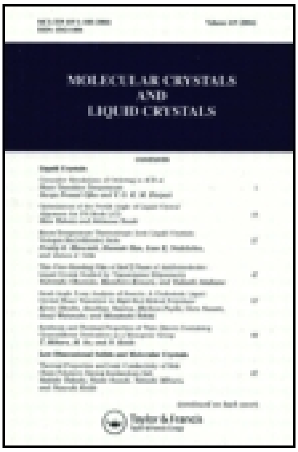

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Luminance Control of Organic Light-Emitting Diodes Using an Organic Bistable Memory Device

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The luminance control of organic light-emitting diodes (OLEDs) using an organic bistable memory device was investigated. A quantum dot embedded organic bistable memory device was connected to the OLED instead of a common thin film transistor to manage the luminance of the OLEDs. Multilevel luminance control of the OLEDs could be enabled by simply controlling the setting voltage of the organic bistable memory device. High luminance was obtained at the writing voltage corresponding to the high current state, while low luminance was obtained at the erasing voltage corresponding to the low current state.

Keywords Organic memory; organic light-emitting diode; luminance control

Introduction

Organic light-emitting diodes (OLEDs) have been developed for more than 20 years for applications as a display and a light source [1–3]. In particular, the OLEDs have been mostly used as active matrix type OLEDs and passive matrix type OLEDs in display applications.

Active matrix type OLEDs utilizes a thin film transistor (TFT) to control the luminance of the OLEDs [4]. Polysilicon or amorphous silicon TFTs have been used as driving units of the OLEDs and they were effective to manage the luminance of the OLEDs. However, the fabrication process of the TFT is too complicated even though the performances of the silicon based TFTs were good enough to driving the OLEDs. An alternative for the silicon based TFT was organic TFT with organic semiconductors instead of the silicon [5–7]. Although there were several studies using the organic TFT as a driving unit of the OLEDs, it suffers from low mobility and poor stability. In addition, the device structure and fabrication process are also complicated.

The TFT is a kind of switching device and the device with the same switching performances as the TFT can be used as a substitute of the TFT. It has been known that organic bistable devices (OBDs) could be used as the switching device to control the conductance depending on the switching voltage [8–15]. Therefore, they can be applied as the switching devices in combination with the OLEDs due to the switching performances of the OBDs. Various OLED structure can be combined with the OBD units [16,17].

In this work, OBDs with bistable switching performances were combined with OLEDs to manage the luminance of the OLEDs and the luminance control of the OLEDs by the

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OBDs was investigated. Quantum dot (QD) embedded OBDs were fabricated and three level luminance control of the OLEDs by the OBD was demonstrated.

Experimental

The device structure of the OBD was indium tin oxide (ITO, 150 nm)/poly(9,9′-dioctylfluorene-co-bis-N,N′-(4-ethoxycarbonylphenyl)-bis-N,N′-phenylbenzidine (PFO-co-NEPB):QD (100 nm, 5%)/Al (200 nm). The PFO-co-NEPB was supplied from Dow Chemical Co.. A CdSe/ZnS core-shell type QD with a peak wavelength of 545 nm was purchased from Lumitec Co. and it was used as the nanoparticle in the OBD. The PFO-co-NEPB was dissolved in toluene at a concentration of 0.5 wt% and spin coated at a spin speed of 1,000 rpm. The OLED had the device structure of ITO (150 nm)/*N,N*′-diphenyl-*N,N*′-bis-[4-(phenyl-*m*-tolyl-amino)-phenyl]-biphenyl-4,4′-diamine (DNTPD, 60 nm)/*N,N*′-di(1-naphthyl)-*N,N*′-diphenylbenzidine (NPB, 30 nm)/ /tris(8-hydroxyquinoline) aluminum(Alq_3, 50 nm)/LiF(1 nm)/Al(200 nm). The OBD was connected to the OLED to control the luminance of the OLED and device configuration for the luminance control system is shown in Fig. 1. The writing voltage of the OBD was set as 3 V, 5 V and 7 V. The current-voltage performances of the OBD and the current density-voltage-luminance characteristics of the OLEDs driven by the OBD were measured with Keithley 2400 source measurement unit and CS 1000 spectroradiometer.

Results and Discussion

It is well known that the blend of the QD with an organic charge transport material shows high on/off ratio and stable bistable performances in OBDs due to the charge trapping and detrapping by the QD nanoparticles [16]. On/off ratio which is defined as the current density ratio of the OBD at high current state and low current state is one of important parameters for OBD and it is essential to achieve high on/off ratio to control the current density of the OLED. Therefore, the QD embedded PFO-co-NEPB OBD can be used as the memory unit to drive the OLED.

Figure 2 shows the current-voltage characteristics of the QD embedded PFO-co-NEPB OBD depending on the setting voltage of the OBD. The setting voltages of the device were 3 V, 5 V and 7 V. The current levels of the device were determined by the setting voltage of the OBD and high current was obtained at the writing voltage of 3 V. Low current level

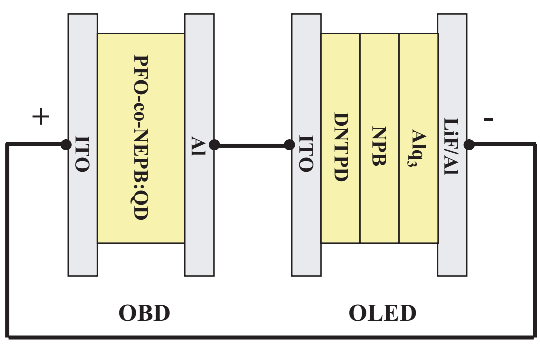

Figure 1. Device structure and electrical connection of the organic light-emitting diode with the organic bistable memory device.

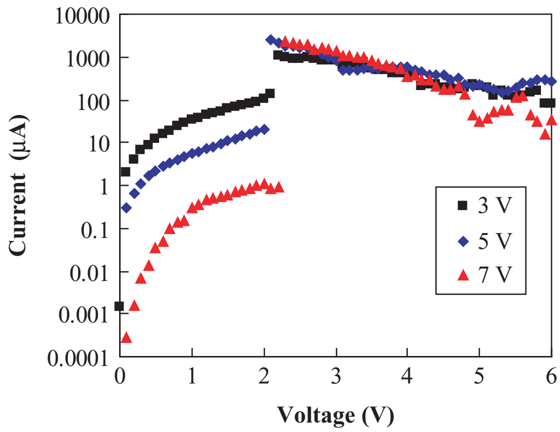

Figure 2. Current-voltage curves of the quantum dot based organic bistable memory device according to the setting voltage of the device.

was observed at a setting voltage of 7 V corresponding to the erasing voltage of the OBD and intermediate current level was observed at a writing voltage of 5 V. As can be seen in the current-voltage curve, the OBD showed a negative differential resistance (NDR) behavior and the writing/erasing voltage of the OBD could be set as 3 V/7 V. Therefore, three different current levels could be obtained by controlling the setting voltage as 3 V, 5 V and 7 V. The current level at the setting voltage of 3 V corresponds to the on state current, while the current level at the setting voltage of 7 V is the off state current. The on/off ratio of the OBD was about 100 between 1 V and 2 V.

As the QD embedded OBD showed stable switching performances, it was combined with the OLED as a driving unit of the OLED. The current density-voltage curves of the OLED connected to the OBD (OLED-OBD) were plotted in Fig. 3 to study the current density dependence on the setting voltage of the OBD. It can be clearly seen that the current density of the OLED-OBD is dependent on the setting voltage of the OBD. The current

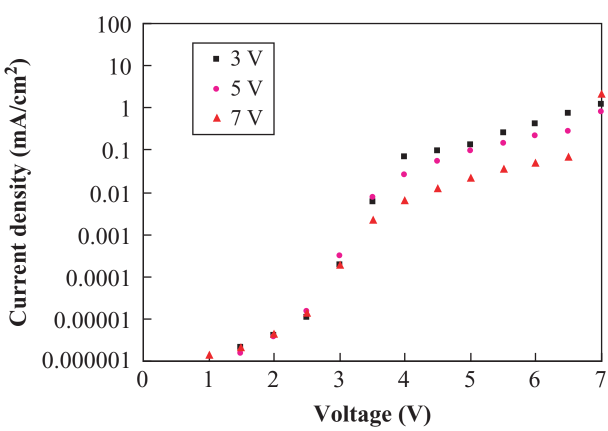

Figure 3. Current density-voltage curves of the organic light-emitting diodes connected to the quantum dot based organic bistable memory device. Setting voltages were 3 V, 5 V and 7 V.

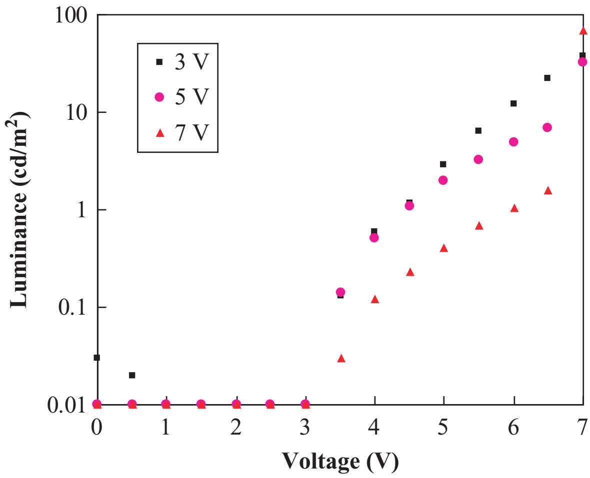

Figure 4. Luminance-voltage curves of the organic light-emitting diodes connected to the quantum dot based organic bistable memory device. Setting voltages were 3 V, 5 V and 7 V.

density was similar irrespective of the setting voltage up to 3 V, but the current density was different depending on the setting voltage between 3.5 V and 6.5 V. There was little difference of the current density above 7 V. The change of the current density is closely related with the switching behavior of the OBD. The OBD showed different current levels between 0 V and 2.1 V. The OLED and OBD were connected in series and the voltage loaded in each device depends on the resistance of each device. The resistance of the OLED is too high compared with that of the OBD at low voltage (<3 V), limiting the current density of the device. In general, the current density of the OLED is very low at a voltage lower than the threshold voltage of the OLED. The threshold voltage of the OLED was 3 V and the current density below 3 V is dominated by the current density of the OLED. The current level of the OBD does not affect the current density of the OLED-OBD due to the high resistance of the OLED. However, the resistance of the OLED is significantly decreased above threshold voltage of the OLED and the current density is determined by both the OLED and OBD. The current density of the OLED is constant, but the current density of the OBD is affected by the setting voltage of the OBD. Therefore, the total current density of the OLED-OBD is changed by the setting voltage of the OBD.

The different current level induced the change of the luminance as well as the current density of the OLED-OBD. Figure 4 shows the luminance-voltage curves of the OLED-OBD. Three different luminance levels were obtained in the OLED depending on the setting voltage of the OBD. High luminance was observed at the setting voltage of 3 V and low luminance was obtained at 7 V. The luminance of the OLED at the setting voltage of 5 V was between the luminance at the setting voltage of 3 V and 7 V. Comparing the luminance of the OLED-OBD at 6.5 V, the luminance range was from 1 cd/m^2 to 22 cd/m^2. The luminance control in the OLED-OBD can be explained by the different current density in the OLED-OBD depending on the setting voltage of the OBD. In general, the luminance is proportional to the current density as the current density indicates the hole and electron density in the device. In the OLED-OBD system, both hole and electron density is increased and the luminance is also increased. This can be confirmed in the efficiency curve of the OLED-OBD in Fig. 5. Although the luminance was changed by the setting voltage of the OBD, the efficiency was not affected by the setting voltage. The efficiency of the device

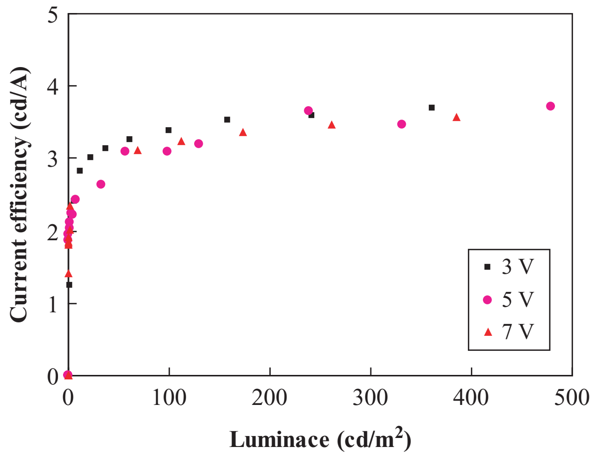

Figure 5. Current efficiency-luminance curves of the organic light-emitting diodes connected to the quantum dot based organic bistable memory device.

was kept constant irrespective of the setting voltage. If only the hole or electron density was enhanced in the device, the efficiency may be increased or decreased because of the change of the charge balance. However, the efficiency was kept constant over all writing voltage range in the OLED, confirming that relative hole and electron density in the OLED device is maintained constant irrespective of the setting voltage of the device.

Conclusions

In summary, the OLED could be effectively driven by the OBD and the luminance was managed by changing the setting voltage of the OBD. Three level luminance control of the OLED by the OBD was realized by controlling the setting voltage of the OBD. It is expected that the multilevel luminance control can be achieved by using high on/off ratio OBD and the OBD can be widely applied as the driving unit of the OLED in the future.

Acknowledgment

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