A gas display device with electron emitter

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Abstract

A display device combining plasma display panel (PDP) and field emission display (FED) is proposed to achieve high luminous efficiency. The device can avoid the main energy loss channels of both PDP (ion loss) and FED (low CL efficiency). 2~6"-diagonal test panels with carbon nano-tube (CNT) electron emitter and Xenon ambient gas showed the luminous efficiency of 4.14lm/W and brightness of 263cd/m^2 at 35V (1kHz, 1% duty), indicating that it is a good candidate for the low voltage driven, highly efficient next generation display.

1. Introduction

A display device combining plasma display panel (PDP) and field emission display (FED) is proposed to achieve high luminous efficiency.

In a PDP, ultraviolet (UV) radiation emitted from excited atoms and molecules excites the photo-luminescence (PL) phosphor to produce visible light. One of the major problems of PDP is the low UV creation efficiency. Simulation studies [1,2] predict that only 15~20% of the input electric energy is used for Xenon excitation. That means, more than 80% of the input energy is lost at the UV creation stage through ion loss, the energy used in ionization and ion heating, which is the main loss channel of PDP.

In an FED, electrons emitted by electron emitters are accelerated to anode and excite the cathode-luminescence (CL) phosphors to produce visible light. Naturally, FED can avoid the ion loss, but the efficiency of CL phosphor is much lower than that of PL phosphor. [3]

In this work, the authors introduce a display device combining the merits of both PDP and FED, avoiding the drawbacks of both devices. In other words, we combine electron emission from field emitter (FED) and PL by UV emitted from excited gas species by accelerated electrons (PDP). The desirable driving condition is that electrons could excite enough number of atoms and molecules to produce enough UV, but not ionize enough number of neutral particles to produce a self-sustaining discharge like in PDP. This distinguishes the current work from the previous studies to reduce the PDP driving voltage, keeping self-sustaining discharge. [4] This kind of device is expected to avoid the main energy loss channels of both PDP (ion loss) and FED (low CL efficiency).

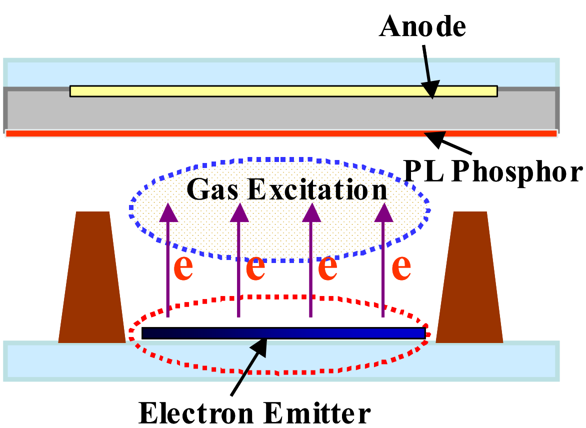
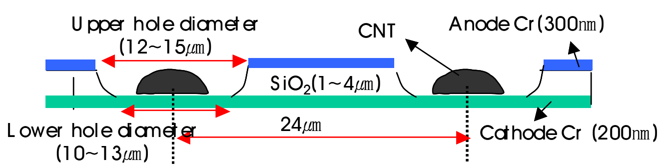


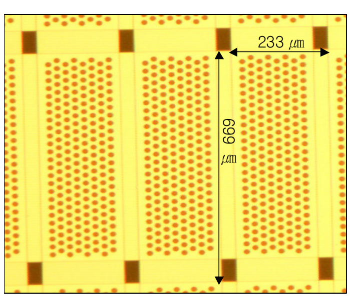
Fig. 1. Schematic diagram of the display device combining PDP and FED

2. Experimental

To investigate properties of the suggested device, the back plate in Fig. 2(a)~(b) was fabricated using carbon nano-tube (CNT) as the electron emitter on the cathode. The fabrication process is almost same as the back plate of a single top-gate FED, the gate electrode of which roles as anode in the current device. On the front plate, only the green phosphor (Zn2SiO4:Mn) was deposited, without any electrode. Usually the transmission phosphor structure described above shows less than half luminous efficiency than the reflection phosphor structure, for PL devices such as PDP or flat discharge backlight. In this study, however, we concentrate on the confirmation of the feasibility of the new concept device, and used only the transmission phosphor structure. Square pulse wave was applied to the anode electrode, cathode being grounded. Figure 2(c) shows the photograph of the visible light radiation when the panel was filled with 3Torr Xenon gas and driven by pulse width modulation (PWM) driving method. We could acquire uniform radiation without flicker or defect.



(a) Side-view of electrode structure



(b) Top-view of one pixel **(c) Visible light**

Fig. 2. Fabricated sample and the photograph of visible light radiation

3. Results and discussion

Figure 3 shows the brightness and efficacy characteristics for 3Torr Xenon ambient gas. The brightness of 506cd/m2 and the luminous efficacy of 3.58lm/W were achieved from a 2"-diagonal test sample driven at 40V, 263cd/m2 and 4.14lm/W at 35V (1kHz, 1% duty).

Not only the high efficiency but also low driving voltage is achieved in the test, the device produces a uniform light, which is one of main technological hurdles for FED. High uniformity can be achieved because the number of holes on the anode (~200 per one sub-pixel) for this device is much larger than that of holes on the gate electrode (~20 or less per one sub-pixel) for FED, which is possible since the electron energy is so low for the new device that we can use barrier ribs to prevent cross-talk. Compared to PDP, the driving cost is much lower, partly because it does not need the X and Y board for sustain discharge, and also because the low driving voltage allows us to use much chipper driving IC's.

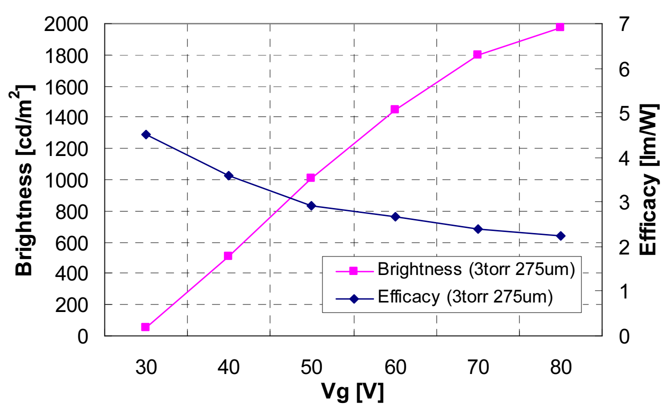


Fig. 3. Brightness and efficacy for 3Torr Xenon gas (1kHz, 1% duty)

In spite of the advantages over PDP or FED, the question still remains if this device can produce enough brightness for HDTV. PDP uses low-energy excitation source (UV photon) but long driving time (full screen simultaneous sustain), and FED uses high-energy excitation source (energetic electron) though the driving time is short (PWM driving). The suggested device, however, uses low energy excitation source (UV photon) like PDP and short driving time like FED (PWM driving). Thus, it can be expected that high voltage, high gas pressure, or new efficient electron emitter or driving scheme is needed for a large size million pixel display to be realized by this mechanism.

In increasing the voltage or gas pressure, the main problem was the degradation of CNT. We identified the origin of such deterioration as the physical attack on CNT by ions, through the comparison of the degradation time among the rare gases. The degradation occurs in the order of Ar > Kr > Xe > Ne > He, the time during which the emission current falls to the half of the initial value being 12.5, 20, 21, 55, and 120*min* for Ar, Kr, Xe, Ne, and He, respectively. The results can be explained considering the ion acceleration energies and sputtering yields of those ion species. [5] The ionization energies for Xe (12.13eV), Kr (14eV), and Ar (15.76eV) are relatively small compared to those for Ne (21.57eV) and He

(24.59eV). The emission currents from CNT at the same voltage (45V) for 3Torr Xenon, Krypton and Argon were much higher than that for vacuum, which means that those gas species are easily ionized under the driving condition, even though the number of ions is not enough for a self-sustaining discharge to occur. Considering the mean free path of the ions, the incident ion energy to CNT is high in the order of Ar, Kr and Xe at the same voltage and pressure. Moreover, the sputtering yield at the same voltage for the species is also high in the order of Ar, Kr, and Xe. The order of incident ion energy and sputtering yield results in the order of degradation. The emission current from CNT at the same voltage (45V) for 3Torr Neon and Helium was small compared to Ar, Kr, and Xe, which means the smaller amount of ions, and less degradation for these species.

Table 1. The time during which the emission current falls to the half of the initial value for 3Torr ambient gas

	Xe	Kr	Ar	Ne	He
(gas current) / (vacuum current)	7.32	6.76	6.58	2.03	1.16
Life time	21min	20min	12.5min	55min	120min

We performed the molecular dynamics (MD) simulation of CNT sputtering by Xe. Various impact points on CNT, incident energies and directions were considered. As a result, the threshold energy for a Xe ion to sputter CNT was 50eV, as shown in Fig. 4. However, considering the thermal motion, defect, and dislocation in CNT structure, the degradation of CNT is expected to start under 50eV.

Incident angle	Side hexagon Center(①)	Side bond Center(②)	Side bond Center(③)	Side onto Carbon(④)	Cap pentagon Center(⑤)
30°			100eV		70eV
45°	120eV		70eV	110eV	90eV
60°	120eV	90eV	60eV	60eV	90eV
90°	90eV	50eV	50eV	60eV	100eV

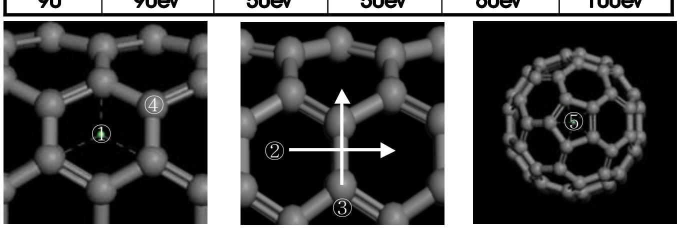


Fig. 4. Threshold energy for a Xenon ion to sputter the CNT

There can be various solutions to the degradation problem, and one of them confirmed by both experiment and electric field simulation is to change the electrode structure, which in turn, changes the electric field structure. The electric potential distribution is the most important factor to determine the acceleration energy of Xenon ions to CNT. We investigated the dependence of the acceleration energy on the height of SiO2 insulating layer between cathode and anode. Figure 5 shows the structures and corresponding lifetimes for the emission current to be halved for various height of SiO2 insulating layer. Changing the height of SiO2 insulating layer from 4um to 1um resulted in the lifetime to extend 10 times, and it was understood from the field simulation results that the ion acceleration energy is much lower for 1um case.

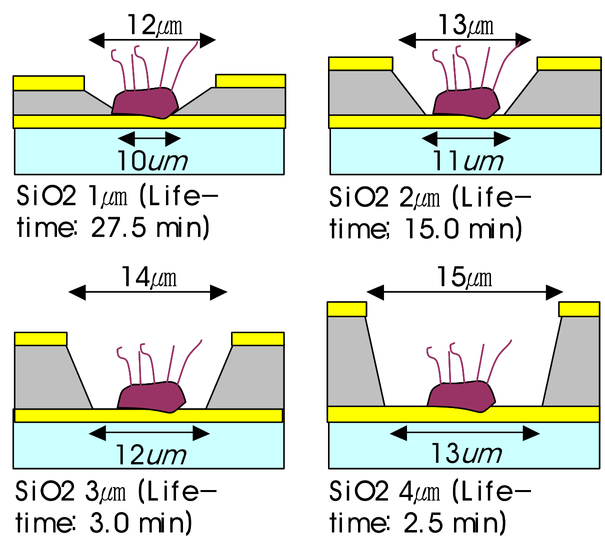


Fig. 5. The lifetime for the emission current to be halved for various height of SiO2 insulating layer

Figure 6 shows the electric potential distribution for various heights of insulating layer. The ionization averagely happens around one mean free path distance (20um) above CNT. From the potential distribution, the acceleration energy of Xenon ions born in that area and accelerated to CNT by the electric field is expected to be much lower for 1㎛ SiO2 layer than for 4㎛ SiO2 layer. The field simulation results explain why the height of SiO2 insulating layer between cathode and anode is a determining factor for the lifetime of CNT.

Figure 7 shows the SEM images of CNT before and after driving until the emission current reduces to half of the initial current. For 1µm and 2µm SiO2 layer, there was no recognizable change on CNT shape after driving. On the other hand, for 3µm and 4µm SiO2 layer CNT became shorter and thicker compared to the initial state, which was resulted from the sputtering of CNT by ions. It is supposed that CNT degradation for 1µm and 2µm SiO2 layer is resulted from the generation of defect and dislocation of CNT atom by ion attack.

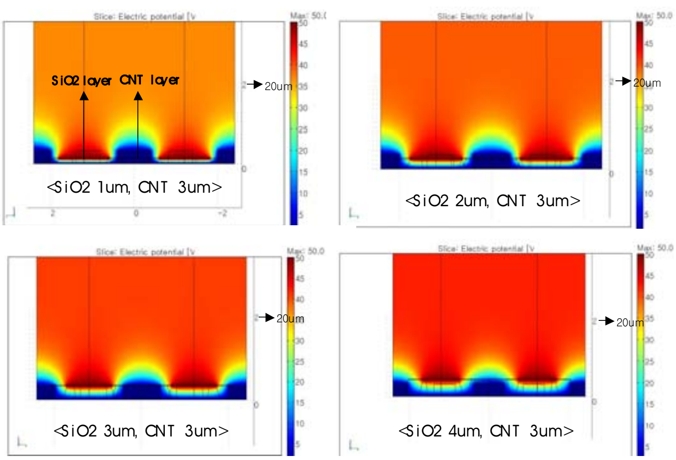


Fig. 6. Electric potential distribution for various heights of insulating layer

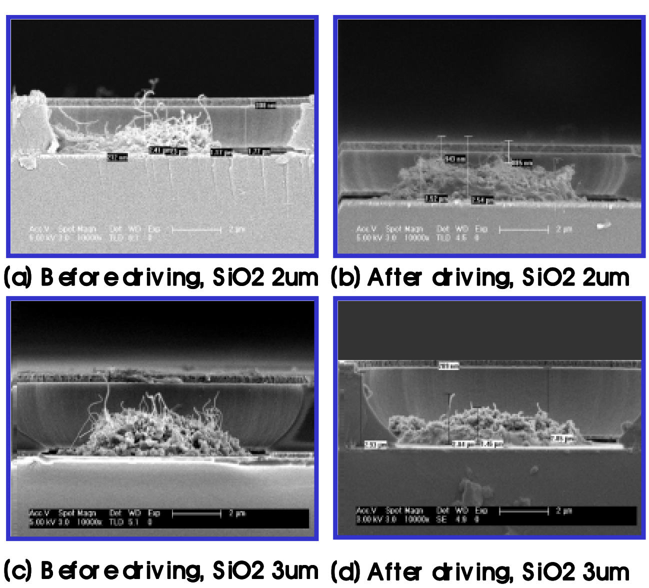


Fig. 7. SEM images of CNT before and after driving until the emission current reduces to half of the initial current

More fundamental ways to remove the degradation, for example, energy controlled electron emitter to avoid the ion production, new driving method other than PWM driving, and ion barrier formation process, are currently being studied, and the solution to this problem will lead the new device to a practical next generation display of high efficiency and low voltage.

4. Summary

A display device combining electron emission from field electron emitter (FED) and UV excited PL through gas excitation by accelerated electrons (PDP) was proposed to achieve high luminous efficacy. To realize the proposed gas display device with electron emitter, we chose carbon nano-tube (CNT) as the electron emitter and prepared test samples based on the single top-gate structure FED process.

With a typical green phosphor (Zn2SiO4:Mn) for Xenon based PL (PDP) printed on the inside wall of the anode, we could acquire uniform radiation without flicker or defect. The brightness of 506cd/m2 and the luminous efficacy of 3.58lm/W were achieved from a 2"-diagonal test sample driven at 40V (1kHz, 1% duty). And at 35V, the brightness was 263cd/m2 and luminous efficacy was 4.14lm/W.

Compared to PDP, the driving cost can be much lower, partly because it does not need the X and Y board for sustain discharge, and also because the low driving voltage allows us to use much chipper driving IC's.

Because the device structure, materials and driving condition were not optimized at all for this early stage test sample, the results can be considered as a clear sign that the gas display device with electron emitter has great potential to become the next generation display succeeding PDP and FED with high efficacy and brightness. Further investigation to improve the performance of the device and to analyze the detailed mechanism will be reported elsewhere in the near future.

5. References

1. J.P. Boeuf, Seminar (1997).
2. K.W. Whang, FPD International (2004).
3. D. Engelsen and K. Kortekaas, Monthly Publication of the SID, Vol.20, No.10, pp.22-26, (2004).
4. Yong-Seog Kim et al., IDW (2003).
5. N. Matsunami et al., IPPJ-AM-32, Institute of Plasma Physics, Nagoya University, Japan, (1983).