Journal of Luminescence 144 (2013) 69–73

Contents lists available at SciVerse ScienceDirect

Journal of Luminescence

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

Influences on the white emission and stability of single layer electroluminescent devices

Emine Tekin*

The Scientific and Technological Research Council of Turkey (TÜBİTAK), National Metrology Institute (UME), PK 54, 41470 Gebze, Kocaeli, Turkey

ARTICLE INFO

Article history:
Received 7 March 2013
Received in revised form
7 June 2013
Accepted 27 June 2013
Available online 6 July 2013

Keywords:
Electroluminescence
Polymer electronics
White light emission
OLED

ABSTRACT

A detailed survey about the influences on the white emission color of polyfluorene based polymer light emitting diodes (PLEDs) is reported. First, the effect of active layer thickness was studied. Subsequently keeping the polymer thickness at optimum level, PLEDs were fabricated varying polymer concentrations. All fabricated devices were fully characterized in terms of luminance, current–voltage characteristics, efficiencies, electroluminescent spectra, and CIE color coordinates. It was found that at higher polymer concentrations, electroluminescence spectra shifted to the bathochromic region so that the resulting color becomes warm white. Furthermore, the accelerated lifetimes of the PLEDs were measured and the results are discussed in terms of polymer inter-chain interactions. Consequently, the 8 mg/ml was found to be the optimum level not only for the device performances but also for the device lifetime.

1. Introduction

Organic light emitting devices (OLEDs) [1] have been the focus of many research groups in the past years because of their potential applications for flat panel displays and solid state lighting. OLED technology is generally classified into two categories, namely, small molecule OLEDs (SMOLEDs) [2,3] and polymer OLEDs, (PLEDs) [4]. SMOLEDs are fabricated by vacuum deposition while PLEDs can be fabricated by solution processing [5]. Due to the compatibility with low cost, large area coating techniques like roll-to-roll processing or inkjet printing [6–12] PLEDs are very advantageous for industry. In this regard, white emitting PLEDs become particularly attractive due to large area lighting capabilities.

A conventional approach to obtain white emission is to use physical blends of several polymers [13–17] such as a combination of blue-, green- and red-light-emitting polymers at certain ratios [13,18]. Although promising efficiencies have been achieved, disadvantages of this strategy are the negative impact of phase separation and bias dependent electroluminescent (EL) spectra. Recently, white emitting PLEDs based on single white emissive polymers have been reported and high light-emitting performances were obtained [19,20]. Generally the molecular structures of the white emitting polymers are based on polyfluorene (PFO) [21–24]. Many researches are working on the synthesis of new PFO derivatives including chemically doped small amounts of RGB emitters in its side or main chains [25,26]. However studies on the stabilities of the white emission of the single layer PLEDs are very limited.

In this work, the effects of the polymer concentration on the white color purity and the stabilities of the single layer PFO-based white emitting PLEDs were investigated. It was found that polymer concentration plays an important role not only for device performances but also for electroluminescent colors. Moreover, the accelerated lifetimes of the operating PLEDs were measured and compared against polymer concentrations. Although active layer thickness was kept constant, increasing polymer concentration affected the stability adversely due to the inter-chain interactions of the polymers.

2. Experimental

The ITO coated glass substrates (ITO thickness 120 nm, 15 Ω/sq.) were determined from Visiontek Systems. PEDOT:PSS was purchased from Heraeus Clevios GmbH. The Polymer White (Livilux-SPW-111) was purchased from Merck.

The polymer solutions were prepared in toluene yielding 6, 8 and 10 mg/ml concentrations. Solutions were filtered through 0.45 μm membrane filters. For the fabrication of OLEDs, ITO coated glass substrates were cleaned ultrasonically in a detergent PCC-54 solution (2 wt% dispersed in H_2O) and then cleaned with deionised water, acetone and isopropyl alcohol. Then, they were dried under N_2 flow.

PEDOT:PSS, as a hole injection layer (~55 nm), was spin-coated onto the pre-cleaned ITO coated glasses by 3000 rpm for 30 s.

---

* Tel.: +90 262 679 5000; fax: +90 262 679 5001.
E-mail address: emine.tekin@tubitak.gov.tr

0022-2313/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jlumin.2013.06.042

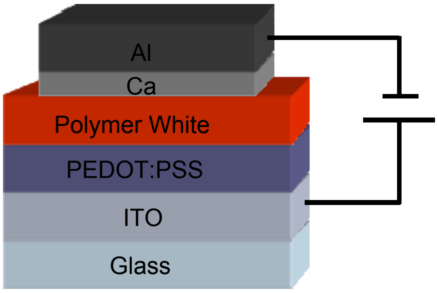

Fig. 1. Device layout of the fabricated white polymer light emitting diodes.

On top of PEDOT:PSS; polymer solutions were spin-coated by varying rpms to obtain different thicknesses. Then, they were baked at 120 °C for 10 min in the glove box. Finally calcium (Ca) as an electron injection layer (6 nm) and aluminum (Al) (~120 nm) as a cathode layer were deposited by the vacuum evaporation (under ~5×10^{-6} mbar) technique. Device layout of the fabricated PLEDs is given in Fig. 1.

Electroluminescence, brightness (luminance), luminous efficiency, and current–voltage relations of the white emitting PLEDs were measured by a Hamamatsu PMA-12 C10027 Photonic Multichannel analyzer and a digital multimeter (2427-C 3A Keithley). All devices were measured in a dark sample chamber to keep off any influence of ambient light. A stylus profiler (KLA Tencor P-6) was utilized to determine thickness of organic layers. All of the device's active emission area is 9 mm^2.

3. Results and discussions

The white emitting polymer solution in toluene having 8 mg/ml concentration was spin-coated with different rotation speeds in order to obtain different layer thicknesses. The thicknesses of the resulting films were measured with a stylus profiler. Three different thicknesses; 70, 80 and 90 nm were selected for active layer optimization. PLEDs with ITO/PEDOT:PSS/Polymer White/Ca/Al architecture and varied active layer thicknesses were fabricated and characterized. The influences of the layer thickness on the device performances can be observed from Fig. 2. According to the luminance–voltage curves, the maximum luminance increased with decreasing active layer thickness (Fig. 2a). Turn-on voltages obtained from 70 nm and 80 nm thicknesses were almost the same; 2.9 V and it was 3.2 V for 90 nm thickness. It should be noted that turn-on voltages were calculated as the minimum required voltage to attain 1 cd/m^2 luminance.

Although 70 nm thickness gave the highest luminance value, the best efficiency (6 cd/A) was obtained from 80 nm active layer thickness. Therefore for the rest of the work 80 nm was selected as an optimum active layer thickness.

In the second phase, PLEDs with active layers coated from polymer solutions with varied concentrations were fabricated. The spin coating speeds were adjusted for each concentration individually so as to provide same thicknesses (80 nm). The fabricated devices were encapsulated and fully characterized in order to elucidate the effects on the white color and stabilities. Fig. 3 demonstrates the device characteristics namely; luminance–voltage, turn-on voltages, luminous efficiency and external quantum efficiency (EQE)–current density curves. The highest luminance (brightness) value and the lowest turn-on voltage were achieved with 8 mg/ml concentration. On the other hand, the luminous efficiency and in parallel to that the external quantum efficiency (EQE) of the PLED fabricated with 6 mg/ml were relatively enhanced compared to those of other devices.

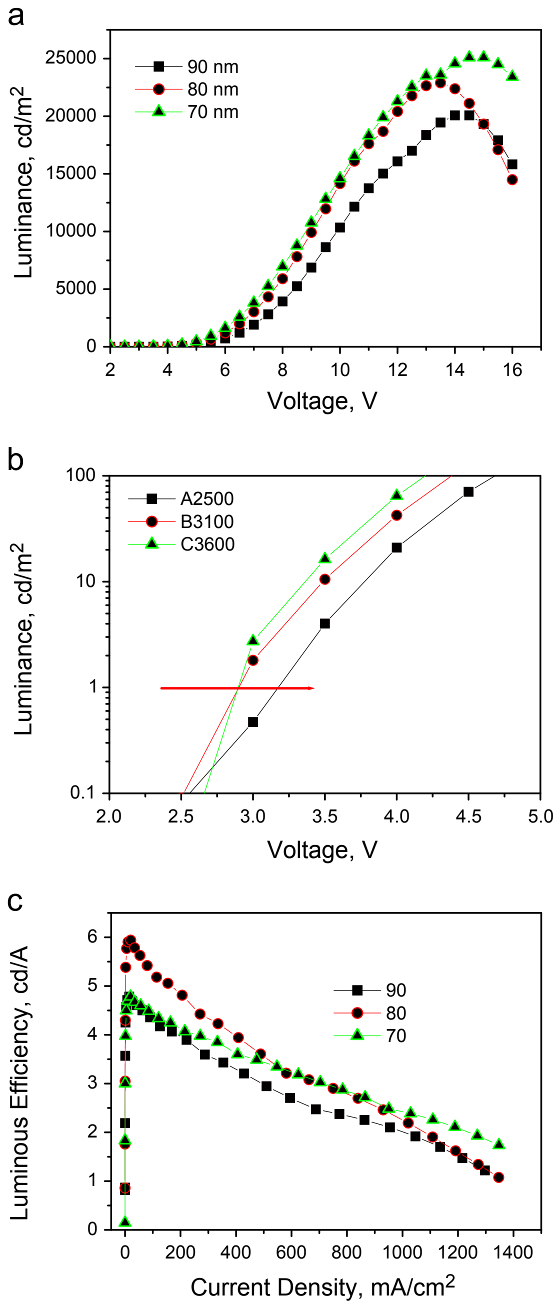

Fig. 2. The effects of the active layer thickness on the device characteristics; (a) luminance (brightness), (b) turn-on voltage and (c) luminous efficiency.

The color coordinates (x, y) of the PLEDs were measured versus applied voltages and are shown in Fig. 4. Here, it is obvious that both polymer concentration and applied voltage play an important role for white emission. The x and y values measured for 6 mg/ml concentration are decreasing with increased voltage, but all of the determined values are in the white region of the 1931 CIE color chromaticity diagram. Increasing the polymer concentration from 6 to 8 mg/ml, the overall x and y values slightly increase. They are getting close to the borders of the white region. Moreover, increasing concentration to 10 mg/ml shift the x and y values to warm white region. Although the active layers' thicknesses were kept constant, the color coordinates were changed only by changing the polymer concentration in the solutions used for spin coating. It means that inter-chain interactions of the polymer are affected by the concentration so that it influences the emission properties. Inter-chain interactions, in other words excimer