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Effect of doping different dyes in Alq_3 on electroluminescence and morphology of layers using single furnace method

Mohammad Janghouri, Ezeddin Mohajerani *, Amir Khabazi, Zahra Abedi, Hosein Razavi

Laser and Plasma Research Institute, Shahid Beheshti University, G.C., Tehran 1983963113, Iran

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ABSTRACT

A method for obtaining red emission from organic-light emitting diodes has been developed by dissolving red and green dyes in a common solvent and thermally evaporating the mixture in a single furnace. Devices with fundamental structure of ITO/PEDOT: PSS (55 nm)/PVK (90 nm)/Alq_3: porphyrin (50 nm)/Al (180 nm) were fabricated. The emission properties and chromaticity coordinates of the devices depend on the energy transfer between the emission of host and the absorption of the dyes. TPP and $TPPNO_2$ doped in Alq_3 showed more pure red emission compared to 3,4-TPP, and PdTPP doped in Alq_3 based devices. AFM measurement showed that the morphology of the layers depends on the type of dyes and uniform mixing of porphyrin compounds and Alq_3 at constant deposition rate. It is shown that this new method is a promising candidate for fabrication of low cost red OLEDs at more homogeneous layer.

1. Introduction

Organic light emitting diodes (OLEDs) and polymer light emitting diodes (PLEDs) are of considerable interest owing to their potential for low cost, efficient, flexible, and large area emitting devices [1–5]. Two main deposition methods including spin-coating and thermal evaporation are common in device fabrication. Performance of OLED device and its optical and electrical characteristics including efficiency, lifetime and quantum yield, greatly depends on the deposition method [6]. Typically, OLED fabricated with thermal evaporation method exhibits much higher efficiency but spin-coating also draws great attention for easier fabrication [7–11]. OLED fabricated with high quantum efficiency requires the application of phosphorescence materials and efficient light out-coupling methods [12–15]. While OLED fabricated with specific emission spectrum requires the doping of distinct dyes. It has been shown that by doping the organic active layer with a small amount of dye, one can tune the emission layer for specific color [16–18]. Doping a host matrix with highly fluorescent dyes has proven to be an efficient strategy to achieve narrow emission spectra [19–23]. In this doped system, the energy of the host (donor) materials is transferred to the guest materials (acceptor) through the efficient Forster resonant energy transfer or charge transfer processes [24–26]. Doping with evaporation takes place at least by two evaporation sources of host and guest materials, separately [27–29]. Especially, the dopant with the HOMO/LUMO energy levels between HOMO/LUMO energy levels of host has to be evaporated at a precise rate, as small fluctuations of its low concentration can significantly change the device color [30]. Doping dye into host is possible by both mixing host and guest in their common solution or simultaneous evaporation of the materials. In order to control the doping concentration ratio, these materials will be deposited on substrate by controlling the related evaporation parameters using the constant evaporation rate for each of the host and guest materials.

Up to now, for fabrication of OLED from two different materials, spin coating method and evaporation of two dyes at two separate furnaces were used. In the previous work, we reported the deposition of the mixture of Alq_3 with one of the derivatives of TPP with additional functional group [31]. In this paper, we used a single source of evaporation to mix dyes at different concentrations. We have utilized a mixture of porphyrin and Alq_3 to study the EL performance of the fabricated devices by single source evaporation method. A layer of only porphyrin molecules is not efficient in charge transport and needs a host such as Alq_3 and an efficient Forster energy transfer to show efficient emission. Here, Alq_3 and porphyrin compounds are as host and guest, respectively. Therefore, porphyrin molecules are used as dopant in Alq_3 with capability of hole or electron transport to increase the injection of holes and electrons into the layer, which leads to an increase in probability of exciton formation. Alq_3 which is employed here as host material, has high electron transferring ability in light emitting layer.

2. Experimental

2.1. Materials

Apart from the porphyrin compounds which are synthesized in the Department of Chemistry and prepared and purified according

* Corresponding author. Tel.: +98 21 29904003.
E-mail address: e-mohajerani@sbu.ac.ir (E. Mohajerani).

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to the literature procedures [32–33], all other materials including PEDOT:PSS (poly(3,4-ethylenedi-oxythiophene):poly(styrenesulfonate)), PVK (polyvinylcarbazole) and Alq_3 tris(8-hydroxyquinolinato)aluminum(Alq_3) are purchased from Sigma Aldrich and used without any further purification. Fig. 1 depicts the structures of the materials. Structure of meso-tetraphenylporphyrin, tetra (4-Nitrophenyl)porphyrin, meso-tetrakis(3,4 dimethoxyphenyl) porphyrin, and tetraphenylporphyrin palladium are referred with labels TPP, $TPPNO_2$, 3,4-TPP, PdTPP in this paper, respectively.

2.2. Fabrication of OLED

The first step of fabrication process was cleaning of ITO substrates by detergent, acetone, dichloromethane, ethanol, methanol and deionized water in ultrasonic bath. PEDOT: PSS as hole injection layer was spin coated on clean ITO substrate at thickness of 55 nm and baked in oven for 1 h at 120 °C. Following this step, PVK was also spin coated over the sample at thickness of 90 nm as a hole transport layer and was baked in oven for 1 h at 120 °C to soften the sharp peaks of PVK layer and to achieve more even surface. The main part in fabricating our OLED was preparation of light emitting layer (LEL). In order to prepare this layer, porphyrin compounds and Alq_3 were dissolved in dichloromethane. The solution was then left in ultrasonic bath for 15 min to make a homogeneous solution. This solution was poured on identical quartz furnaces and exposed to heat at 50 °C for 20 min until the solvent was evaporated. Finally, dried mixture of porphyrin compounds:Alq_3 with evaporation rates 0.2–0.3 nm/s was coated in evaporation chamber to make layers of 50 nm thicknesses. The aluminum cathode was deposited on the top of the structure through a shadow mask. The device structures and the steps of this method are shown in Table 1 and Fig. 2. Thickness measurements were performed by DekTak 8000; EL and PL of fabricated OLEDs were performed by USB2000 and HR4000 Ocean Optics. The current–voltage–luminance characteristics and atomic force microscopy (AFM) measurements were checked by Keithley source meter 2400 model, optical meter Mastech-MS6612 and easy scan 2.

3. Results and discussions

3.1. Photoluminescence characteristics

Fig. 3a shows the photoluminescence (PL) emission of four porphyrin compounds at long wavelengths which show a good red chromaticity. The PL emission of four porphyrin compounds

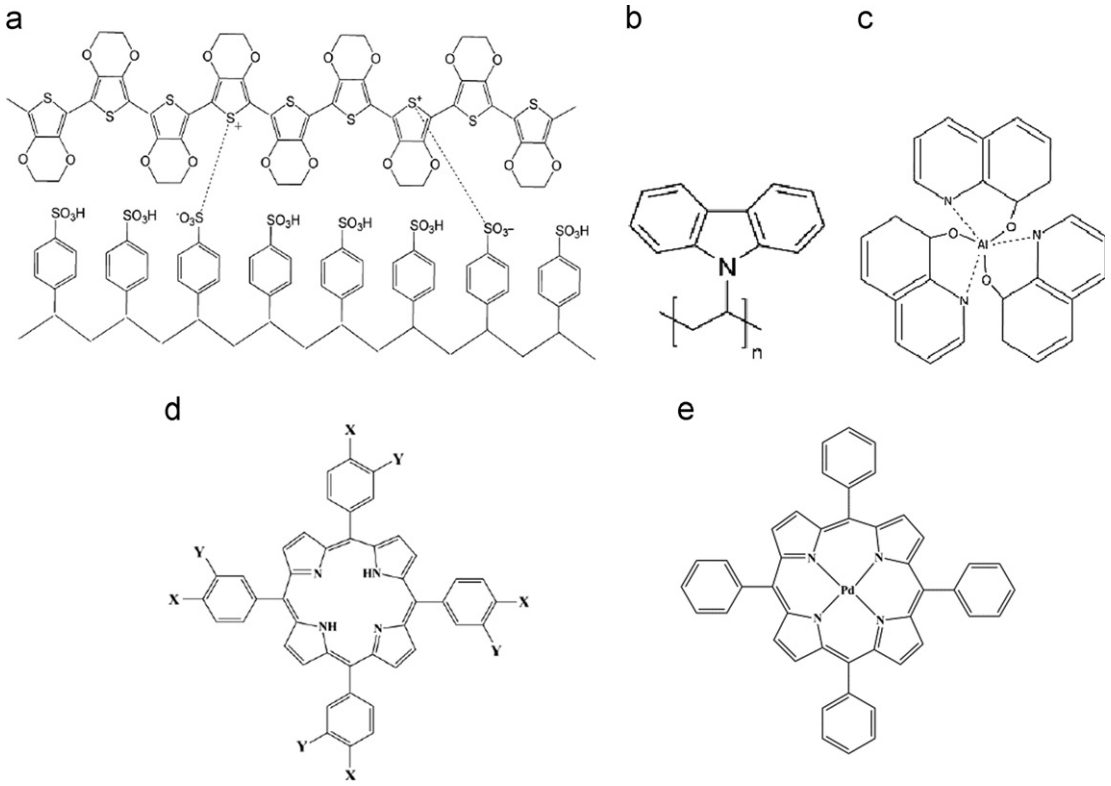

Fig. 1. Graphical structure of (a) PEDOT:PSS, (b) PVK, (c) Alq_3 and (d, e) porphyrin compounds. d)X=H,Y=H(TPP);X=NO2Y=H(TPPNO2);X=OCH3,Y=OCH3(3,4-TPP) anb e) (PdTPP).

Table 1
The device structures.

Device	Structure
Device 1	ITO/ PEDOT: PSS(55 nm)/ PVK (90 nm)/Alq_3:5,10,15 wt%(3,4-TPP) (50 nm)/Al(180 nm)
Device 2	ITO/ PEDOT: PSS (55 nm)/PVK (90 nm)/Alq_3:5 wt%(TPP) (50 nm)/Al(180 nm)
Device 3	ITO/ PEDOT: PSS (55 nm)/PVK (90 nm)/Alq_3:5 wt%(PdTPP) (50 nm)/Al(180 nm)
Device 4	ITO/ PEDOT: PSS(55 nm)/PVK (90 nm)/Alq_3:5 wt%($TPPNO_2$) (50 nm)/Al(180 nm)