Module of Carbon Nanotubes Backlight

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Abstract

Carbon nanotubes backlight unit (CNT-BLU) that lightened by field emission was developed into practicability. According to our novel structure, AC mode circuit design and simple printing process, CNT-BLU could achieve 85% of uniformity, 8000 nits of brightness and low material and fabrication cost. Based on these performances, this new planar backlight technology has chances to proceed to mass production and has the potential to replace traditional backlight technology because of its good properties, like the simple processes, easy to large scale, low surface temperature, low power consumption, optical film-free and Hg-free, etc.

1. Introduction

Since carbon nanotubes (CNTs) were reported firstly in 1991 [1], this new material has been attracting great attention because of their unique physical properties and their potential for a variety of applications. Due to their high aspect ratio and small radii of curvature, it has been reported that CNTs possess excellent field emission characteristics such as high field emission current density and low turn-on electric field [2]. Therefore, some companies in the world are developing the CNT field emission display (FED) [3-7]. According to the great performances of optics and power consumption of the CNT-FEDs, a new application of CNT-FEDs was reported recently. CNT-FEDs have been developed to replace the cold cathode fluorescent lamp (CCFL) into LCD monitors and LCD TVs and the so-called CNT backlight unit (CNT-BLU) has been the considerable technology of the backlight [8-9].

In this paper, we will introduce the requirements to be the module of the CNT-BLUs and our work to achieve them. For the purpose of low cost and optics performance, we had developed screen printing and designed the simple cathode and package structure based on electric field and stress simulation. For the purpose of low power consumption, we have developed the dynamical driving method based on low-side frequency pulse circuit design.

2. CNT-BLU Structure

The structure of the CNT-BLU developed by DTC/ITRI was shown in Fig. 1. In Fig. 1, the gate and cathode electrodes were parallel on the cathode plate and they were fabricated in the same process. After electrode process, CNT emitters were fabricated on the cathode electrodes by screen printing. The anode electrode was coated on the anode plate, and then the phosphor layer was printed on the anode electrode. The anode electrode was the high reflex metal and was also the reflector in our CNT-BLU structure. The field emission electrons induced by the electrical field between the gate and cathode electrodes would be accelerated by the strong electrical field between the anode and gate electrodes. The accelerated electrons would hit the phosphor layer and the light then would emit toward the anode and cathode plates. The light toward the anode plate would be reflected by the anode electrode served as the reflector layer.

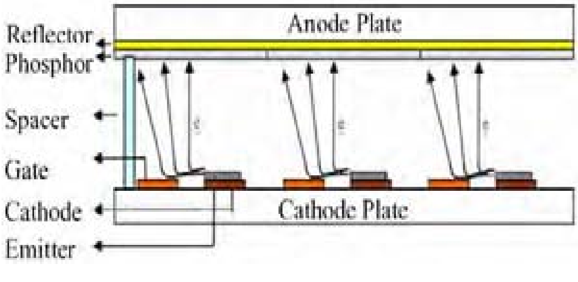

Fig. 1 The structure of the CNT-BLU

The lightening mechanism was shown in Fig. 2 and we compared our new structure with the conventional structure.

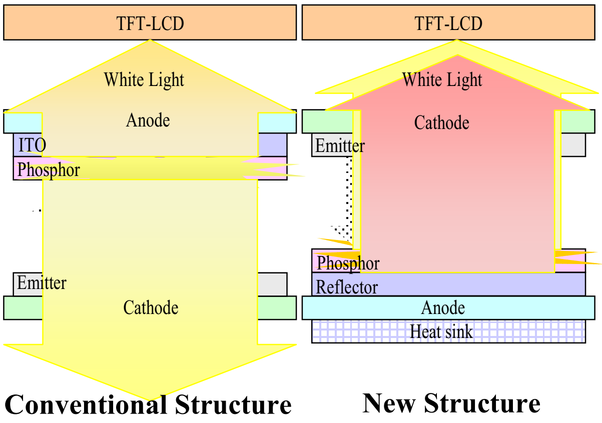

Fig. 2 CNT-BLU lightening mechanism comparison

3. Uniformity

For the purpose of the reduction in cost and process steps, we used screen printing to fabricate the electrodes and CNT emitters. Since the printing process was the less accurate process, the cathode plate of the CNT-BLU had a distorted pattern, like the Fig. 3. The distortion of the electrodes on the cathode plate would induce the inaccurate distance between the cathode and gate electrodes and the deviation from CNT emitters to the edge of the cathode electrodes. These phenomena would change the designed electrode field between the cathode plate and anode plate and influenced the uniformity of the CNT-BLU.

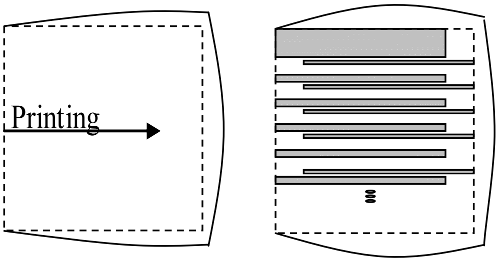

Fig. 3 The distortion of the printing pattern

To solve this issue, the symmetry pattern could be a good candidate to increase the accuracy. Then, the design of central electrode would follow the symmetric design. From previous report [10], the cathode electrode locating at the edge was a better design. To simplify the electrical operation, the voltage applied on central electrode was the same as the voltage applied on the cathode electrode. The schematic graph was shown in Fig. 4 and the dash line was the symmetrical line for these patterns.

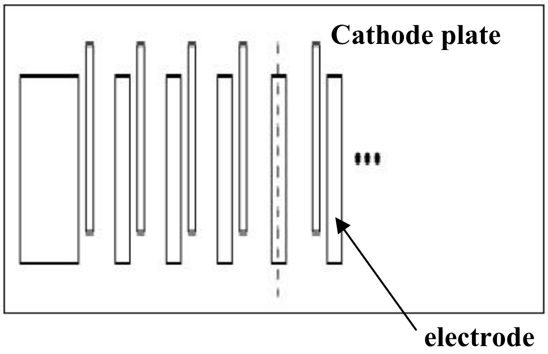

Fig. 4 The symmetry design of the cathode patterns

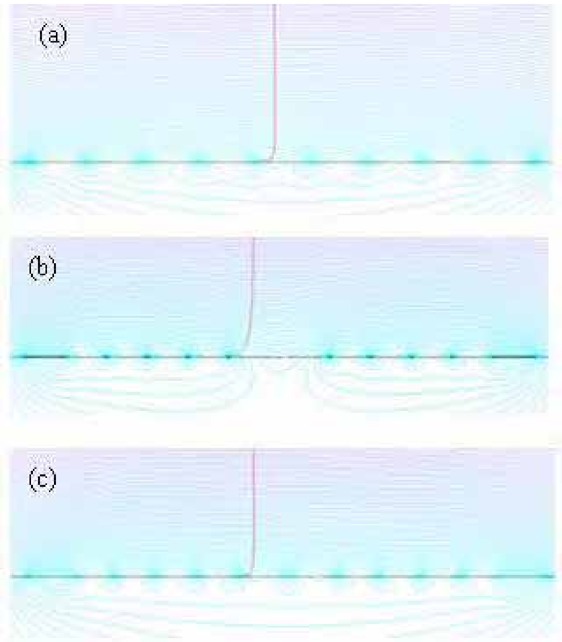

Fig. 5 The contour map of electrical potential (a) the normal structure; (b) the symmetrical structure without center electrode; (c) the symmetrical structure with center electrode.

We also used MATLAB 5 to calculate the electrical field between the cathode plate and anode plate based on this novel design and the electrical potential contour maps were shown in Figs. 5. Fig. 5(a) showed the contour map of normal structure. Fig. 5(b) showed the contour map of symmetrical structure without center electrode while Fig. 5(c) was the contour map of symmetrical structure with center electrode.

From the contour map of electrical potential of these three structures, the one possessing the most uniform field was the symmetrical structure with central cathode electrode. Finally, we got the cathode structure with wide cathode electrodes on the both edges, the symmetry design, and the central electrode on the cathode structure. With these modifications on cathode structure, the electrical field became uniform by calculations.

This design has been applied on our 4 inch and 20 inch CNT-BLU. The uniformity of the 20 inch CNT-BLU was 74.1 % and 4 inch was 85%. The uniformity was calculated from the emission pattern which captured by MINOLTA CS100 with 0.1 neutral density (N.D.) filter and the definition of standard deviation of sample uniformity: [1 - (standard deviation)/(average value)] of 16 points.

4. Brightness

If we applied the conventional structure CNT-BLU in Fig. 1 to be the backlight unit for TFT-LCD, there would be few problems. For examples, because of the low transmittance of the LCM, we had to raise the brightness of the CNT-FED. It meant that we would raise the anode voltage to accelerate the electrons to hit the phosphors and there would be more and more heat occurred in the phosphor layer. The heat from the phosphor layer was hard to be released because the anode plate was directly contacted with the TFT-LCD in the conventional CNT-BLU. The high temperature of the anode plate would affect the LC or polarizer films of TFT-LCD or lead to the damage of CNT-BLU itself. Besides, the light leakage from the anode to cathode plate reduced the light emitting efficiency. For those reasons, we invented the new structure to solve those problems.

Unlike the conventional structure in Fig. 1, the novel structure had a metal layer (Ag) substituting for the ITO layer. This silver layer was an excellent reflector and conductor. The light emitting from the phosphor toward the anode would redirect toward the cathode plate. Consequently, the total light emitting efficiency was increased. The measured brightness is about 1.7 times higher than the brightness of the conventional CNT-BLU. In addition, the heat from the anode was able to be released by the heat sink and the cathode plate would keep the room temperature.

Although the phosphor layer excited by the accelerated electrons would emit light to both anode and cathode sides, the light toward anode side was much less that toward cathode side due to the light multi bounce, scattering, or absorption in the phosphor layer. That resulted in the huge brightness difference between anode and cathode side. Additionally, the reflective silver layer contributes almost 30% increment to the brightness in our measurement. Actually, the new structure CNT-BLU was about 1.7 times brightness of the conventional one.

Based on this new structure, the brightness of our 4 inch CNT-BLU was 10000 nits and 20 inch was 8000 nits while the efficiency was 16.06 lm/w. Fig. 6 was the lightening of 20 inch CNT-BLU and there were no optical films on it because it was the planar light source.

Fig. 6 The lightening of 20 inch CNT-BLU

Fig. 7 showed the transmission factors of components from the backlight unit to the surface of LCD and the comparison of total transmission percentage between the CCFL and CNT-BLU through the LCD structure. According to the Fig. 7, the brightness of our CNT-BLU achieved the specification of the LCD-TV.

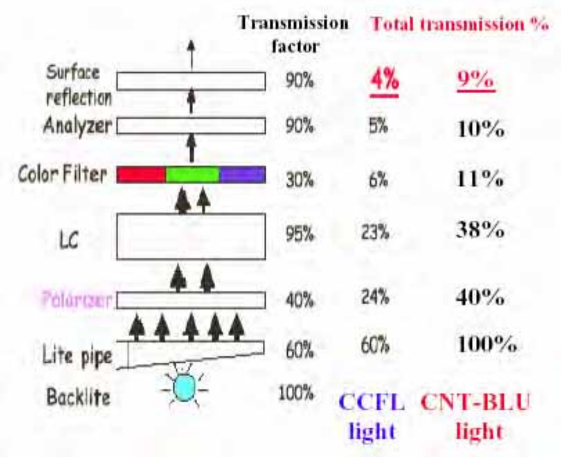

Fig. 7 Total transmission percentage of CCFL and CNT-BLU through LCD

5. Power Consumption

The traditional driving method of the CNT-BLU was to apply DC voltage to the gate electrode and the anode and cathode electrodes connected to a fixed high and ground voltages respectively. This characteristic of the DC driving method was that the electrons would continuously hit and excite the phosphor of the CNT-BLU. The result would lead to a shorter lifetime, more wasteful power consumption, and low illuminating efficiency. The pulse mode driving method had been proposed to make use of the phosphor's persistence property [11]. High driving frequency of 25k Hz had to be provided in gate electrode to gain 50-84% more efficiency. If we wanted to use the asymmetric property between the exciting and resting periods of the phosphor in order to fully utilize the persistence property of the phosphor, the required frequency would become excessive high because the duty of the pulse was fixed. The higher the driving frequency, the larger the power would be consumed by the driving system. Another problem of the fixed duty pulse driving method was that the brightness of the CNT-BLU could only be changed by adjusting pulse amplitude. The pulse amplitude of several hundreds volts, however, could not easily be controlled by the popular digital controllers. To overcome the problems of the traditional driving methods, we adopted the low-side frequency pulse (LFP) driving method. The scheme of the 20 inch CNT-BLU was shown in Fig. 8.

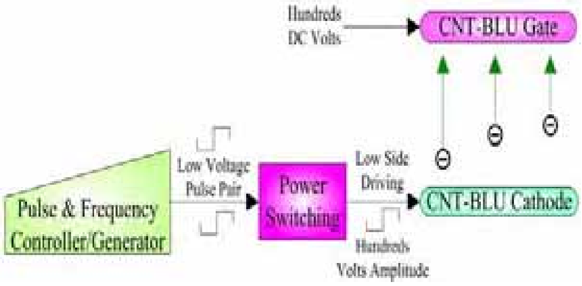

Fig. 8 The low-side frequency pulse driving method of 20 inch CNT-BLU

The pulse and frequency control signals were generated in pair with reversed phase. The paired low voltage pulse signals were sent to a power switching circuit to produce a high voltage pulse driving signal. Unlike the traditional driving methods, the high voltage pulse was applied to the cathode electrode of the CNT-BLU, where the gate electrode was connected to a DC voltage higher or equal to the amplitude of the driving pulse. The block diagram of the power switching, pulse controller, frequency controller and generator was shown in Fig. 9. The control signals could be generated by a CPLD and a commercial function generator plus a pair of inverters could also produce the required control signals. The duty and frequency of the resulting driving pulse could be controlled in the CPLD or function generator. The output stage in Fig. 9 was a push-pull n-channel power MOSFET pair. The push-pull circuit was adopted for the power saving. The n-channel type was chosen to achieve a high speed switching for high voltages. The power MOSFET was selected in order to generate high voltage pulse with amplitude of several hundreds volts.

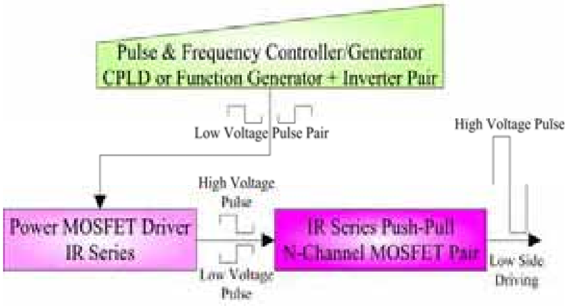

Fig. 9 The block diagram of power switching and pulse & frequency controller/generator

For the higher switching speed for several hundreds volts, a power MOSFET driver was arranged before the push-pull circuit in Fig. 9. The purpose of the power MOSFET driver was to supply a large current in a short duration to the gate of the power MOSFET for charging the gate capacitance and higher switching frequency. Summery in Fig. 8 and Fig. 9, the low-side driving scheme was designed for two purposes. The first purpose was to provide a DC bias pre-charge between the gate and cathode electrodes easily. The DC bias was set by the difference between the gate voltage and the cathode driving pulse amplitude. For reducing the required driving pulse amplitude as large as possible, the DC bias could be set to the level for the field emission current about to occur. The second purpose was to absorb the ripple effect in driving voltages. The high level in the driving pulse was used to turn off the field emission current. If the margin set by the DC bias was enough, the normal ripple in the high level did not affect the turn off function.

6. Reliability

As we knew, besides the optics and electrical performances, the reliability was also the important requirement of the CNT-BLU to be the backlight technology in the future. The reliability could be evaluated by lifetime and mechanical shock resistance. To achieve the requirement of reliability, the materials and mechanical structure of the CNT-BLU had to be arranged for the aging process and simulation firstly.

In our aging process, we had developed the constant current scanning method on cathode electrode. During the scanning aging process, the constant current was 0.2 mA and the cathode was connected to the ground. The anode voltage was set to 1KV and gate voltage was adjusted by programming controller. After the constant current scanning aging process, we used the DC driving to accelerate the decay of material and measured the lifetime. Fig. 10 was the emission current measurement under DC driving. Based on the lifetime definition of T_{50}, we got the time that was more than 650 hr and then we could get the lifetime of the CNT-BLU was more than 13000 hr under 5% duty driving.

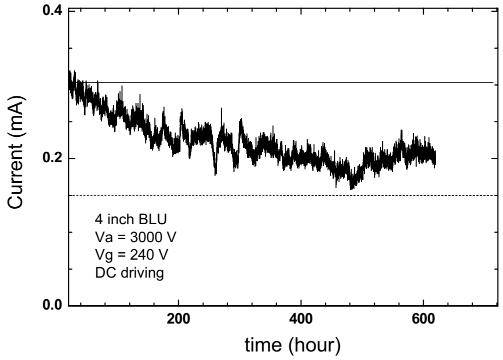

Fig. 10 The decay of emission current under DC driving

In Fig. 1, the mechanical structure of the CNT-BLU was like the vacuum vessel and assembled by glass plates, glass side frames and spacers. Owing to the printing process and package process, the high temperature sintering process would produce some residual stress in the glass components and the residual stress might cause a crack under the air pressure difference when the CNT-BLU met the outside vibration or thermal shock in module operation. To avoid this problem, we used the FEMLAB 3 and ANSYS workbench 10 to establish the physical model and calculate the stress of the structure. Based on the simulation, the geometry and material of the components could be designed into the CNT-BLU. Fig. 11 was the von Mises stress simulation of the CNT-BLU after package and vacuum process. In Fig. 11, most part of the CNT-BLU was less than 9.7MPa and 29MPa was the maximum stress on the spacers and was less than the fracture strength of the glass components.

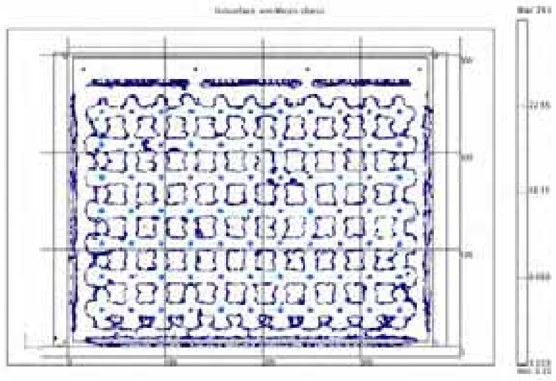

Fig. 11 The calculation of von Mises stress in the 20 inch CNT-BLU

Fig. 12 The prototype of 20 inch TFT-LCD with CNT-BLU

7. Conclusion

According to the previous discussion, a 20 inch CNT-BLU was proposed. Based on our novel structure, AC mode circuit design and simple printing process, CNT-BLU could achieve 74.1% of uniformity, 8000 nits of brightness, more than 13000 hr of lifetime and low power consumption. Because of the low material and fabrication cost, the CNT-BLU could have the potential to replace the CCFL of the TFT-LCD in the future.

8. Acknowledgements

This work was supported by Display Technology Center (DTC) of Industrial Technology Research Institute (ITRI) and MOEA project 5361A51210 from Ministry of Economic Affairs, R.O.C.. We would like to express our appreciation to Dr. Chao-Chiun Jiang, Mr. Chiao-Nan Huang and the W division of DTC for valuable discussions and technical support.

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