A Study on Phosphor Activation and Persistence for High Performance Driving 20” Carbon Nanotube Backlight Units

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Abstract

For high performance driving carbon nanotube backlight units, their phosphor must be well studied. This paper experimentally evaluates their activating speed and persisting duration properties. They are proven to be the most efficiency related factors. High performance driving schemes are derived from them and implemented in this paper.

1. Introduction

For increasing the illuminating efficiency of carbon nanotube backlight units (CNT-BLUs), this paper studies the activation and persistence properties of their phosphor. High performance driving schemes can then be derived from them.

Carbon Nanotubes (CNTs) [1] have tiny diameters and high aspect ratios [2, 3]. These geometric properties induce one attractive display related property of excellent field emission characteristics; high current density of $10mA/cm^2$ and low threshold electric field of 0.8V/um can be obtained [4]. Based on the superior field emission characteristics, CNTs are successfully applied in FED and backlight units (BLUs) [5, 6, 7, 8, 9, 10]. For Triode type CNT-BLUs [5, 6] or CNT-lamps [11], the traditional driving method is to apply DC voltage to their gate electrodes, with their anode and cathode electrodes connected to a fixed high voltage and ground voltage respectively. This DC method continuously excites the phosphor in CNT-BLU. The results are shortened lifetime and more wasteful power consumption. A pulse mode driving method has been proposed to make use of the phosphor’s persistence property [12]. High driving frequency of 25k Hz must be provided to gain 50-84% more efficiency. The power consumption of the driving system and the gate/cathode electrodes pair, however, will become larger and larger when driving frequency gets higher. The benefits gained in the anode electrode may not balance the loss in elsewhere. Frequency modulation is combined with pulse method in [7] to drive CNT-BLUs. Lower driving frequency for high efficiency can be obtained. A bank-wised driving scheme was proposed in [8] to further increase the illuminating efficiency of the pulse-driven CNT-BLU. Illuminating uniformity can also be improved by this scheme.

All the above-mentioned driving schemes are experimentally and intuitively developed, the physical insight and optimization approach are not clear. The solution developed in this paper is to study the lighting and dimming characteristics of phosphor, the most critical component in CNT-BLUs.

2. Experimental Setup and Procedures

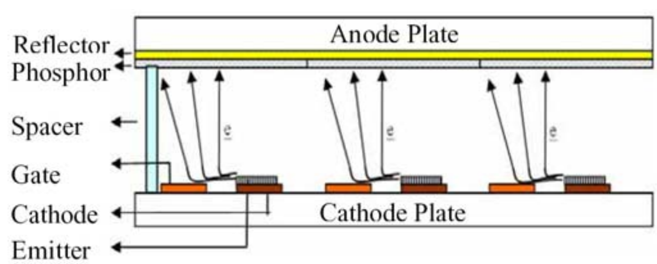

Figure 1. The structure of the driven CNT-BLU

The structure of the 20” CNT-BLU developed by DTC/ITRI is shown in Fig. 1. In Figure 1, the gate and cathode electrodes are fabricated on the same cathode plate, where CNTs are screen printed on the cathode electrodes. The anode electrode is coated on the anode plate, and then the phosphor layer is printed on the anode electrode. The field emission electrons induced by the electrical field between the gate and cathode electrodes will be accelerated by the strong electrical field between the anode and gate electrodes. The accelerated electrons will hit the phosphor layer and the light will then emitted toward the anode and cathode plates. The light toward the anode plate will be reflected by the anode electrode served as the reflector layer. This reflective structure of the 20” CNT-BLU causes its illuminating efficiency 1.7 times that of the conventional structure [6].

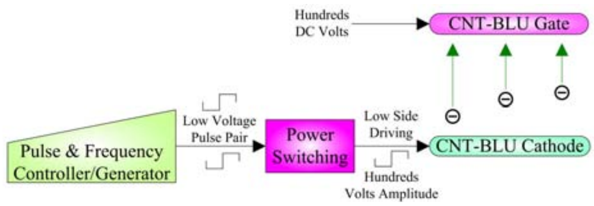

Figure 2. The LFP driving scheme proposed in [7]

The block diagram of one of the driving methods for studying the phosphor is the LFP driving scheme proposed in [7] and is shown in Figure 2. The pulse and frequency control signals are generated in pair with reversed phase. The paired low voltage pulse signals are sent to a power switching circuit to produce a high voltage pulse driving signal. Unlike the traditional driving methods, the high voltage pulse is applied to the cathode electrode of the CNT-BLU, where the gate electrode is connected to a DC voltage higher or equal to the amplitude of the driving pulse. The required amplitude and hence power consumption of the driving pulse can be reduced by this driving scheme. One problem of the LFP driving scheme is the great capacitance of the large size CNT-BLU it has to drive. This will prolong the RC delay and then decrease the achievable driving frequency. Another problem is its one-area driving characteristics prohibits the possibility of dynamic image improvements.

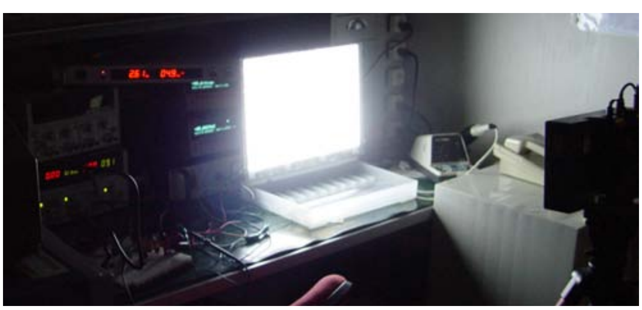

Figure 3. The experiment setup for measuring illuminating efficiency of DTC’s 20” CNT-BLU

To increase the illuminating efficiency in a systematic approach, it is essential to have physical insight into the lighting mechanism of CNT-BLUs. The most critical illuminating related component of CNT-BLUs is phosphor. This paper studies the illuminating characteristics of phosphor by real-time measuring the curves of brightness versus time in phosphor’s lighting and dimming phases. By PR-650 or similar instruments, the measured brightness is real-time converted into voltage signals and then send to an oscilloscope to obtain the corresponding curve of brightness versus time. The experimental setup is shown in Figure 3. The measuring instruments can be area-wised or point-wised with different suitable distances to the CNT-BLU. The anode voltage is set to 2.4kV, the gate voltage is set to DC 500V, and the cathode driving voltage pulse has the amplitude of 400V.

3. Results and Discussions

To observe the frequency response of the CNT-BLU’s phosphor in lighting and dimming phases, the curves of brightness versus time are measured in several frequencies. Figure 4 and Figure 5 are the driving voltage, the induced field emission current, and the measured brightness of the DTC’s 20” CNT-BLU experimentally driven in 125Hz, 233Hz, 465Hz, and 2 kHz. The driving pulse has the duty cycle of 50%.

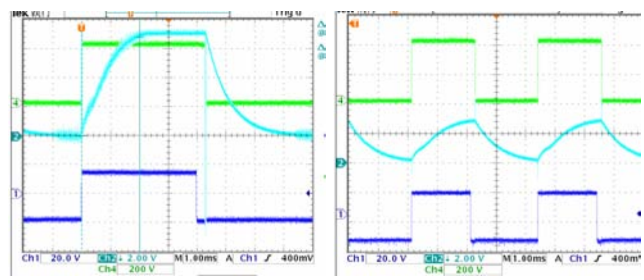

Figure 4. The driving voltage (top curve), the induced field emission current (bottom curve), and the measured brightness (middle curve) of the driven CNT-BLU in 125Hz (left) and 233Hz (right)

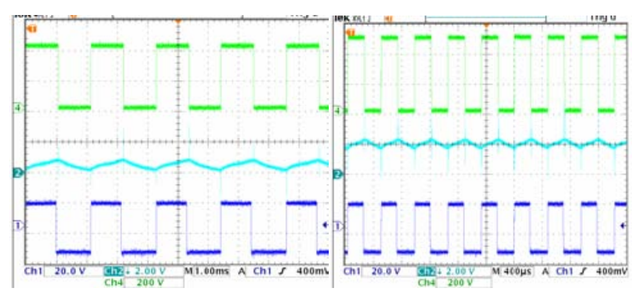

Figure 5. The driving voltage (top curve), the induced field emission current (bottom curve), and the measured brightness (middle curve) of the driven CNT-BLU in 465Hz (left) and 2 kHz (right)

It can be observed from the left part of Figure 4 that less than 1ms is required for activating the phosphor from 10% to 90% brightness and more than 1ms is necessary for the phosphor to decay from 90% to 10%

brightness. Therefore, the illuminating efficiency is improved under this condition. If the driving frequency is increased, as shown in the right part of Figure 4, the time left for phosphor activation is not sufficient to achieve the same highest brightness as in lower driving frequency. This phenomenon can also be observed in Figure 5, where the driving frequencies are higher, the time left for phosphor activation is shorter, and the exhibited brightness is dimmer. Furthermore, examining Figure 5 in more detailed, it can be observed that the required phosphor activation time is not sufficiently less than the necessary phosphor decay time. This limits the amount that can be improved in the illuminating efficiency. The above-mentioned phenomena can be verified by brightness, power consumption, and illuminating efficiency measuring experiments as shown in Figure 6. In Figure 6, brightness and power consumption decrease as the driving frequency increases. The consequence is that the measured illuminating efficiencies remain almost the same.

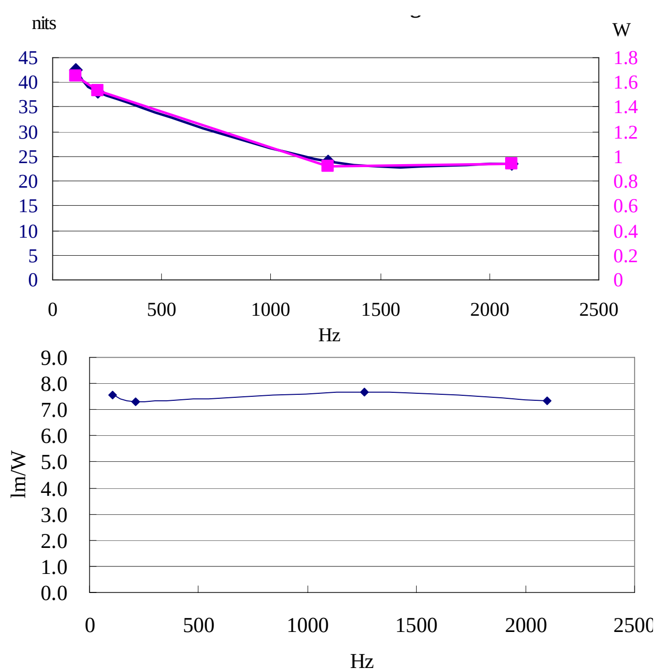

Figure 6. Driving the CNT-BLU in different frequencies, the measured brightness and power-consumption are shown in top figure, and the measured illuminating efficiencies are shown in the bottom figure.

After analyzing the phosphor activation and persistence, one scheme to improve the illuminating efficiency can be deduced. This paper decreases the driving duty cycle and observes the phosphor's frequency responses in lighting and dimming phases, as shown in Figure 7. Examining Figure 7, it can be observed that the time required for activating the phosphor from 10% to 90% brightness is significantly smaller than the time necessary for the phosphor from to decay from 90% to 10% brightness. Therefore, the illuminating efficiency gained in persistence phase is considerably greater than that lost in activation phase. The consequence is increased exhibited illuminating efficiency.

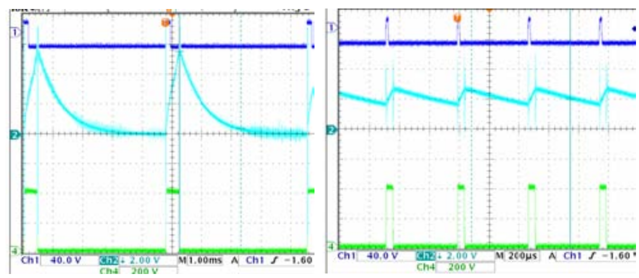

Figure 7. The driving voltage (top curve), the induced field emission current (bottom curve), and the measured brightness (middle curve) of the driven CNT-BLU in 210Hz (left) and 2.1 kHz (right), where the duty cycle is 10%.

Examining Figure 4, 5, and 7, there are two other ways to improve the illuminating efficiency. One way is to decrease the required phosphor activation time. This can be achieved by choosing a quick response phosphor or designing a CNT-BLU to uniformly activating the phosphor. The other way is to increase the required phosphor persistence time. This can be accomplished by choosing long persistence phosphor.

4. Summary

The physical insight to pulse driving CNT-BLUs is first revealed in this paper by studying the phosphor activation and persistence. Optimal driving frequency and duty cycle can be found accordingly. Previously published works can only determined the driving frequency experimentally and intuitively.

For increasing the illuminating efficiency, this paper systematically reasons several ways: decreasing driving duty cycle, choosing quick response phosphor, uniformly activating the phosphor, and choosing long persistence phosphor.

5. Acknowledgements

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