Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 230-231

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Organic Light Emitting Diodes with a Nanostructured Fullerene Layer at the Interface between Alq_3 and TPD Layers

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1. Introduction

There has been impressive progress in the development of organic electroluminescent (EL) materials and devices. Organic light emitting diodes (OLEDs) have been widely and greatly investigated for their potential applications in high efficiency, low drive voltage, full-color flat panel displays and so on [1-5]. It is very important to improve their characteristics in order to develop commercial devices. Recently, various experiments on OLEDs with inserted buffer layers and dopants have been carried out by many workers [6-10]. In this study, we fabricated OLEDs with nanostructured fullerene (C_{60}) [11] layer at the interface between electron- and hole-transport layers using a vacuum evaporation method. The fundamental EL properties have been investigated for the OLEDs.

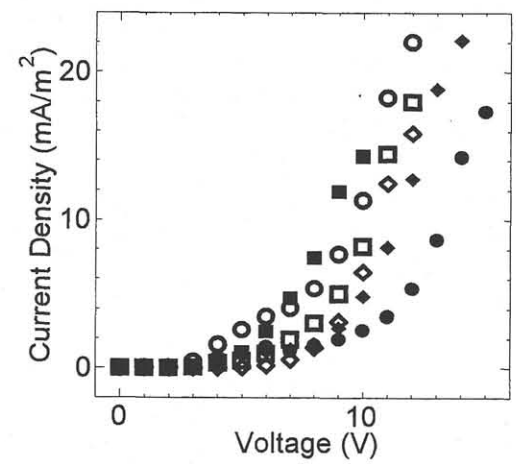
2. Experimental Details

The OLEDs in this work were fabricated on glass substrates coated with indium-tin-oxide (ITO) using a vacuum evaporation method. The ITO substrates were etched to form anodes with the effective area of 9 mm^2. 8-hydroxyquinoline aluminum (Alq_3) and N,N'-dephenyl- N, N'-bis(3-methylphenyl)-1,1'-diphenyl-4,4'-diamine (TPD) were used for the electron- and hole-transport layers, respectively. Copper phthalocyanine (CuPc) and LiF were also used for the anode- and cathode-buffer layers, respectively. Al was used for the cathodes. The OLEDs had a fundamental structure of ITO/CuPc(10 nm)/TPD(80 nm)/Alq_3(80 nm)/LiF(0.3 nm)/ Al(150 nm). C_{60} layers with 0.2-1.0 nm thicknesses were inserted at the TPD/Alq_3 interface and at the different positions in the Alq_3 layer near the TPD/Alq_3 interface. All the films were evaporated on ITO substrates sequentially without breaking the vacuum. The thickness of each layer was calculated from masses in a quartz crystal microbalance (QCM) measurement assuming that the each layer is uniform. The thickness was automatically controlled using a QCM and a vacuum evaporation system constructed in our laboratory.

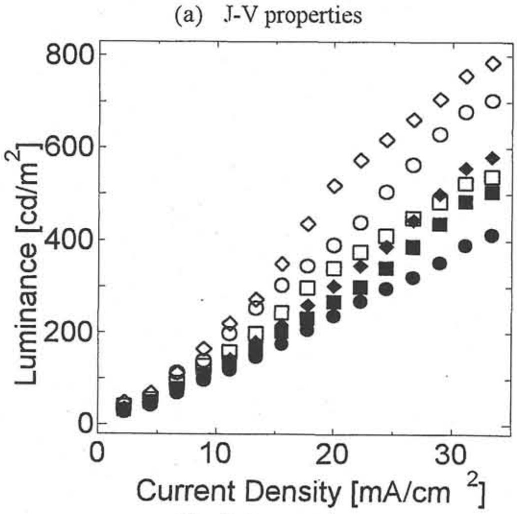
The characteristics of current density vs. voltage (J-V) and luminance vs. current density (L-J) were measured for the OLEDs with and without C_{60} layer. The dependences on the thickness of C_{60} layer and on the position of the inserted C_{60} layer in the Alq_3 layer from the TPD/Alq_3 interface were also investigated.

3. Results and Discussion

Fig. 1 (a) and (b) show J-V and L-J properties of the OLEDs with C_{60} layers of various thicknesses inserted at the TPD/Alq_3 interface, respectively. From Fig. 1 (a), it is found that the drive voltages for all the OLEDs with C_{60} layers



(a) J-V properties



(b) L-J properties

Fig. 1. Characteristics of current density vs. voltage (J-V) and luminance vs. current density (L-J) in the OLEDs with C_{60} layers of various thicknesses inserted at the TPD/Alq_3 interface. (●: without C_{60} layer, ◆: 0.2 nm, ■: 0.4 nm, ○: 0.6 nm, ◇: 0.8 nm, □: 1.0 nm)

were lower than that without C_{60} layer. It is well known that C_{60} molecule acts as an electron acceptor and is photoconductive [11]. The observed improvement is tentatively thought to be due to such as charge accumulation, carrier photogeneration and so on. However, it has not been clarified yet. The luminance was also found to be enhanced by inserting C_{60} layers in the OLEDs from Fig. 1 (b).

The dependence of EL current efficiency on the thickness of C_{60} layer is shown in Fig. 2. The OLED with 0.8 nm-thick C_{60} layer showed the highest efficiency. Since the diameter of C_{60} molecule is about 0.7 nm, the result indicates that the OLED with a C_{60} monolayer inserted at the TPD/Alq_3 interface has the highest efficiency. The strong emission is thought to be observed because the carriers were trapped in the C_{60} monolayer at the TPD/Alq_3 interface.

Fig. 3 shows the dependence of the voltage ratio at 20 mA/cm^2 of the OLEDs on the position of 0.8 nm-thick C_{60} layer in the Alq_3 layer from the TPD/Alq_3 interface. This result indicates that the drive voltage of the OLED with C_{60} layer becomes lower with increase of the position of C_{60} layer from TPD/Alq_3 interface. The dependence of the luminance at at 20 mA/cm^2 of the OLEDs on the position of 0.8 nm-thick C_{60} layer is also shown in Fig. 4. It is found

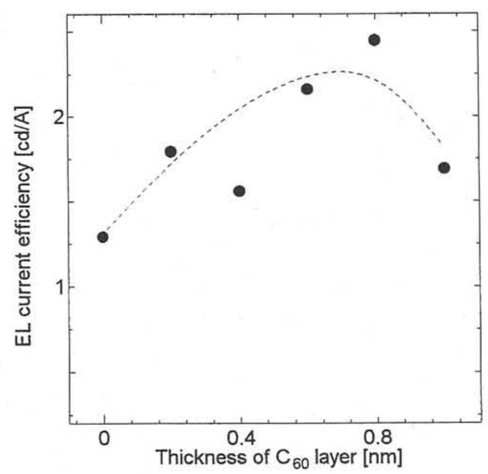


Fig.2. Dependence of the EL current efficiency on the thickness of C_{60} layer.

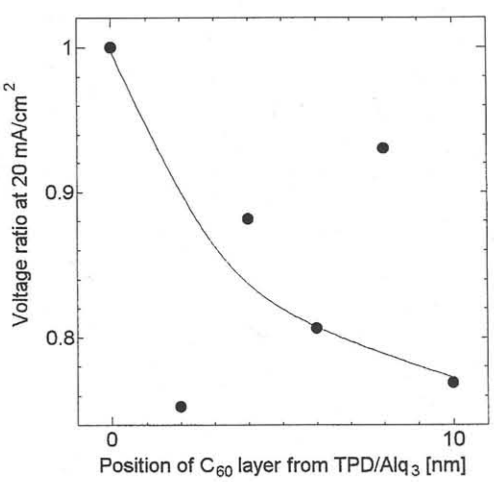


Fig. 3. Dependence of the voltage ratio at 20 mA/cm^2 on the position of 0.8 nm-thick C_{60} layer.

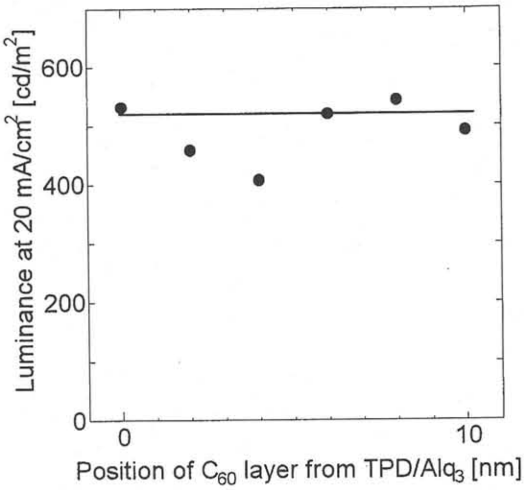


Fig. 4. Dependence of the luminance at 20 mA/cm^2 on the position of 0.8 nm-thick C_{60} layer.

that the luminance hardly changes with the position of the C_{60} layer.

The EL spectra from the OLEDs with and without a C_{60} layer were also measured. Similar spectra were observed for all the OLEDs and the spectra had a peak at 540 nm due to the fluorescence of Alq_3.

4. Conclusion

The fundamental EL properties have been investigated for the OLEDs with a nanostructured C_{60} layer at the TPD/Alq_3 interface. The dependences of the EL properties on the thickness of the inserted C_{60} layer and on the position from the interface were examined. The improvements of the drive voltage and EL efficiency in the OLEDs were observed. The OLED with a C_{60} monolayer inserted at the TPD/Alq_3 interface showed the highest efficiency. This work is useful for improving the device performance.

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