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# Characteristics of optical response in red organic light-emitting diodes using two dopant system for application to the optical link devices

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**Abstract**

We investigated the transient electroluminescence (EL) and modulation characteristics of red organic light-emitting diodes (OLEDs) consisting of 4-(dicyanomethylene)-2-i-propyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran (DCJTI) and 5,6,11,12-tetraphenylnaphthacene (rubrene) doped into tris(8-hydroxyquinoline)aluminum ($Alq_3$). The transient EL waveforms showed two components, an initial overshooting peak followed by a constant component, indicating that the excess amount of accumulated charges simultaneously recombine at the moment of onset. This overshoot effect reduced the rise time of transient EL and enhanced the optical output of the OLEDs, and hence the cutoff frequency was increased when the pulse voltage was applied to the device. We demonstrated that the red OLEDs are suitable for use in high-speed switching applications driven at more than 100 MHz, and in electro-optical conversion devices for transmitting video signals.


*Keywords:* Organic light-emitting diode; Electro-optical conversion device; Transient EL; Overshoot effect

## 1. Introduction

Since the first report of efficient emission from a triphenylamine derivative/tris(8-hydroxy-quinoline)aluminum ($Alq_3$) bilayer structure, organic light-emitting diodes (OLEDs) using low molecular weight dyes and polymer materials have been widely studied due to their potential applications in flat-panel displays [1,2].

Recently, the demand for OLEDs has increased to new application such as electronic paper, optical conversion device, and various light sources [3,4]. In particular, promising results have been obtained indicating the potential of OLEDs as light sources for data communication systems [5–7]. The combination of OLEDs and optical fibers provides huge advantages for fabricating optical integrated circuits and switches due to the advantages of OLEDs to fabrication on various substrate types, including glass and polymers. For example, the deuterated-polymethylmethacrylate (d-PMMA) based polymer waveguide has a low transmission loss in the near-infrared and red emission region, so the use of red OLEDs as a light source is an efficient tool for optical integration [8].

OLEDs have lower optical power than laser diodes (LDs). Thus, they are suited to applications requiring light sources acting over short distances and involving multimode paths, and can also be used to generate high-speed optical pulses in electro-optical conversion devices. The development of red OLEDs is important for high-speed switching in local-area network (LAN) applications such as fiber to the home (FTTH) and car-LAN.

To prevent concentration quenching and improve the luminous efficiency of OLEDs, a doping system is utilized in the red emission from the emitting layer consisting of a host material and red guest fluorescent dye. In addition, use of a two-dopant system containing an assistant dopant has also been shown to be an efficient approach when the energy transfer from host to dopant is not complete [9].

In the present study, we used tris(8-hydroxyquinoline)aluminum ($Alq_3$) as the host material due to its charge transport ability and because the emission from $Alq_3$ sufficiently overlaps with the absorption of red dyes. To achieve the red emission, 4-(dicyanomethylene)-2-i-propyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran (DCJTI)

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and 5,6,11,12-tetraphenylnaphthacene (rubrene) were used as the emissive material and emitting assistant dopant, respectively.

We fabricated red OLEDs utilizing a two-dopant system in which both DCJTI and rubrene were doped with $Alq_3$, and estimated the transient electroluminescence (EL) response and modulation characteristics of this system to examine its possibility for application in electro-optical conversion devices.

## 2. Experimental

The device configurations and molecular structures of the organic materials used in this study are shown in Fig. 1. Red OLEDs with three different structures, referred to as type I, II, and III, were fabricated to examine the dependence of the transient characteristics on the device structure. The thickness of *N*,*N*′-di-[(1-naphthyl)-*N*,*N*′-diphenyl]-(1,1′-biphenyl)-4,4′-diamine (α-NPD) was 50 nm in all devices, and that of the doped emissive layer was 50, 30, and 25 nm in device types I, II, and III, respectively. In addition, a 20 nm-thick $Alq_3$ layer and 10 nm-thick 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) layer were inserted in devices II and III. Thus the total thickness of the organic layers was 100 nm in all devices.

All organic layers were prepared by the organic molecular beam deposition (OMBD) method using a vacuum level of $2 \times 10^{-7}$ Torr. The doping concentrations of DCJTI and rubrene were fixed at 2 and 5 v/v% relative to the $Alq_3$, respectively. After deposition of the organic layer, 0.5 nm-thick lithium fluoride (LiF) and 50 nm-thick Al electrodes were sequentially deposited at $2 \times 10^{-6}$ Torr on top of the organic layer. The deposition rate was 1 Å/s for both LiF and Al. To protect the metal electrode, a 100 nm-thick layer of Ag was additionally deposited onto the top of the Al electrode. The active emission area was a 100 or 300 μm-diameter circle to reduce the device capacitance.

The optical absorption and photoluminescence (PL) of organic materials were measured using a UV–VIS–NIR scanning spectrophotometer (Shimadzu, UV-3100FS) and spectrofluorometer (Jasco, FP-6500), respectively. The electroluminescence (EL) spectra of the devices were measured using a photonic multi-channel analyzer (Hamamatsu PMA-11).

For the transient EL measurements, a pulse generator (Agilent 8110A) was used to apply voltage pulses to the OLEDs. The duty cycle was maintained at 1%, operating with a repetition rate of 1 kHz and a pulse width of 10 μs. The transient EL signals were measured by digital oscilloscope (Tektronix TDS 3054) using a photocurrent from a photomultiplier (Hamamatsu H6780). The voltage pulse and transient EL waveforms were simultaneously displayed on a digital oscilloscope and the rise time was calculated from the EL waveforms. The measurement for transmitting the signals of the moving picture was performed using ZL271-275 optical transmission and receiver equipments (Melco Technorex).

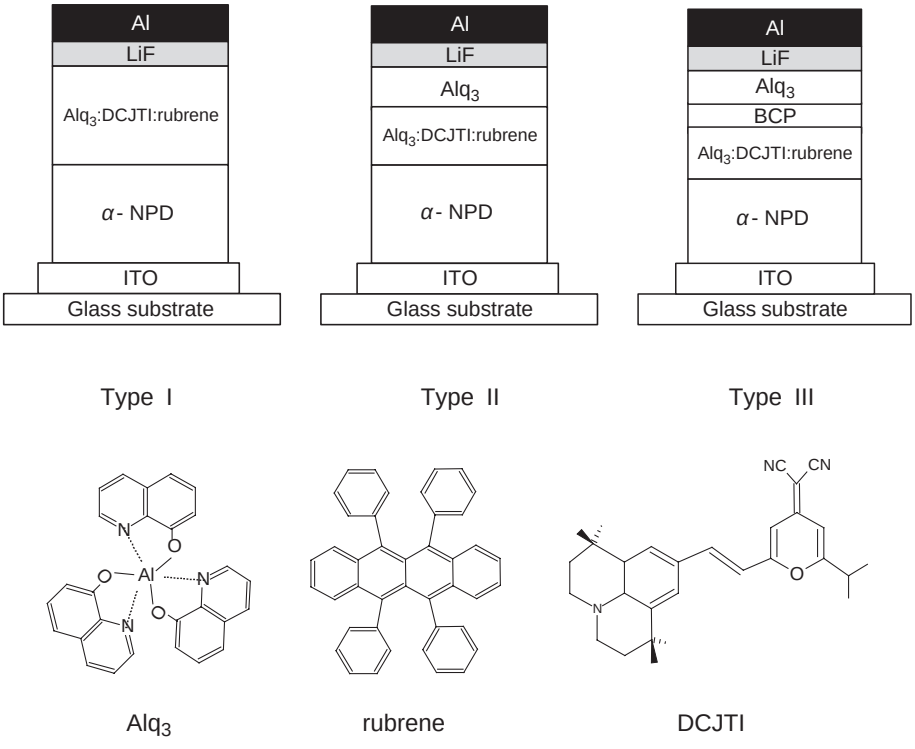


Fig. 1. Structures of the three kinds of devices fabricated in this study, and molecular structures of $Alq_3$, rubrene, and DCJTI used as the doped emitting layer.