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Solution processable small molecule based organic light-emitting devices prepared by dip-coating method

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ABSTRACT

Solution-processed organic light-emitting diodes (OLEDs) are currently attracting a lot of attention for their simple fabrication process. However, most laboratory-scale solution-processed devices are fabricated by spin-coating method which is not the optimum method for fabricating devices with a larger area as much of the material is wasted. Herein, a dip-coating method is introduced for its advantages for producing large-sized devices. The method is a more reliable and material saving fabrication process. In the present study, both the hole-transporting layer (HTL) and emitting layer (EML) were prepared by dip coating, and solution-processed green thermally activated delayed fluorescence (TADF) based OLEDs with high efficiencies were fabricated.

1. Introduction

After the first highly efficient OLED was fabricated by C. W. Tang [1], OLEDs have attracted more and more attention [2,3]. It was predicted that OLEDs would be the future display technology and light source because of their unique advantages of high electroluminescence (EL) efficiency, wide viewing angle, high contrast, high-speed response, low color temperature, large area, and low weight [4,5]. In particular, TADF-based devices are very promising and regarded as the next generation OLED [6–11]. Owing to the ability to precisely control the thickness and morphology of the deposited layers in a high vacuum ambient, vacuum evaporation is the most common method to fabricate all organic optoelectronic and electronic devices; functional molecular materials are evaporated onto the substrates layer by layer [12,13]. However, the method has its limitation when applied to TV-sized panels, at the same time the expensive manufacturing line and complicated fabrication process further restrict the commercialization of large-area OLEDs.

Spin-coating and ink-jet printing have long been popular solution-processed methods for their simple, low manufacturing cost and fast processing [14–20]. For the traditional spin coating method, the thicknesses and morphologies of the spin-coated layers will be determined by the amount of material dropped on the substrates and the spinning speed [21,22]. For small-sized and laboratory-scaled devices, high-performance devices can be achieved by spin-coating method [23]. However, the spin-coating method is not compatible with larger areas and much material will be wasted during the spin-coating process. In addition, spin-coating is not appropriate for mass production of high-quality organic electronic and optoelectronic devices [16]. While ink-jet printing is an ideal solution for preparing TV-sized pixelated RGB patterns in OLED display industry for large-scale manufacturing, it may not be very useful for those organic electronic and optoelectronic devices that do not require pixelation. Also, the inks that are suitable for printing are very demanding [24].

On the contrary, dip-coating method is commonly used for making thin film transistors (TFTs), organic TFTs and electrodes for organic electronic devices owing to its high potential for large-sized devices, improved reliability and material saving fabrication process [25–28]. However, HTL and EML fabricated by dip-coating process for OLED fabrication is rarely reported. In this work, dip coating is introduced as a novel method for making multilayered solution-processed OLEDs. We demonstrate high-efficiency green TADF OLEDs composed of dip-coated HTL and EML layers.

2. Results and discussion

Scheme 1 shows the dip-coating procedure. The thickness of the material is achieved through controlling the dipping time, dip-coating

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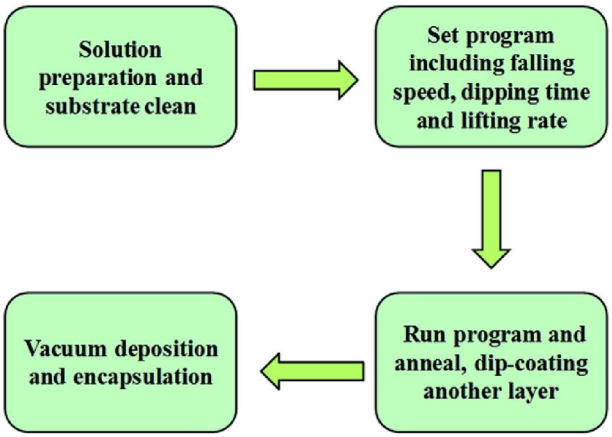

Scheme. 1. Dip-coating procedure.

speed and the concentration of the HTL and EML solutions. The dip-coating system is carried out in an enclosed chamber to isolate the solutions from the ambient. By precisely controlling the dipping time and dip-coating rate, smooth and large-area layers can be deposited repeatedly [28,29]. In our study, poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) films were prepared on ITO substrates using the dip-coating method at different speeds varied from 200 to 2000 μm/s. PEDOT:PSS film spin-coated with an optimized speed of 3000 rpm was used as a reference film (Fig. S1) [30]. All films were annealed at 120 °C for 10 min. AFM images of the dip-coated and spin-coated PEDOT:PSS films are shown in Fig. 1. The root-mean-square roughness of the dip-coated films are 1.10 nm, 0.62 nm, 0.81 nm and 1.35 nm for dipping speeds of 200 μm/s, 500 μm/s, 1000 μm/s and 2000 μm/s, respectively, and the spin-coated film has a RMS roughness of 1.36 nm. It can be seen that the morphologies of the dip-coated films are as smooth as the spin-coated one, or even better. The film formation of dip-coated film is influenced by dip-coating speed and the solvent evaporation rate [31]. All of the as-prepared PEDOT:PSS properties are summarized in Table 1.

Table 1
Properties of PEDOT:PSS films on ITO substrate prepared by different dipping speeds and spin-coating.

Film	Thickness (nm)	Sheet resistance (Ω/square)	RMS (nm)
2000 μm/s	30	15.7	1.35
1000 μm/s	35	12.8	0.81
500 μm/s	75	13.2	0.62
200 μm/s	55	14.2	1.10
Spin-coated	80	16.5	1.36

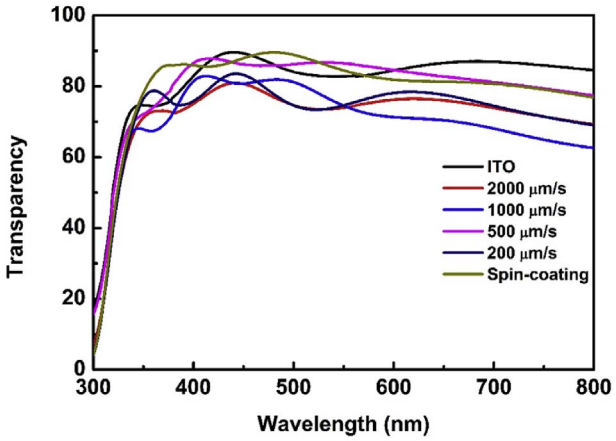

Fig. 2. Optical transparency of ITO bare substrate and PEDOT:PSS coated ITO films prepared by dipping coating and spin-coating.

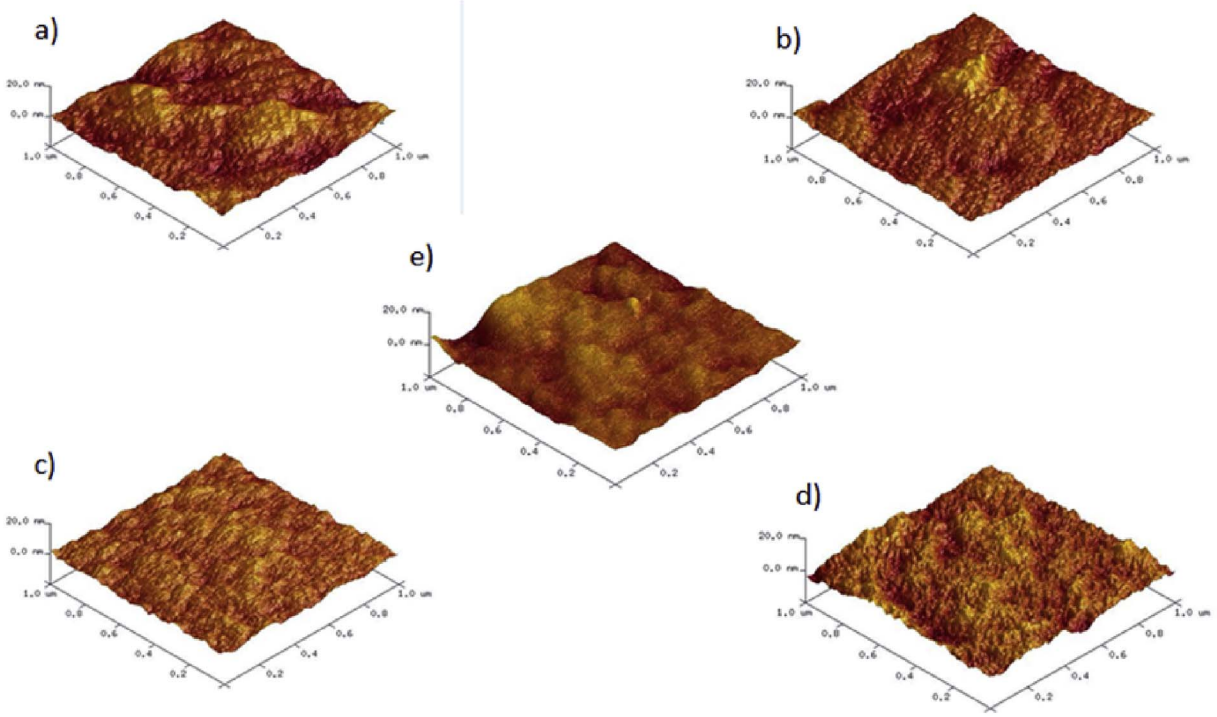

Fig. 1. AFM images of dip-coated PEDOT:PSS films with dipping speeds of a) 200 μm/s b) 500 μm/s c) 1000 μm/s d) 2000 μm/s, respectively; e) spin-coated PEDOT:PSS film at a speed of 3000 rpm.