Organic Electronics 14 (2013) 2001–2006

Contents lists available at SciVerse ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel

# Fabrication of color tunable organic light-emitting diodes by an alignment free mask patterning method

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ARTICLE INFO

*Article history:*
Received 1 March 2013
Received in revised form 5 April 2013
Accepted 20 April 2013
Available online 9 May 2013

*Keywords:*
Organic light-emitting diodes
Lighting
Color tunability
Time sequential driving
Side-by-side

ABSTRACT

An alignment free mask patterning method has been proposed for fabricating the side-by-side color tunable organic light-emitting diodes (OLEDs). The demonstrated color tunable OLEDs consists of blue sub-OLEDs and inverted orange sub-OLEDs; both color sub-OLEDs share the same electrodes. With time sequential pulse driving, the blue sub-OLEDs and the inverted orange sub-OLEDs are alternately turned on. Tunable color, resulting from the mixing of the blue and the orange emission, has been realized by simply varying the amplitude ratio of the positive and negative pulses.



## 1. Introduction

Since the demonstration of low-voltage organic light emitting diodes (OLEDs) in 1987 [1], OLEDs have attracted much attention for the application in flat panel display. Recently, people also begin to pay attention to OLEDs' application in solid-state lighting, especially the room lighting, due to their inherent advantages [2–4]. For example, the efficiency of the white light OLEDs can be as high as 100 lm/W at a illumination level of 1000 cd/m$^2$ [2], which is beyond that of the incandescent bulb and comparable with that of the fluorescent tube. OLEDs are a true surface/area lighting source thus inherently offering very uniform illumination; also heat dissipation is not as demanding as that of a point source like LEDs. OLEDs are mercury free thus environmentally friendly. More importantly, OLEDs can be flexible like paper, transparent like window or reflective like mirror, which will open new architectural and design opportunities.

For decorative or color matching purposes, the color of the OLEDs are required to be tunable. The first demonstrated color tunable OLEDs make use of polymer blend [5,6]: each component of the blend emits at a different wavelength. The color is tuned by varying the bias voltage. Higher voltage leads to the emission increase from the blue component. However, this method cannot switch off the orange emission. As a result, the color can only be tuned from orange to white. Moreover, the luminance of individual color cannot be separately controlled. Yang and Pei reported using electrochemical doping to make the two color polymer LEDs, in which two colors can be obtained by changing the polarity of the bias voltage [7].

To truly achieve real time color tunability, tandem structure with two to three color sub-cells serial connected was employed [8–12]. By extracting the intermediate electrodes, each sub-cell can be separately addressed, thus offering a route for independently controlling the luminance of each sub-cell. Alternately, a side-by-side red,

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http://dx.doi.org/10.1016/j.orgel.2013.04.040

green and blue sub-cells arrangement scheme can be adopted for realizing the color tunability. In both cases, a wide range of color, defined by the color triangle of the sub-cells, can be obtained by separately tuning the luminance of each sub-cell. However, both methods require fine patterning/aligning either the intermediate electrodes for the tandem case or the organic layers for the side-by-side scenario. It is known that the fine mask alignment is an expensive, complicate and time consuming step [13], and thus it is desirable to eliminate the fine alignment in the fabrication of color tunable OLEDs.

In this work, an alignment free mask patterning method has been proposed for fabricating the side-by-side color tunable OLEDs. The demonstrated color tunable OLEDs consists of blue normal bottom-emitting sub-OLEDs (b-NBOLED) and orange inverted bottom-emitting sub-OLEDs (o-IBOLED); both sub-OLEDs share the same electrodes and hence only one sub-OLEDs can be turned on at a certain bias polarity. With alternate current (AC) driving, the b-NBOLED and the o-IBOLED are alternately turned on. The luminance of both sub-OLEDs can be separately controlled by varying the amplitude of the positive bias and the negative bias respectively. If the frequency of the AC driving is high enough, a new color resulting from the mixing of the blue and the orange emission appears. By simply changing the amplitude ratio or duty ratio of the AC driving, the mixing color can be continuously tuned in a wide range.

## 2. Fabrication and driving method of the proposed color tunable OLEDs

Fig. 1 illustrates the fabrication steps of the proposed color tunable OLEDs and reveals the mask alignment free advantage of our method. Before the deposition, the ITO is pre-patterned to be an electrode for the OLEDs and an electrical contact for the Al electrode. Then, the o-IBOLED defined by a fine pattern shadow mask and a rough common shadow mask are deposited. At this step, the two masks mentioned above are used simultaneously to pattern the organic layers of o-IBOLED. Then the rough common shadow mask, which is used to protect the ITO contact from being covered by the organic layers, is removed and the remaining fine pattern shadow mask serves to define the Al anode of o-IBOLED alone. Here, ITO electrode which serves as the cathode for the o-IBOLED and

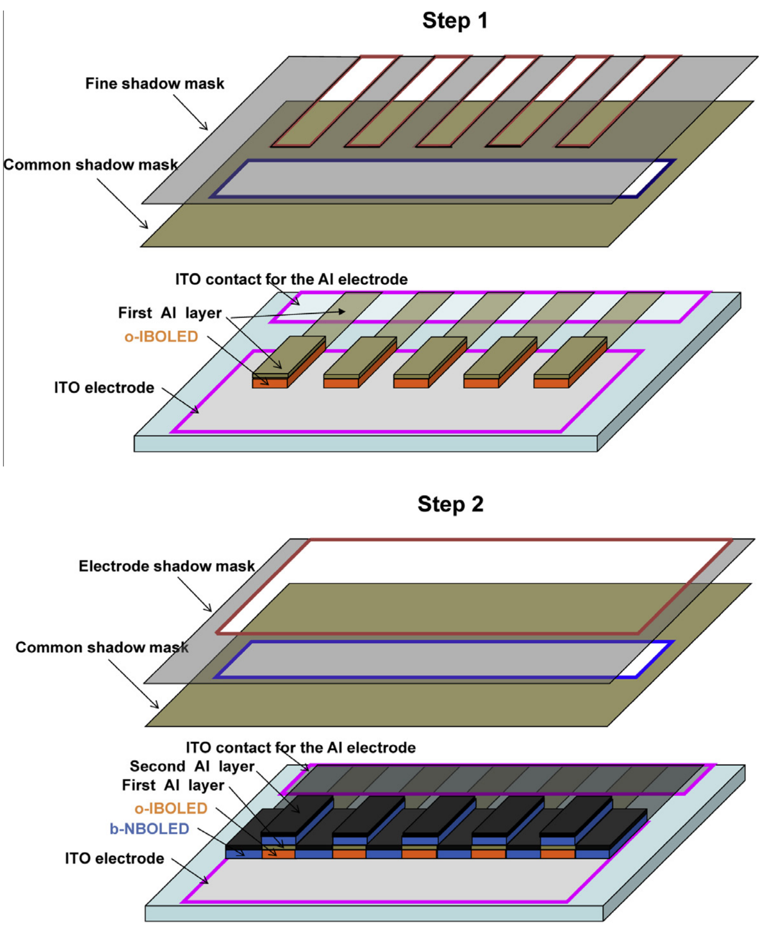


**Fig. 1.** Fabrication steps of the proposed color tunable OLED. The o-IBOLED is firstly deposited with a fine mask, followed by depositing the b-NBOLED without fine mask. Both o-IBOLED and b-NBOLED share the same electrodes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)