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ScienceDirect
Solid-State Electronics 52 (2008) 7–10
SOLID-STATE ELECTRONICS
www.elsevier.com/locate/sse

Letter

Low frequency optical noise from organic light emitting diode

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Received 4 January 2007; received in revised form 6 June 2007; accepted 3 July 2007
Available online 28 August 2007

The review of this paper was arranged by Prof. Y. Arakawa

Abstract

The luminance–time behavior of organic light emitting device (OLED) was measured using a photodiode and the low frequency noise–time spectrum from photodiode current is also measured and investigated. Square pulses noises were observed in time domain and the laws of their occurrences were obtained and studied. The square pulses are believed to be related to sudden change in carrier numbers in the device as part of degradation process. It shows that two dominant mechanisms take turn to generate the optical noise levels. The degradation process is postulated to describe the corresponding noise change. This optical noise observation is a direct reflection of polymer intrinsic degradation.

Keywords: Low frequency noise; Organic light emitting device

1. Introduction

Organic light emitting diodes (OLEDs) long-term stability remains a critical issue for practical applications. The understanding of the factors that influence the stability and degradation of such devices require further studies [1,2]. Conventional techniques for studying device degradation are mainly based on lifetime tests under accelerated stress conditions, and they are well suited for collecting statistical information on the expected lifetime of given set of devices.

Low frequency noise is a sensitive diagnostic tool to examine the internal mechanisms of electrical devices [3–6]. By studying noise, the intrinsic degradation mechanism in the device, which is hard to be observed by static voltage or current characteristics, can be deduced and examined. Up to now, no report has been found on the observation of the optical noise in OLED, which provide a direct probe of the intrinsic fluctuations in the radiative recombination rate and reveal certain optical processes and recombination mechanisms.

In this letter, degradation studies of non-encapsulated OLED devices with emphasis on electroluminescence (EL) and low frequency optical noise are presented.

2. Experimental details

ITO-coated glass with a sheet resistance of 20 Ω/sq. was used as a substrate for OLED device fabrication. The routine cleaning procedure includes sonication in acetone and methanol followed by oxygen plasma treatment. Seventy-five nanometers naphthyl-substituted benzidine derivative (NPB) hole-transport layer and 75 nm aluminum tris(8-hydroxyquinoline) (Alq_3) electroluminescence layer are deposited in high vacuum 2×10^{-5} Pa. A 5 Å lithium fluoride (LiF) and a 200 nm thick aluminum (Al) are deposited as cathode.

The device is kept in a shielded metal box and powered by a constant current supply, which is powered by batteries.

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0038-1101/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.sse.2007.07.004

The photodiode is also put in the metal box for light detection. The voltage across the OLED and the current from photodiode are measured by Keithley low noise digital multimeter. The noises from OLED photodiode current were measured by low noise amplifier and Hewlett–Packard (HP) dynamic signal analyzer 35670 A. A verification of the system noise measurement is done using a commercial metal film resistor.

3. Results and discussion

Fig. 1 shows the device voltage versus time and luminescence versus time curves. The inset figures show the low frequency noise spectrum and $1/f^{\alpha}$ fitting from both the device and the optical noise detected from photo sensor. The α values are 1.25 and 1.87, respectively. The device noise analysis is subjected to another publication [7]. The device was operated at a constant current of 2 mA, corresponding to a current density of 0.05 A cm^{-2} at room temperature of $T = 295$ K in air. From the curves it is seen that the device was operated for about 80 h. With increase in stress time, the luminescence decreases while the driving voltage increases. During the device lifetime test, the devices underwent a series of process and physical changes, which is difficult to be seen in the smooth current and voltage monitoring curves shown in Fig. 1.

Square pulses were observed in the photodiode current noise with time elapse. Fig. 2 shows the photodiode current noise power spectrum density (PSD) versus time, for example, at 30 Hz. It can be seen that this square pulses repeatedly appear and the noise intensity is basically at two discreet levels. Complimentary behavior at nearby frequencies was also observed in the experiment results. Noise PSD at 29 Hz is also shown together in Fig. 2. This noise pulses only happen at certain frequency range. Nearly every 5 Hz, the pulses and complimentary pulses appear once. The width of pulse changes with time. For example, the duration of the pulse at 30 Hz decreases from 9 h to 7 h and to 6 h. Similar behaviors were also observed in other samples, which show that the pulses did not happen randomly. The background noise level of the detector was measured for 100 h and the curve is also shown in Fig. 2. No pulses or obvious fluctuation in the background curves were observed. Therefore, these pulses in the optical noise behaviors observed in different devices are related to the intrinsic mechanism and degradation properties of OLED.

In order to correlate the optical noise in the light emitted from the OLED to the device operating parameter, such as carrier number changes, calculation were done based on Hooge's equation [8]: $S_v(f) = \gamma \frac{V_{DC}^{2+\beta}}{N_c f^{\alpha}}$. Here α, β and γ are constants ($\beta = 0$), N_c is the number of charge carriers in the sample, and f is the frequency. According to the experiment carried out by Leung et al., γ changes with temperature [9]. In our experiment the temperature was kept constant at room temperature during the OLED device test. Hence we assume that γ is constant. (Hooge has unified the noise processes in metals and semiconductor with $\gamma \approx 2 \times 10^{-3}$. Since OLED is different from metal and semiconductor, γ cannot just be simply treated as having this value.) Since γ is constant, and V_{DC} and $S_v(f)$ can be extracted from experiment data, the trend of N_c changing with time can be estimated using $\frac{N_c}{\gamma} = \frac{V_{DC}^2}{S_v(f)}$ ($f = 1$ Hz), Fig. 3 shows N_c/γ versus time curve and for comparison the optical noise at 37 Hz present in the detector current is also shown together in the figure. It can be seen that the edges of the noise pulses correspond to the inflection point of the carrier number curve. It can be deduced that the pulse noise phenomenon observed in the detector current is related to the carrier number change in the OLED. It also means that the electroluminescence mechanism

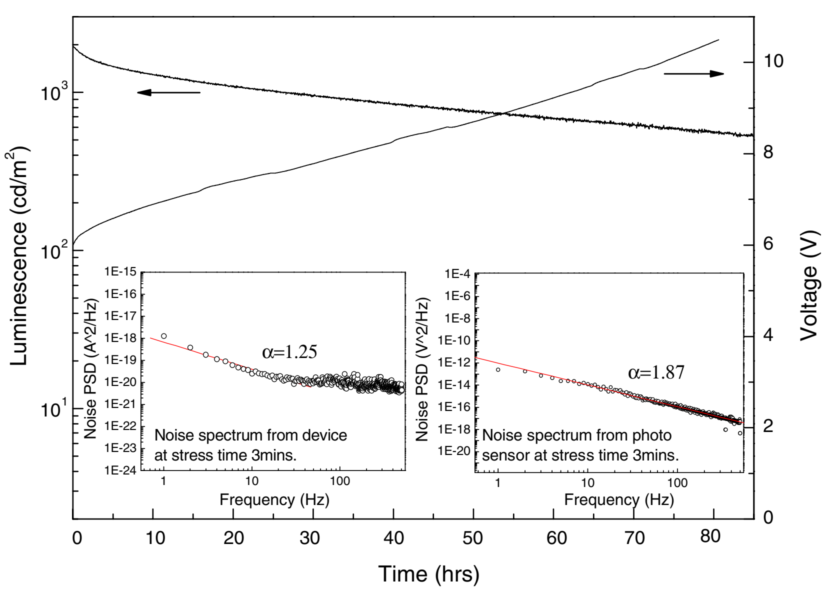

Fig. 1. Device voltage versus time and luminescence versus time, the inset figures show noise spectrum from OLED device and noise spectrum from photo sensor at stress time of 3 min.