Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp1068-1069

Enhancement of Carrier Injection in OLEDs Utilizing Field Concentration to Carbon Nanotubes

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Abstract

We propose a method to enhance carrier injection in OLEDs with carbon nanotubes, utilizing field concentration effect to the nanostructure. The simulation results show that hole injection can be improved drastically even when Schottky barrier as high as 0.7 eV exists. This suggests that low-voltage operation can be achieved in simpler OLED structure with carbon nanotube electrode.

1. Introduction

Transparent conductive films (TCFs) are essential element for OLED displays and lighting equipment. Although indium thin oxide (ITO) is most commonly used for TCFs, various alternative materials such as carbon nanotube (CNT), graphene, conductive polymer, metal nanowires, and so on, have been searched because of the resource problem of ITO. Among them, CNT films have attractive advantages such as abundant element, low refractive index, low haze, flexibility and so on. Recently, CNT touch screens have been commercialized in smart phones. Another beneficial applications of CNT TCFs are flexible devices, utilizing their flexibility. In particular, CNT TCFs can be use as contact electrodes of flexible OLEDs. Recently, some group reported flexible OLEDs with CNT contact electrodes [1-4]. However, the devices have not shown better characteristics than those with conventional ITO electrodes.

In this work, we show a possibility to enhance carrier injection from CNT electrodes to OLEDs, utilizing field concentration effect. The device simulation has been carried out to find the optimal condition to obtain the field concentration effect. The results demonstrate a possibility of low-voltage operation of OLEDs with CNT electrodes.

2. Simulation

Figure 1 shows the schematics of field profile in a semiconductor layer with (a) planar electrode and (b) electrode of a sparse CNT film. In the case of planar electrodes, i.e., ITO and high-density CNT films, only the carriers that have thermal energy enough to overcome the Schottky barrier can be injected to the semiconductor layer, resulting in high-contact resistance. In the case of sparse CNT electrodes, on the other hand, electric field is concentrated to each CNT. Then, it can be predicted that the Schottky barrier is bent strongly, and as the consequence, carriers injection can be enhanced by tunneling process.

We simulated an OLED structure that consists of double layers of Alq3 (electron transport and emission layer) and α-NPD (hole transport layer) as shown in Fig. 2 [5]. The thicknesses of Alq3 and α-NPD are both 60 nm. CNTs were used as the anode electrode, making a contact to α-NPD. We assumed a CNT to be a metal wire with a diameter of 1 nm and a work function of 4.8 eV [6]. Then, a Schottky barrier of 0.7 eV for a hole is formed at the interface between CNT and α-NPD. A planar cathode electrode was placed on the bottom of Alq3, forming a Schottky barrier of 0.5 eV for an electron [7]. The other energy band and carrier transport parameters used in the simulation were determined based on literatures [7, 8].

4. Results and discussion

First, we investigated the dependence of current on the

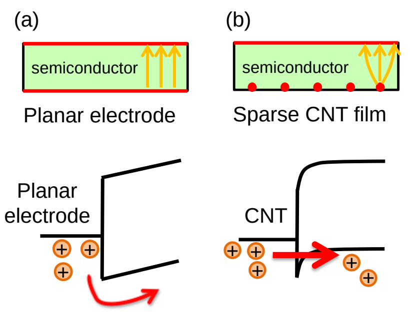

Fig. 1 Schematics of field profile and energy band for (a) planar and (b) sparse CNT electrodes.

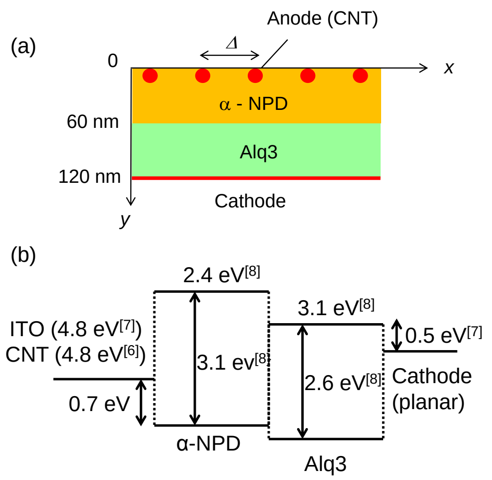

Fig. 2 (a) Device structure and (b) energy band diagram of OLED examined in simulation.

spacing between CNTs (Δ). The maximum current was obtained when Δ was 125 nm. It was found that the optimal Δ was determined by two factors; the field enhancement effect and the effective area of contact electrodes.

Figure 3 shows the calculated energy band structures for the planar and CNT electrodes. In the case of the CNT electrode, the Schottky barrier formed at the anode was strongly modulated so that the barrier thickness was decreased as compared to the planar electrode. This is due to the field concentration onto the CNTs.

As the consequence, the device current was enhanced by a factor of about 10^2 as shown in *I-V* characteristics of Fig. 4. This result suggests that it is possible to reduce the operation voltage to obtain certain value of driving current of the OLED.

We also investigated the dependence of current on Schottky barrier height. As shown in Fig. 5, in the case of the planar electrode, the current decreased exponentially with increasing barrier height. In contrast, the dependency is much weaker in the case of the CNT electrode. Carrier injection is possible even for high Schottky barrier as 0.7 eV. In order to improve hole injection in OLEDs, a hole injection layer, which is supposed to form lower Schottky

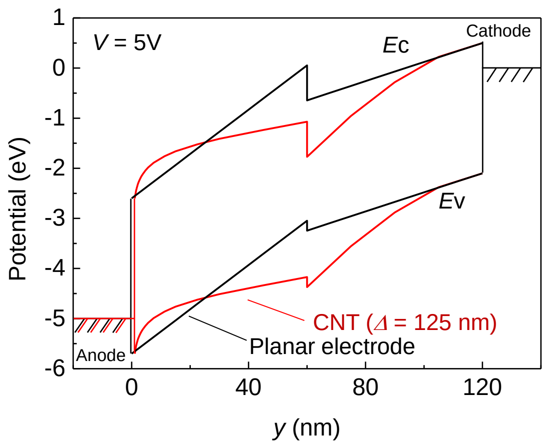

Fig. 3 Calculated energy band structures at 5V for planar electrode (black curve) and CNT electrode with $\Delta = 125$ nm (red curve).

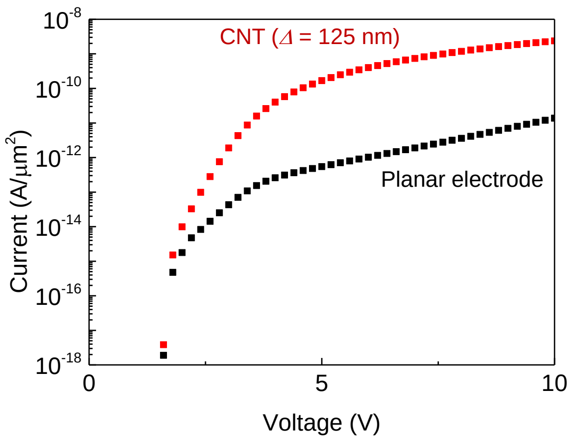

Fig. 4 Calculated *I-V* characteristics for planar electrode (black dots) and CNT electrode with $\Delta = 125$ nm (red dots).

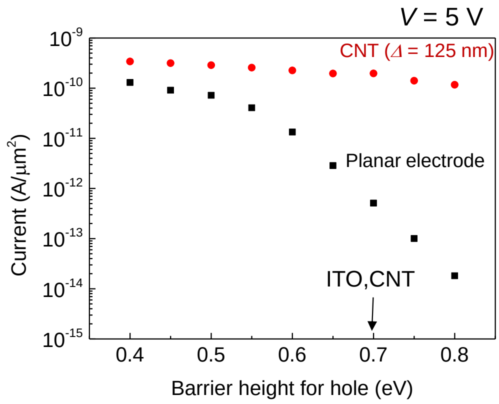

Fig. 5 Dependence of current of OLED on Schottky barrier height for hole at 5 V.

barrier, is normally introduced. By utilizing the field concentration onto CNTs, however, holes can be injected efficiently even in simple two-layered OLED structure without a hole injection layer.

5. Conclusions

We have proposed a method to improve carrier injection in OLEDs, utilizing field concentration to CNTs. The simulation results showed that the carrier injection can be enhanced by a factor of 10^2 at low-voltage regime and then operation voltage of OLEDs can be reduced. The carrier injection is possible even for high Schottky barrier as 0.7 eV, suggesting that low-voltage operation is enabled in a simple OLED structure without carrier injection by using CNT electrode.

Acknowledgements

This work was partially supported by ALCA/JST, SICORP/JST, and Grant-in-Aid of MEXT.

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