# A dense local block CNT-FEL BLU with common gate structure

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## Abstract

*We have developed 15 inch, 130 blocks local dimming FEL using printed CNT emitters, in which multiple FE blocks were built with a common gate electrode. Cathode electrode formed by the double-metal technique, in which an insulator is interposed between the addressing bus and cathode electrode.*

## 1. Introduction

In recent, a CNT-based field emission lamp (FEL) has attracted much attention rather than FED [1-5]. The technical huddles in CNT-FED can lessen in the FEL technology meanwhile another performance factors such as luminance, efficiency, and lifetime are crucial for the FEL application. The CNT-FEL for back light unit (BLU) in liquid crystal display (LCD) has been developing to improve the image quality of LCD. The conventional BLU, at present, adopts a cold cathode fluorescent lamp (CCFL) or an external electrode fluorescent lamp (EEFL) based on gas-discharge principle and provides a constant light source to the LCD panel, resulting in a low contrast ratio, a motion blur and a high consumption power with an intrinsic liquid crystal property. There is always a small amount of transmitted light even when an LCD presents a black image. Since the CCFL-BLU illuminates the whole display area including the black image area, it is not possible to represent the black image with a very low grayscale. Another critical limit of the conventional LCD with a CCFL-BLU is the motion blur phenomenon. It is caused by its sample-and-hold nature, i.e. the liquid crystal remains in the same state after addressing during a whole frame. When displayed objects move as is the case of TV images, it causes a blurred image of the objects on the retina of a viewer [6]. The local dimming BLU controls the luminance locally according to LCD images, enhancing the contrast ratio and also another function of an impulsive scanning of BLU can overcome the motion blur, showing a cathode ray tube (CRT)-like image with the LCD panel.

## 2. Experimental

We have developed a 130-blocks local dimming CNT-FEL for LCD BLU using printed CNT emitters, in which multiple FE blocks were built with a common gate electrode. All FE blocks were electrically separated another while the gate electrode was common over the FEL. Each FE block can be randomly addressed through the cathode electrode with a constant DC voltage to the common gate for field emission from CNT emitters. The luminance of each FE block can be actively modulated by a current controlling method.

Perspective view of the dynamic 15” dynamic CNT FEL with common gate structure is shown in Fig.1. The common gate structure has only one gate sheet like a metal mesh with many openings for gate holes, in which the dimming signals are addressed through only the cathode electrodes connected to each local block separately. The gate insulator in the common gate structure supports the spacing between the cathode electrodes and the common gate sheet and so may be formed in a discrete insulation spacer made of glass. The CNT emitters and the metal-plate gate were prepared separately, and then they were joined together during a vacuum packaging process. The gate holes were formed on a metal plate such as a nickel-cobalt ferrous alloy called Kovar. It is noted that the matching of thermal expansion coefficient between the cathode glass and the metal is very crucial. Since the metal-plate gate cannot carry the dimming signals in contrast with normal gate structure, a current driving method is needed. The anode is composed of cathodoluminescent (CL) phosphors with a back metal of aluminum (Al). The CL phosphors Y2O3:Eu for Red, ZnS:Cu,Al for Green and ZnS:Ag,Al for blue were mixed in appropriate proportion to produce white color.

Since the cathode electrode block must be connected to external terminal electrode, the number of local blocks has limitation, if the cathode electrode be formed in a single plane. However, this limitation can be solved by a double-metal technique with contact holes, as shown in Fig. 2. Figure 2 shows an array architecture of random-access addressed local blocks by the double-metal technique, in which an insulator is interposed between the addressing bus and cathode electrode and the through hole is formed on the insulator for electrical contact between the two layers. The double-metal structure for a dense local block is easily achieved by a screen-printing process, providing a large-area CNT-FEL with a low cost.

## 3. Results and discussion

The luminance and average luminescence efficiency as a function of anode voltage for a fixed anode current density is shown in Fig. 3. In the evaluation of efficiency, we assume that the CNT-FEL has a Lambertian distribution as a surface emitting light source and L is measured at a vertical position to the panel plane. As a result, the average efficiency is given by $\eta = \pi L/(V_a J_a)$ [7], in which the driving consumption power for local addressing is not considered because it is negligible compared with the anode power. The driving consumption power, for example, was calculated to be about 17.3 mW for the 15 inch diagonal CNT-FEL at a driving frequency of 60 Hz, a cathode-to-gate capacitance of 2.3 nF for the gap of 100 um between the cathode and the metal gate, and a cathode-to-gate modulation voltage of about 500 V induced by addressing of dimming signals.

The luminescence efficiency followed a sub-linear dependence on the anode voltage and might be nearly saturated on higher anode voltage than 14 kV. The luminance increased as the anode voltage with a power law dependence, $L=C_v V_a m$, where $C_v$ is a constant and m is a power factor of about 2.1, as shown in Fig. 3(b). The power relation between the luminance and the anode voltage might vary with the anode current. The peak luminance was observed to be over 12,000 cd/m$^2$ and the average efficiency was estimated to be around 35 lm/W. The luminescence efficiency of CNT-FEL was fairly lower compared with that of CCFL, resulting from a low efficiency of CL phosphors and a non-optimized phosphor layer for FEL.

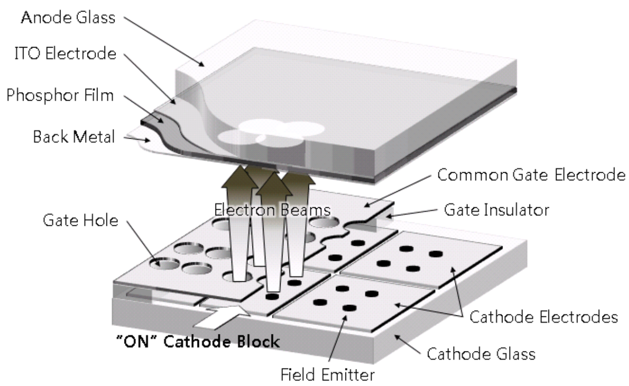



**Fig. 1. Perspective view of the dynamic 15" dynamic CNT FEL with common gate structure.**

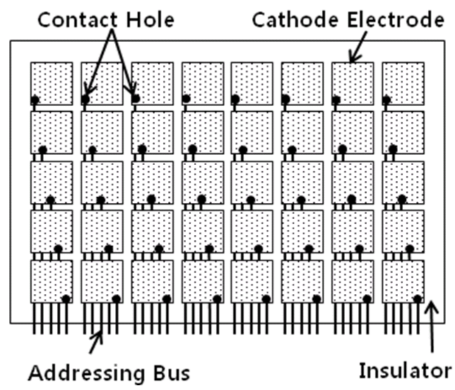
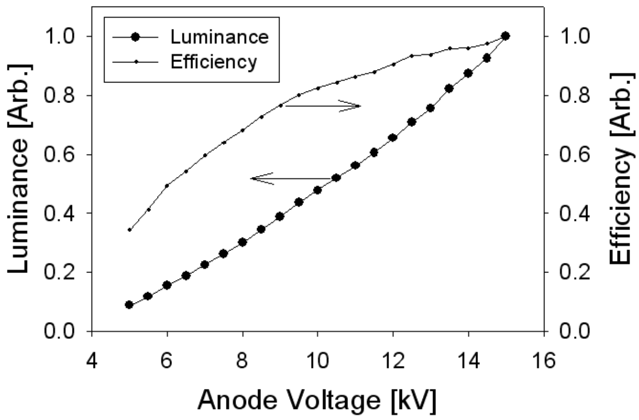
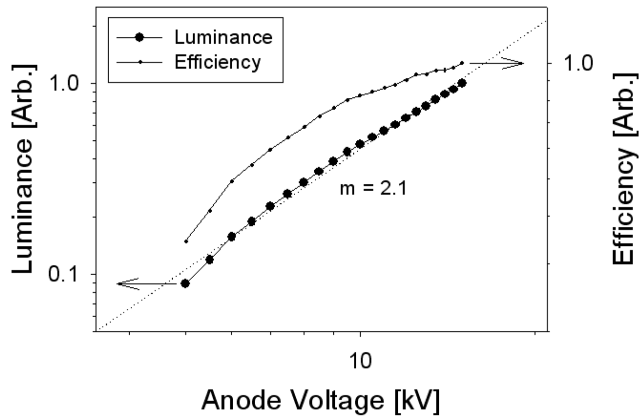



**Fig. 2. Array architecture of random-access addressed local blocks with a common gate by a double-metal technique.**




(a)




(b)

**Fig. 3. (a) Linear and (b) log-log plots of luminance (L) and efficiency (η) versus anode voltage ($V_a$) for a fixed anode current density. The dotted line shows the power relation of $L=C_aV_am$, where $C_a$ is a constant and m is a power factor of about 2.1.**

The local dimming/brightening CNT-BLU could improve the image quality of LCD such as contrast ratio, motion blur, and consumption power. Our current controlled dynamic CNT-FEL with common gate structure can be a good candidate for commercial CNT-BLU. This structure can be easily fabricated by using a metal mesh and a screen printing process. Also, it has an additional advantage of high immunity to a high acceleration voltage compared with the normal-gated CNT emitters. Specially, the duty time to each local block can be enlarged to nearly the refresh time of the image, 1/f, enhancing or maintaining the total luminance of CNT-FEL irrespective of the number of local blocks. Secondly, the active controlling of field emission current can improve the uniformity, stability, and reliability of CNT-FEL. The addressing transistor with a wide saturation regime in the output curve (drain current versus drain voltage) provides more uniform, stable and reliable emission current than a linear resistive layer commonly adopted as a ballast in an FED application [8, 9]. Specifically, the degradation of CNT emitters can be compensated by the wide saturation behavior of emission current as the gate bias voltage.

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