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# Electroluminescent properties of color/luminance tunable organic light emitting diodes and their lifetime enhancement with encapsulation

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ABSTRACT

In this work, color/luminance tunable organic light emitting diodes (OLEDs) (ITO glass/naphthyl phenyl benzidine (NPB; 80 nm)/4,4′-bis(diphenylvinylenyl)-biphenyl (ADS082BE; 35 nm)/1,3-bis[2-(2,2′-bipyridine-6-yl)-1,3,4-oxadiazo-5-yl]benzene (Bpy-OXD; 20 nm)/tris-[8-hydroxy-quinoline]aluminum ($Alq_3$; 50 nm)/lithium fluoride (LiF; 3 nm)/aluminum (Al, 80 nm)) with low turn-on voltage (3 V) and high luminance (4850 cd/m$^2$ at 9 V) have been successfully manufactured. The experimental results reveal that their electroluminescent properties (e.g. hue, luminescent intensity, etc.) can be modulated by the manipulation for the layer thickness of NPB/ADS082BE/Bpy-OXD and the applied voltages. In addition, we have also demonstrated lab-made UV-curable silicone-acrylate encapsulating resin exhibits excellent gas barrier capability so that the half-lifetimes of OLEDs reach 98 h whereas those without encapsulation are only 9 h.



## 1. Introduction

Organic light emitting diodes (OLEDs) possess the advantages of high contrast ratio, large view angle, less power consumption, fast response time as well as self-luminescence and are extensively applied for illumination and flat panel displays (FPDs) [1–3]. However, most studies focus on the synthesis of electroluminescent materials as well as the fabrication of light-emitting devices and the literatures about the manipulation of electroluminescent (EL) colors of OLEDs with the experimental conditions are less reported.

In recent years, the lifetime improvement has been a vital factor for commercialization of OLEDs since oxygen and moisture in the air erode the organic layers and metal electrodes, dramatically diminishing the lifetimes [4,5]. Without the block of moisture and oxygen in the air into the devices, their lifetimes are so short that they cannot be applied practically.

In this work, color/luminance tunable OLEDs have been successfully fabricated by vacuum evaporation, lighted up with different operational parameters, and packaged by ultraviolet (UV)-curable encapsulating adhesives. The experimental results manifest that the emitting hues and luminance of OLEDs can be ingeniously modulated with not only the thickness of organic layers but also applied voltages and the encapsulation dramatically prolongs the lifetimes of devices.

## 2. Experimental

### 2.1. Materials and instruments

Naphthyl phenyl benzidine (NPB; hole transport material), 4,4′-bis(diphenylvinylenyl)-biphenyl (ADS082BE; blue-color emitting material), 1,3-bis[2-(2,2′-bipyridine-6-yl)-1,3,4-oxadiazo-5-yl]benzene (Bpy-OXD; electron blocking material), tris-[8-hydroxyquinoline]aluminum ($Alq_3$; green-color emitting material), lithium fluoride (LiF; electron injection material), and alumina (<20 nm; filler) were obtained from Aldrich Co., 3-(trimethoxysilyl)propyl methacrylate (silicone-acrylate monomer of encapsulation resin) and the photoinitiators (Irgacure 651, Darocur 1173, and Irgacure 819) were purchased from UCB Co. and Ciba Co., respectively. The chemical structures of these two ingredients are depicted in Fig. 1. All materials were utilized without further purification. The ITO glass was supplied by Merck Co.

We measured the molecular weight, viscosity, and gas permeation rate with a Waters Alliance GPC V200, a Viscolite 700, and

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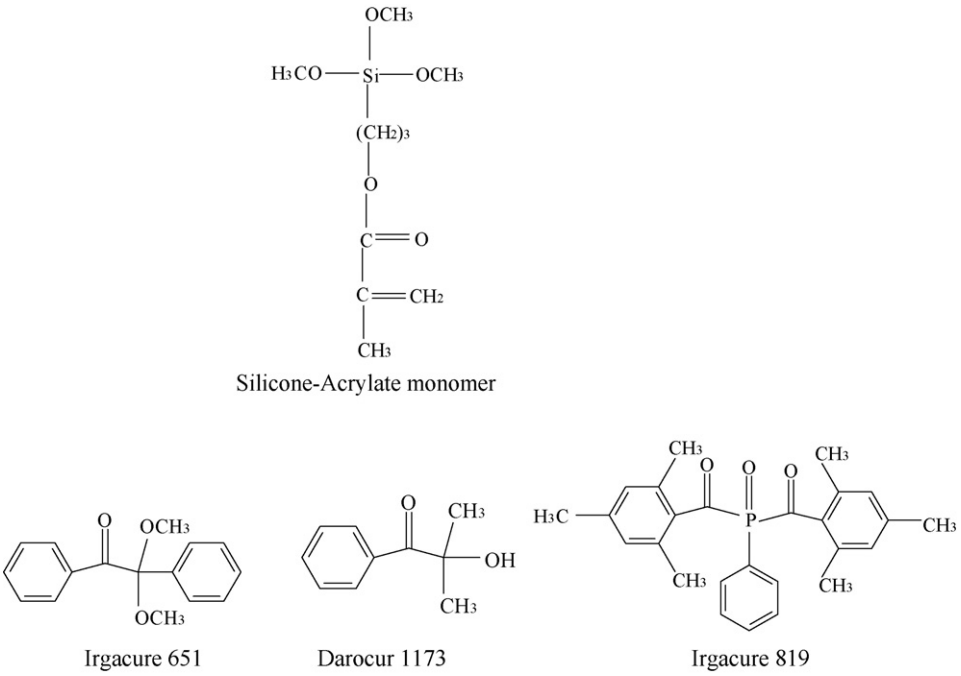


**Fig. 1.** The chemical structures of silicone-acrylate monomer and photoinitiators.

an Illinois-8501, respectively. Moreover, the EL properties and lifetimes of OLEDs were recorded by Keithley 2400 and Spectrascan PR650, respectively.

### 2.2. Fabrication of OLEDs

Firstly, we ultrasonically cleaned the ITO glass (sheet resistance = 5 Ω/□; substrate size = 5 cm × 5 cm) with the acetone, methanol as well as de-ionized water for 5 min and dried it with a stream of nitrogen as well as a 120 °C baking oven. After the treatment of oxygen plasma for 90 s, NPB (50 or 80 nm), ADS082BE (35 or 50 nm), $Alq_3$ (50 nm), LiF (3 nm), and Al (80 nm) were deposited sequentially layer-by-layer on the ITO glass by a vacuum evaporation system (Fig. 2; vacuum level = $4 \times 10^{-6}$ Torr; deposition rate of organic materials = 0.3–0.5 Å/s; deposition rate of LiF and Al = 2–5 Å/s) to form the Device I as illustrated in Fig. 3(a). The similar procedure was executed in the fabrication of Device II (Fig. 3(b)). The diversity of Devices I and II is that the electron blocking layers (Bpy-OXD) of 10, 20 or 30 nm thick are introduced in the Device II. In addition, the device sizes of Devices I and II are 1 cm × 1 cm.

### 2.3. Synthesis of UV-curable silicone-acrylate resin for OLED encapsulation

Silicone-acrylate monomer (180 g), Irgacure 651 (2 g), Darocur 1173 (1 g), Irgacure 819 (0.5 g), and alumina (20 g) were mixed and illuminated by a UV lamp (Entela UVP; wavelength = 365 nm) at the power of 100 W for 20 min (Scheme 1). The number-average molecular weight ($M_n$), weight-average molecular weight ($M_w$), $M_w/M_n$ ratio, and viscosity of silicone-acrylate resin were 37,300, 83,200, 2.23, and 7200 cps, respectively.

The silicone-acrylate composite resin was subsequently used for the sealing of Device II containing 20-nm thick Bpy-OXD *via* spin-coating technique (stage I: 1000 rpm for 10 s; stage II: 2500 rpm for

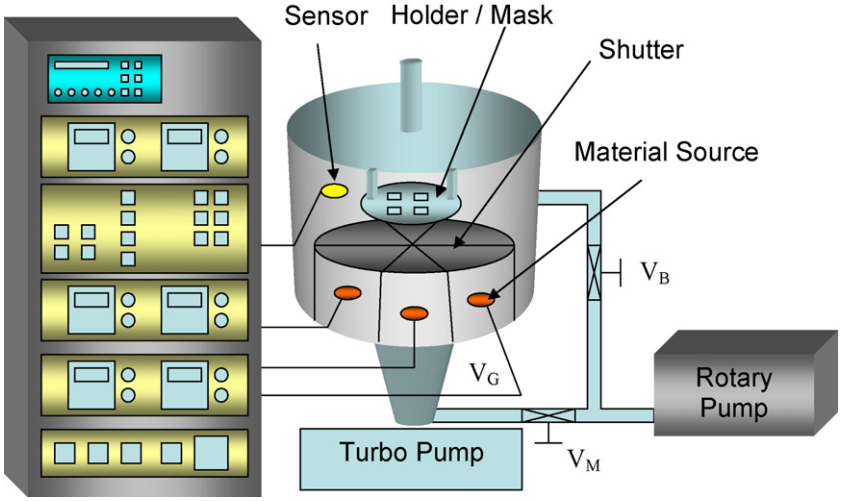


**Fig. 2.** The vacuum evaporation system used in the experiments.