A High Efficiency and Low Power Dynamical Driving Scheme for Carbon Nanotube Backlight Units

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Abstract

Dynamic Driving Carbon Nanotube Backlight Units (CNT-BLUs) can well utilize the persistence of their phosphor. This paper studies several dynamic driving schemes for the CNT-BLU developed by DTC/ITRI. Their illuminating efficiencies are experimentally evaluated. From these evaluations, this paper develops a new driving approach and even better efficiencies are obtained.

1. Introduction

Since Carbon Nanotubes (CNTs) were discovered [1], plenty of researches have been invested on their fabrication, properties, manipulations, and applications. CNTs 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]. Comparing with CCFL and LED backlight units, CNT-BLUs have the advantages of low cost, less power consumption, optical films needless, no toxic chemicals, and superior color performance [7].

For Triode type CNT-BLUs [6, 7] or CNT-lamps [5], the traditional driving method is to apply DC voltage to the gate electrode, with the anode and cathode electrodes connected to a fixed high and ground voltages respectively. This DC driving method continuously excites the phosphor in CNT-BLUs. The results are shortened lifetime, more wasteful power consumption, and low illuminating efficiency. Pulse mode driving method has been proposed to make use of the phosphor's persistence property [8]. 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 pair, however, will become larger and larger when driving frequency gets higher. The benefits gained in the anode may not balance the loss in elsewhere.

Aiming at energy saving green FPD having compact size without heat sinks, the objective of this paper is to develop a high illuminating efficiency and long lifetime driving scheme for CNT-BLUs. This paper proposes a low-side frequency pulse (LFP) driving scheme to achieve the aforementioned objectives. The proposed scheme combines frequency modulation and pulse tuning to respectively prolong operating lifetime and increase illuminating efficiency of the CNT-BLUs. Furthermore, low side driving approach is integrated into the proposed driving scheme to reduce the power consumption of the driving system. The proposed LFP driving scheme is experimentally evaluated on the 20" CNT-BLU developed by DTC/ITRI. The 20" CNT-BLU, traditional driving methods, and the LFP driving scheme are described in Section 2. In Section 3, the experiment results and discussions are presented. Finally, several conclusions are drawn in Section 4.

2. The 20" CNT-BLU and Traditional Driving Methods

2.1 The 20" CNT-BLU [7]

The structure of the 20" CNT-BLU developed by DTC/ITRI is shown in Fig. 1. In Fig. 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.

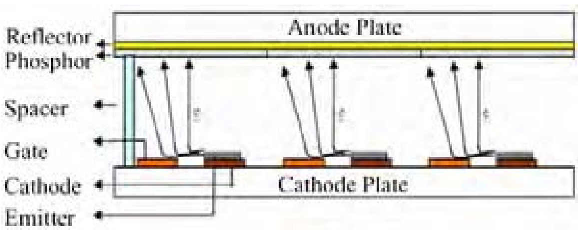

Fig. 1. The structure of the 20" CNT-BLU

2.2 Traditional Driving Methods

Traditional driving methods for CNT-BLUs are shown in Fig. 2. The traditional DC driving method is shown in the left side of Fig. 2 [5, 6, 7]. Depending on the gap between the gate and cathode electrodes, a DC voltage of several hundreds volts may be required to apply to the gate electrode in order to induce field emission electrons. The shorter the gap, the smaller the DC voltage is required to apply between the gate and cathode electrodes. The controllability of the gate voltage to the field emission current will become larger when the gap gets shorter. This DC driving method does not make use of the persistence property of the phosphor at all. The lifetime of the phosphor and the CNT will become shorter. The temperature of the phosphor layer and hence the anode plate will get hotter. The continuously applied DC voltage can not save any field emission current. The illuminating efficiency hence can not increase at all.

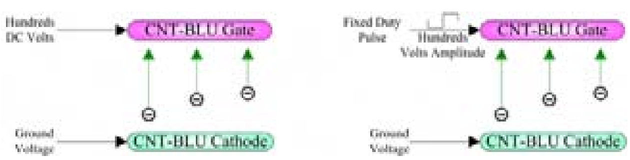

Fig. 2. Traditional driving methods for CNT-BLUs: DC driving method (left) and fixed pulse driving method (right).

To make use of the persistence property of the phosphor in order to increase the illuminating efficiency, the pulse driving method is proposed in [8] and is shown in the right side of Fig. 2. The duty of the pulse is fixed. This pulse driving method, therefore, does not exploit the asymmetric property between the exciting and resting periods of the phosphor. The result is the required frequency will become excessive high in order to fully utilize the persistence property of the phosphor. The higher the driving frequency, the larger the power will be consumed by the driving system. The cost of longer phosphor/CNTs lifetime and higher illuminating efficiency, therefore, is the larger power consumption of the driving system. By this fixed duty pulse driving method, the brightness of the CNT-BLU can only be changed by adjusting pulse amplitude. The pulse amplitude of several hundreds volts, however, can not easily be controlled by the popular digital controllers such as micro processors or CPLDs.

2.3 A New LFP Driving Scheme

To overcome the problems of the traditional driving methods, this paper proposes a new low-side frequency pulse (LFP) driving scheme for the 20" CNT-BLU. The proposed LFP driving scheme is shown in Fig. 3.

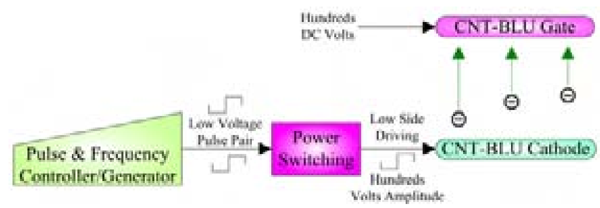

Fig. 3. The proposed LFP driving scheme

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 block diagram of the power switching and pulse & frequency controller/generator is shown in Fig. 4.

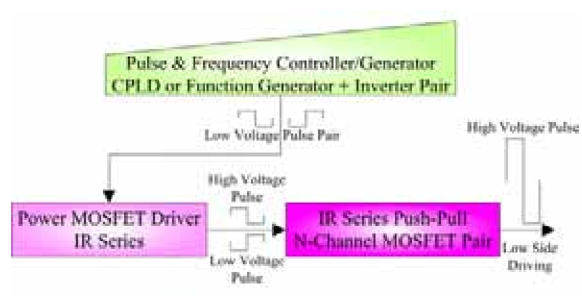

Fig. 4. The block diagram of power switching and pulse & frequency controller/generator

The control signals can be generated by a CPLD. A commercial function generator plus a pair of inverters can also produce the required control signals. The duty and frequency of the resulting driving pulse can be controlled in the CPLD or function generator. The output stage in Fig. 4 is a push-pull n-channel power MOSFET pair. The push-pull circuit is adopted for the sake of power saving. The n-channel type is chosen to achieve a high speed switching for high voltages. The power MOSFET is selected in order to generate high voltage pulse with amplitude of several hundreds volts. In this paper, the selected n-channel power MOSFET is fabricated by International Rectifier [9].

For an even higher switching speed for several hundreds volts, a power MOSFET driver is arranged before the push-pull circuit in Fig. 4. The purpose of the power MOSFET driver is to supply a large current in a short duration to the gate of the power MOSFET for charging the gate capacitance and then achieving an even higher switching frequency. In this paper, the chosen power MOSFET driver is fabricated by International Rectifier [10].

In Fig. 3 and Fig. 4, low-side driving scheme is designed for two purposes. The first purpose is to easily provide a DC bias pre-charge between the gate and cathode electrodes. The DC bias is 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 can be set to the level for the field emission current about to occur. The second purpose is to absorb the ripple effect in driving voltages. The high level in the driving pulse is used to turn off the field emission current. If the margin set by the DC bias is enough, the normal ripple in the high level does not affect the turn off function.

3. Experiments, Results, and Discussions

For evaluating the performance of the proposed driving scheme, experiments for measuring illuminating efficiency of the 20" CNT-BLU, under various frequencies and duties, are conducted in this paper. The experiment setup is shown on Fig. 5.

In Fig. 5, a DC voltage of 500 volts is supplied to the gate electrode; the driving pulse with the amplitude of 400 volts is applied to the cathode electrode; the average brightness is measured by the photometer equipment in front and normal direction of the CNT-BLU. The illuminating efficiency can then be calculated by the average brightness, the CNT-BLU area, the supplied voltage, and the measured current.

Fig. 5. The experiment setup for measuring illuminating efficiency of the DTC's 20" CNT-BLU

For various driving frequencies ranging from 100 Hz to several kHz until the saturation in the illuminating efficiency occurs, the CNT-BLU illumination efficiencies are measured under driving duties from 20% to 80%. The evaluation results are shown in Fig. 6. Maximum efficiencies of about 10.9 are observed under a 20% duty at frequencies about 2k Hz and 4k Hz. The lower driving frequency can much reduce the power consumption and electromagnetic interference. Comparing with the most DC-like conditions of 80% duty and 100 Hz in Fig. 6, the efficiency is improved by 13.5%.

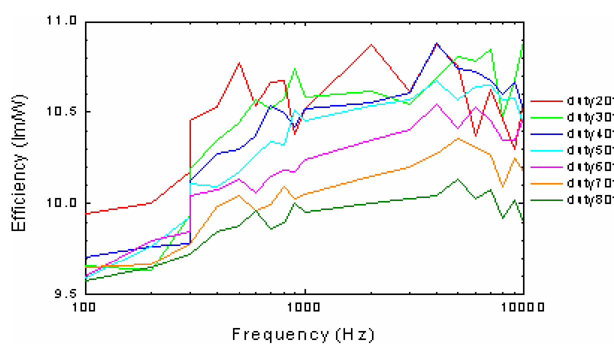

Fig. 6. Illumination efficiencies measured under various frequencies and duties

For the phosphor and CNTs, the traditional 50% pulse duty has the period of resting (persistence) the same as that of exciting. In comparison, the duty of 20% has the persistence period 4 times the exciting period. The lifetimes of the phosphor and CNTs under 20% duty driving can then prolong 2.5 times. Comparing to DC driving method, according to a similar reasoning, the lifetime of the phosphor and CNTs under 20% duty driving can prolong 5 times.

When varying the driving pulse duty, the brightness of the 20” CNT-BLU alters apparently. The longer the exciting duty, the brighter the CNT-BLU illuminates. The relationship between the driving duty and the brightness is almost linear. The LPF driving scheme developed in this paper provide a convenient way to control the brightness of CNT-BLUs.

4. Conclusions

This paper combines frequency modulation and pulse tuning to drive the 20” CNT-BLUs. The frequency modulation well utilize the persistence of the phosphor and has better efficiency than those in [5, 6, 7]. The pulse tuning can shorten the exciting period of the phosphor and has longer lifetime than that in [8]. The driving frequency is more reasonable and affordable than that in [8], the power consumption in the driving system and gate/cathode pair can then be reduced quite substantially. According to the experimentally measured linear relationship between the driving pulse duty and the brightness of the CNT-BLUs, the proposed LFP driving scheme can control the brightness in an easily way. For the sake of the low-side driving feature possessed by the proposed LFP driving scheme, the driving power can be saved substantially and the ripple in the driving signal of several hundred volts can be absorbed without affecting the field emission current.

5. Acknowledgements

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6. References

[1] S. Iijima, “Helical microtubules of graphitic carbon,” Nature 354, pp. 56–58, 1991.

[2] C.H. Tsai1, S.P. Chen, G.W. Hsieh, C.C. Liang, W.C. Lin, S.J. Tseng, and C.H. Tsai, “Selective carbon nanotube growth on silicon tips with the soft electrostatic force bonding and catalyst transfer concepts,” Nanotechnology, Vol. 16, No. 5, pp. S296-S299, 2005.

[3] W.C. Lin, Y.J. Yang, G.W. Hsieh, C.H. Tsai, C.C. Chen, and C.C. Liang, “Selective local synthesis of nanowires on a microreactor chip,” Sensors And Actuators A: Physical, SNA 5283 1–8, 2006. (to be published)

[4] A.G. Rinzler, J.H. Hafner, P. Nikolaev, L. Lou, S.G. Kim, D. Tomanek, P. Nordlander, D.T. Colbert, and R.El Smalley, “Unraveling nanotubes: field emission from an atomic wire,” Science, Vol. 269, No. 5230, pp. 1550-1553, 1995.

[5] Hyeon-Jae Lee, Yang-Doo Lee, Woo-Sung Cho, Seung-II Moon, and Jai-Kyeong Kim, “Field Emission Properties of 4.5 inch Triode Type Flat Lamp using the Screen Printing Method,” SID 05 Digest, pp. 422-425, 2005.

[6] Cheng-Chung Lee, Biing-Nan Lin, Ming-Chun Hsiao, Yu-Yang Chang, Wei-Yi Lin, and Liang-Yua Jiang, “Development of CNT-FED by Printing Method,” SID 05 Digest, pp. 1716-1719, 2005.

[7] T.H. Tsou, M.H. Lin, B.N. Lin, W.Y. Lin, Y.C. Jiang, C.H. Fu, L.Y. Chiang, Y.Y., Chang, M.C. Hsiao, and C.C. Lee, “Reflective Structure for Carbon Nano-Tube Backlight Unit,” IDW/AD’05, pp. 1695-1696, 2005.

[8] M. Nakamoto, H. Kominami, Y. Nakanishi , Y. Takigawa, Y. Ohgi, H. Hiraki, and M. Haba, “White Color Flat Field Emission Lamps for High Quality General Lighting,” IDW/AD’05, pp. 1997-1998, 2005.

[9] http://www.irf.com/product-info/hexfet/

[10] http://www.irf.com/product-info/cic/fsgatedriverics.html