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Study of the transient electroluminescence process using organic light-emitting diodes with a partial doping layer

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1. Introduction

Recently, organic light-emitting diodes (OLEDs) utilizing fluorescent dyes [1] or conducting polymers [2] have been realized which have a long lifetime and excellent durability for flat-panel display applications. The demand for OLEDs has increased to new application such as electronic paper, optical conversion device, and various light sources.

The dye doping method is practically important because it is easy to improve their performance such as color tunability, efficiency and device lifetime. [3,4] It is difficult to obtain optical pulses of more than 100 MHz using the green emitting OLED with tris(8-hydroxy quinoline) aluminum (Alq_3) as the emissive layer because the fluorescence lifetime of Alq_3 is more than 10 ns. On the other hand, the speed of the optical pulse in the OLED with dye doped in Alq_3 as the emissive layer can be expected to be faster than that with Alq_3 when the fluorescence lifetime of the dye is shorter than that of Alq_3 . We reported Optical pulses of more than 100 MHz were created by directly modulating a yellow emitting OLED with rubrene doped in Alq_3 . [5,6] The dye doping method is also effective to obtain the high-speed optical pulses from OLEDs. The study of the electroluminescence process of OLEDs using a partial dye doping method has been also reported. [7-9] The fundamental properties of these devices are mostly investigated under DC operation.

In this study, we examined the transient electroluminescence process in the interface and bulk of emissive layer by measuring the transient response of OLEDs with a partial doping layer.

2. Experimental

Figure 1 shows the device structure used in this study. The typical device consists of an indium-tin-oxide (ITO) -coated glass substrate, 4,4'-bis[N-(1-naphthyl)-N-phenyl-amino]-bi phenyl (α -NPD) hole transporting layer and Alq_3 emissive layer with a 4-(dicyanomethylene)-2-i-propyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H - pyran (DCJTI) partial doping layer, terminated with a 0.5 nm-thick lithium fluoride (LiF) and Al electrodes cathode.

The layer structure was fabricated by organic molecular beam deposition on ITO-coated glass substrates to form the EL devices at a background pressure of about 10^{-5} Pa. The organic materials were placed in separate Knudsen cells, heated to their sublimation temperature, and subsequently deposited onto the substrate. The layer thickness of the deposited material was monitored in situ using an

oscillating quartz thickness monitor. Finally, a LiF/Al cathode was vapor-deposited at a background pressure of 10^{-4} Pa onto the organic films. Forward bias condition is defined as the case in which the ITO electrode is positively biased against the Mg:Ag electrode, and negative bias, vice versa.

The electroluminescent (EL) spectra were measured using a photonic multichannel spectral analyzer (Hamamatsu Photonics, PMA-11). The current -voltage -luminance ($I-V-L$) characteristics were obtained using a 2000 multimeter (Keithley), a regulated DC power supply (Kenwood, PW36-1.5AD) and a luminance meter (Minolta, LS-100). The transient EL measurements were performed by applying square-wave voltage pulses generated by an HP8110A source (Agilent). The optical pulse was observed using a photomultiplier tube detector (Hamamatsu Photonics). The EL response and voltage were simultaneously digitized by a Sony Tektronix TDS3054 oscilloscope. All of the measurements were carried out at room temperature.

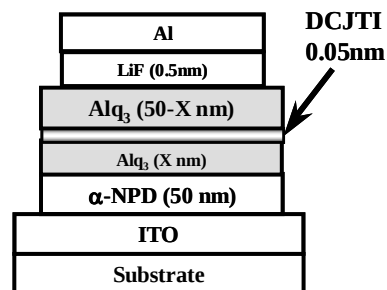


Fig. 1. Device structure employed in this study.

3. Results and discussion

Figure 2 shows the typical EL spectra of the devices with a 0.05 nm thick DCJTI partial doping layer in different regions. The peak wavelength of EL spectra of Alq_3 and DCJTI devices is about 520 and 620 nm, respectively. The EL spectrum of device with a 0.05 nm thick DCJTI partial doping layer at the α -NPD/ Alq_3 interface is mostly attributed to the fluorescence of DCJTI. This result indicates excitons are confined within the narrow region of α -NPD/ Alq_3 interface. In the case of devices with a DCJTI partial doping layer in the Alq_3 layer, the EL intensity of spectrum due to the fluorescence of Alq_3 increases as the DCJTI layer moves into the bulk of the Alq_3 layer.

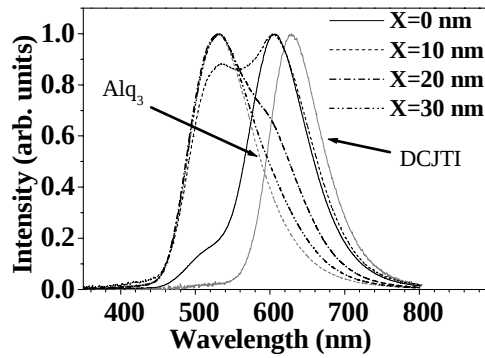


Fig. 2. Typical EL spectra of the devices with a 0.05 nm thick DCJTI partial doping layer in different regions.

The dependence of luminance on the applied voltage for various devices with an active area of 2 mm diameter is presented in Fig.3. The luminance increases significantly in the forward bias direction above a threshold voltage of approximately 2.4 V. The maximum luminance of more than 30,000 cd/m² was obtained from all devices.

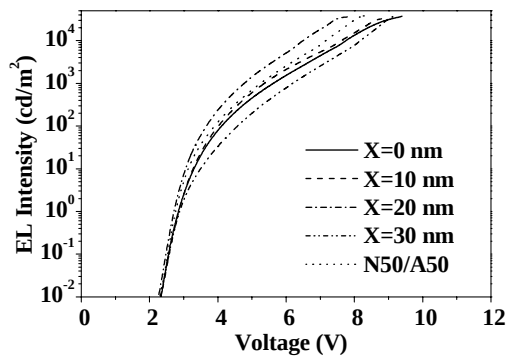


Fig. 3. The typical EL spectra of the devices with a 0.05 nm thick DCJTI partial doping layer in different regions.

Figure 4 shows transient characteristics of EL signals in various devices at 520nm and 620nm corresponding to the peak wavelength of EL spectra of Alq₃ and DCJTI, respectively. The devices with an active area of 0.5 mm diameter are driven at a 1 ms period and duty ratio of 1/100 pulse. The transient EL waveform at 620 nm has an initial overshooting peak, which may be due to recombination of the accumulated charges. The highest occupied molecular orbital of DCJTI is above that of Alq₃ with a difference of 0.6 eV. The partial DCJTI molecules may act as traps for the injected holes, thereby confining the holes to the narrow region of α -NPD/ Alq₃ interface. The rise time of device with a 0.05 nm thick DCJTI partial doping layer at the α -NPD/Alq₃ interface is faster than that with a DCJTI partial doping layer in the Alq₃ layer. In the case of the devices (X=0,10,20), the rise time at 620nm is faster than that at 520nm. The fast response results from an initial overshooting peak of the transient EL waveform at 620 nm. The fact that the rise time of various devices at 520nm is almost same suggests that the initial electroluminescence and transport processes based on Alq₃ are not strongly

influenced by a partial doping of DCJTI. The detailed results for these devices will be shown on the presentation day.

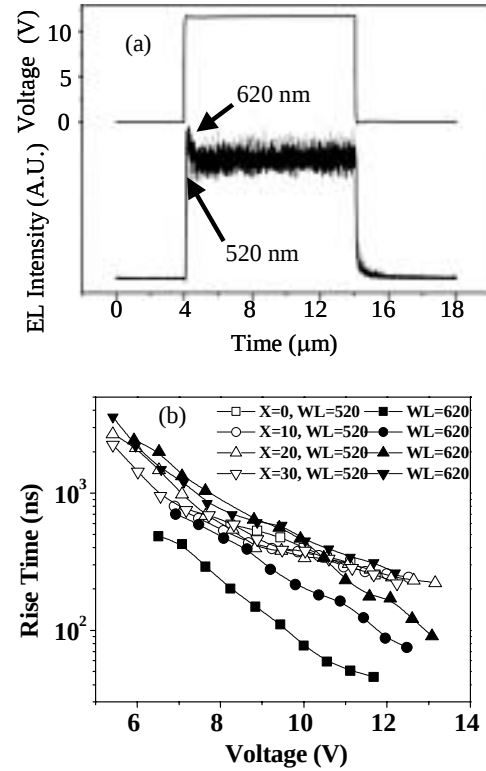


Fig. 4. (a) Transient EL signals of an device (X=0) and (b) voltage dependence of the rise time of various devices with a 0.05 nm thick DCJTI partial doping layer in different regions.

Acknowledgments

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