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FABRICATION OF POLYMER LIGHT EMITTING DIODES WITH ITO/PVK:TPP/ALQ$_3$/AL STRUCTURE

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Abstract Polymer light emitting diodes with the configuration of ITO/PVK:TPP/Alq$_3$/Al were fabricated using indium tin oxide (ITO) as anode, poly(9-vinylcarbazole) (PVK) as host, tetraphenylporphyrin (TPP) as red dopant, tris(8-hydroxyquinoline) aluminum (Alq$_3$) as electron-transporting green emitter and aluminum (Al) as cathode. The electrical and electroluminescence properties of the devices with various TPP doping concentrations by weight in PVK host were investigated and compared with un-doped device. The turn-on voltage of the un-doped device (v_{on} = 21 v) is larger than doped devices (v_{on} = 15 v). Besides, the el emission of the un-doped device originates only from Alq$_3$. As for the doped devices, the light observed was the combination from TPP and Alq$_3$ emission with different ratio. The results show that TPP dopants not only facilitates in transporting the electrons from Alq$_3$ to TPP-doped PVK layer but also tune the emission color of the PLEDs.

KEYWORDS: Polymer light emitting diodes, electroluminescence, PVK, TPP, Alq$_3$

Introduction

Polymer light emitting diode (PLED) is a thin film device in which emitting polymer is sandwiched between two electrodes. It will emit light when electricity is passed through it. PLEDs have attracted considerable interest due to their attractive characteristics and potential applications to full color flat panel displays, such as mobile phones, MP3 players, etc. (Gupta *et al.*, 2005). The dopant/host emitter system is a common strategy to tune the emission color of PLEDs and to enhance the EL efficiency of PLEDs (Uchida *et al.*, 1999; Virgili, *et al.*, 2000). Many dyes have been utilized as emitting center in red PLEDs. Among them, tetraphenylporphine (TPP) has been doped into poly (9, 9-dioctylfluorene) to produce red PLEDs via efficient energy transfer (Virgili, *et al.*, 2000). In this paper, we report an alternative dopant/host emitter system where TPP was doped into poly (9-vinylcarbazole) (PVK). PVK is one of the most frequently used polymeric hosts, due to its excellent film-forming and hole-transporting properties (Kido *et al.*, 1994). Since PVK is mainly hole-transport, owning very limited electron-transport capabilities, it is expected that in the single-layer structure, the carrier recombination zone be closer to the cathode due to the highly unbalanced transport properties of holes and electrons (Kido *et al.*, 1993). Therefore, an electron-transporting material, tris (8-hydroxyquinoline) aluminum (Alq$_3$) was introduced to transport electrons into dopant /host emitting layer, and to separate the emitting layer from cathode to prevent luminescence quenching by the cathode surface (Kim *et al.,* 2000). We have successfully fabricated PLEDs with ITO/PVK: TPP/Alq$_3$/Al structure. We found that TPP dopants not only assist in transporting the electrons from Alq$_3$ to TPP-doped PVK layer but also tune the emission color of the PLEDs.

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Material and Methods

The host polymer PVK, having a high weight-average molecular weight of 1,100,000 g/mole was purchased from Aldrich Co. Inc. The red dopant, TPP and the electron transporting green emitter, Alq_3 were purchased from Tokyo Kasei Kogyo Co. Ltd. All materials were used as delivered without further purification.

The two-layer PLEDs with ITO/PVK: TPP/Alq_3/Al structure was fabricated as shown in Fig. 1. The ITO-coated glass substrates were etched and patterned to serve as anode. The substrates were cleaned with 2-propanol and acetone in an ultrasonic bath each for 10 minutes. 1, 2-dicloroethane solutions containing 10 mg/mℓ of 0.5-5 wt% TPP in PVK were prepared. The solutions were then spin-coated onto the ITO with a typical spinning speed and time at 2000 rpm for 40 s. After drying the polymer layer, the Alq_3 layer was vacuum deposited to a thickness of 3 nm. Lastly, 150 nm aluminum was then deposited by electron gun evaporation technique without breaking the vacuum.

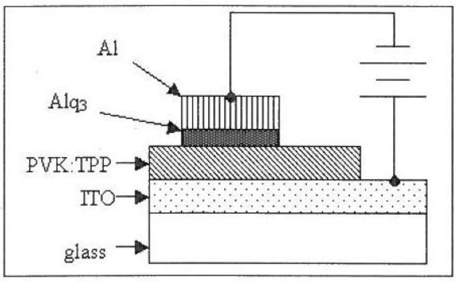

Figure 1. The PLED with ITO/PVK: TPP/Alq_3/Al structure.

The photoluminescence (PL) properties of PVK, Alq_3 and TPP (5 wt% in PMMA host matrix) were investigated by depositing the thin films on glassy silica substrates with Perkin Elmer LS55 luminescence spectrometer. In addition, Keithley 238 source measurement unit was used to measure the electrical characteristics of the devices, while the EL spectrums were obtained with Ocean Optic HR2000 spectrometer. All measurements were carried out at ambient atmosphere.

Results and Discussion

The PL spectra of the materials used are depicted in Fig. 2. As shown in Fig. 2, the PVK exhibited blue emission peaked at 388 nm, and Alq_3 emitted green light peaked at 525 nm and TPP emitted red light peaked at 650 nm.

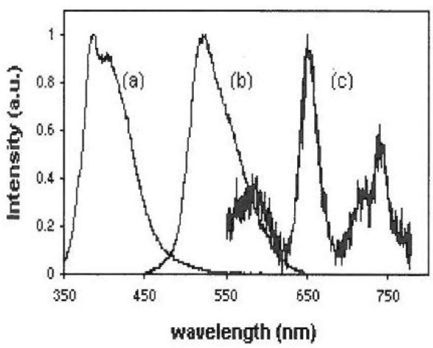

Figure 2. PL of PVK (a) and Alq_3; (b) in thin film, and PL of TPP; (c) in PMMA (5 wt%)

Figure 3 shows the normalized EL spectra of devices for different TPP doping concentrations at the same driving voltage of 28 V. Emission from PVK cannot be observed for all the spectra. The EL emission of the un-doped device originates only from Alq_3. In the case of doped devices, both green and red emissions were detected.

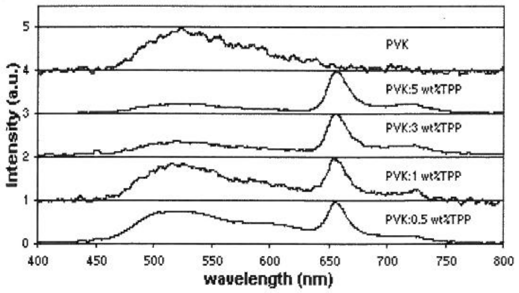

Figure 3. Normalized EL spectra of devices at different TPP concentrations

Figure 4 shows a proposed energy level scheme for the ITO/PVK: TPP/Alq_3/Al device. The Highest Occupied Molecular Orbital (HOMO) and Lowest Unoccupied Molecular Orbital (LUMO) energy levels for all the materials used were taken from reference (Ohmori *et al.*, 2001). Based on the energy diagram, the jump of electrons from Alq_3 to PVK needs to overcome a potential barrier of 0.8 eV while the jumping potential barrier from Alq_3 to TPP is less than zero. For the case of un-doped device, most of the electrons will be blocked at the interface while the holes can easily transport into Alq_3 layer. Thus, a strong Alq_3 EL emission was observed since most of the recombination takes place in the Alq_3 layer where the electrons are confined. For the case of doped devices, a fraction of the electrons are able to transport directly from Alq_3 to TPP. As a result, both green and red lights were emitted from the doped devices. As the TPP doping concentration increased, the electron-hopping rate from Alq_3 to TPP increases too (Chen *et al.*, 2004). Enhancement of the ratio of the emission from TPP to that from Alq_3 with the increase of TPP doping concentration supports this point of view.

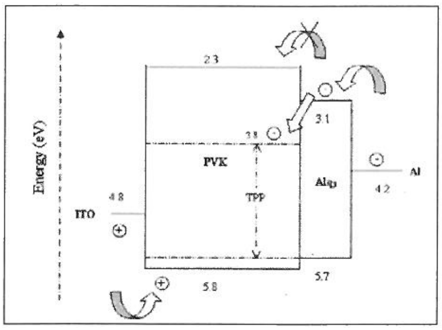

Figure 4. Schematic energy level diagram of the ITO/ PVK: TPP/Alq_3/Al device

Figure 5 shows the effect of TPP doping concentration on the current-voltage characteristics at room temperature. The turn-on voltage of the un-doped device is larger (V_{on} = 21 V) than doped devices (V_{on} = 15 V). This indicates that injection of electron into LUMO of PVK needs higher energy as compared to direct injection of electron into LUMO of TPP. As the concentration of TPP increased, the current slightly decreases at a given bias voltage, which suggests that TPP form a hole trap state within PVK due to its higher lying HOMO level as shown in Fig. 4.

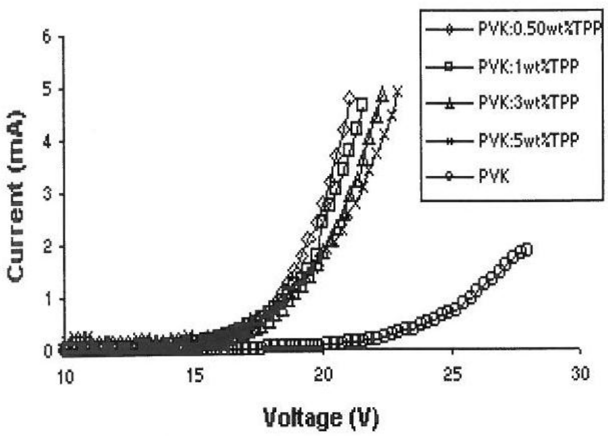

Figure 5. Current-voltage characteristic of devices at different TPP concentrations

Conclusion

The PLEDs with the ITO/PVK: TPP/Alq_3/Al structure has been successfully fabricated. It is found that TPP dopants not only can help to transport the electrons from Alq_3 layer to TPP-doped PVK layer but can also tune the emission color of the PLEDs.

Acknowledgements

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