2. Results and Discussion

2.1 Electron Focusing Structures

Figure 1 shows the schematic cross section of the cathode structures investigated in this study. All the structures are 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.

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, vehicle, frit, and so on. The frit is added to increase the CNT layer's adhesion to the cathode electrode. 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. Two types of the focusing structure are developed.

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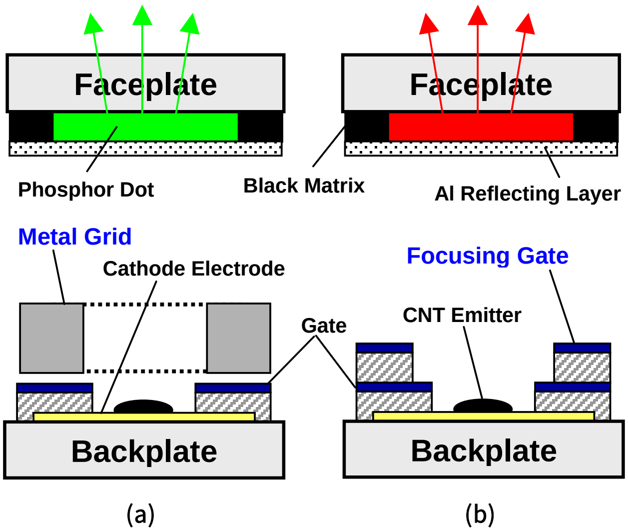

Figure 1 Schematic cross section of faceplate and backplate of CNT FED equipped with (a)metal grid and (b)focusing gate.

Metal grid structure over the typical top-gate cathode is shown in Figure 1(a). Metal grid of 100㎛ thickness is an effective focusing structure. It also protects the cathode structure from damaging due to the high voltage arcing. Furthermore, it screens the emitters from anode voltage penetration, and prevents the uncontrollable electron emission by the anode voltage.

Figure 1(b) shows the other electron focusing structure. In this structure, focusing gate 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 focusing gate structure, therefore, is favorable to the high resolution display.

2.2 Low Switching Voltage of CNT FED

The current-voltage (I-V) characteristics of the CNT FED are shown in Figure 2. The two curves are obtained from the structure with and without focusing gate, respectively. The evaluation is performed at a duty ratio of 1/1000. By applying the focusing gate(double-gate), the current density decreases considerably comparing with that of the structure(single-gate) without focusing gate. It is, however, still sufficiently high for the brightness requirement.

At a certain anode voltage, the brightness is related to the emission current. The dotted line in the figure indicates a criterion of the current level requisite for the brightness for the TV application. In this calculation, it is assumed that the anode voltage and duty ratio is 6㎸ and 1/1000, respectively. 2.5㎂/㎠ is required for obtaining 400cd/㎡ that is sufficient brightness for the large area HDTV.

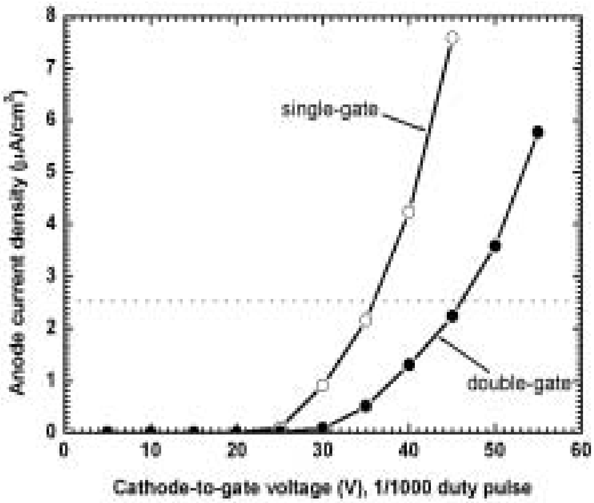

Figure 2 I-V characteristics of single- and double-gated CNT cathodes.

In the FED system with focusing gate structure exist four kinds of electrodes, that is, cathode, gate, focusing gate, and anode. In general, DC voltage is applied to the focusing gate and anode electrode. At the gate electrode, the voltage is scanned with a fixed frequency. Only the cathode electrode is switched according to the data signal and its switching voltage influences the cost of driver electronics.

From the I-V data, the data switching voltage in the CNT FED can be obtained. To define the value more clearly, the I-V data in Figure 2 is converted to the log-plot and shown in Figure 3. The data switching voltage means the voltage applied to the cathode electrode (data line) to shut off the electron emission. By applying it, the voltage difference between the cathode and gate decreases and then the cathode no longer emits electrons. In this process, the current level of no-emission is not required to be zero. In Figure 3, the current density for on- and off-level is marked with dotted lines. The current density for off-level is defined as 1/1000 of on-level current density, which corresponds to the contrast ratio of 1000:1.

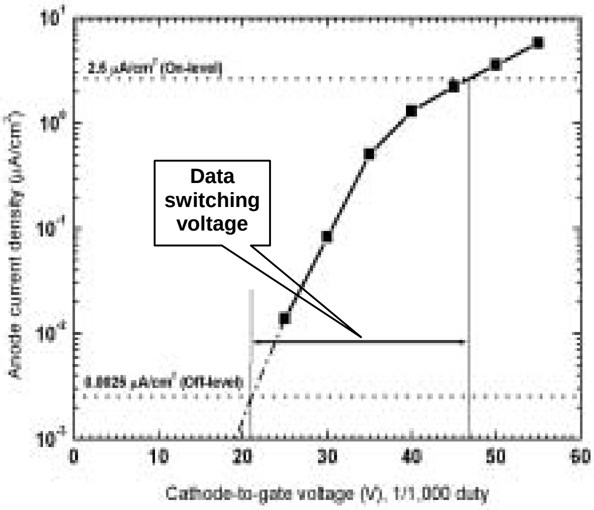

Figure 3 Log-plot of I-V characteristics showing data switching voltage of CNT FED with focusing gate.

The data switching voltage for the CNT FED with focusing gate (double-gate structure) is about 26V. The cost of driver IC is related to the switching voltage and known to abruptly increase for the voltage higher than 50V. Even when considering the tolerance, the data switching voltage of the double-gate structure developed this study can be thought to be sufficiently low and have cost competitiveness in respect to the driver IC.

2.3 Display Performances

To evaluate the display performance such as brightness and color representation, the cathode substrate (backplate) is aligned and assembled with the faceplate on which the anode electrode and phosphor dots are patterned. The assembly is enveloped with sealing frit and evacuated. The gap between the two plates is maintained by the spacers.

Figure 4 shows the dependence of the brightness on the voltage applied to the faceplate. These data are obtained from the CNT FED of double-gate structure. The duty ratio of 1/1000 is adopted. During the brightness measurement, the anode current is set to the same value regardless of the applied voltage.

In the range of the measurement in Figure 4, 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. In general, 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.

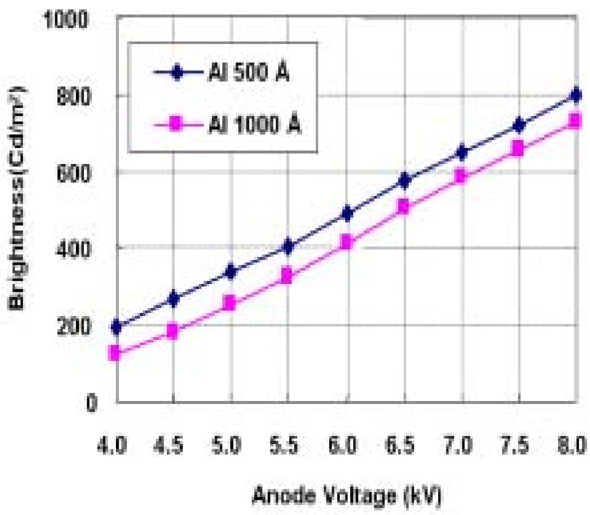

Figure 4 Dependence of the brightness on the voltages applied to the anode with different thickness of aluminum reflecting layer.

In the faceplate, aluminum 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.

In this study, the Al layers with 500Å and 1000Å are tested. The thickness examined is effective to increase the brightness for the anode voltage higher than 4kV comparing with the brightness in the phosphor screen without Al reflecting layer. The phosphor screen with 1000Å-thick Al layer shows lower brightness than the screen with 500Å-thick layer. The difference of the brightness is about 75cd/m². On the other hand, the Al layer plays an assisting role in the improvement of the color representation. The Al layer protects the backscattered or stray electrons from colliding unwanted phosphor dots. Therefore, the thickness of the Al layer has to be determined from careful consideration of the brightness and the color representation.

In general, FED adopts the phosphor powders using CRT or lamp. In this study, P22 phosphor is adopted and modified for the process optimization. The phosphor screen is made by the slurry coating and photo-patterning processes. The color gamut obtained from the CNT FED with focusing gate is about 93% of the value obtained in the conventional CRT. 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 has competitive performance. When new phosphor materials under development are applied, the color gamut increases and exceeds the area of the conventional CRT's.

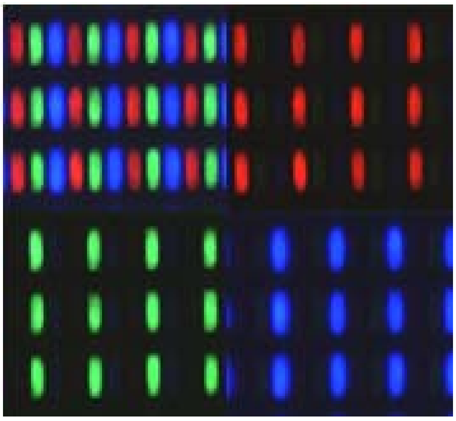

Figure 5 Luminescent images: white, red, green, and blue.

Figure 5 shows the luminescent images of white, red, green, and blue colors. The pixel-to-pixel brightness uniformity is considered as one of the most difficult performance of FED to achieve. The uniformity is defined as '1-(standard deviation/average)'. In the prototype developed in this study, about 95% of uniformity is obtained. For the uniformity issue, the definition, measurement and calculation procedure, and various methods to improve it will be described in detail at presentation.

3. Conclusion

In this study, the CNT FED with electron focusing structure is developed. The metal grid and focusing gate structure are proved to be effective for the focusing. The data switching voltage for the double gate structure is lower than 30V which is competitive value in respect of the cost for driver electronics. The brightness and color gamut are comparable to those of the commercial product such as CRT.

4. References

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