Temporal Response of the Organic Electroluminescent Device with a Vacuum-Deposited Poly(p-phenylene) Thin Film

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Abstract

The temporal response of the electroluminescence (EL) has been studied in the organic electroluminescent devices fabricated with a vacuum-deposited poly(p-phenylene) (PPP) thin film upon the application of a rectangular driving voltage. The blue EL emission arises with a delay time of several hundred nanoseconds and then saturates with the rise time of less than microsecond. The EL delay time is considered as the transit time of holes in the PPP thin film since the hole mobility is much larger than the electron mobility in PPP. The hole mobility is estimated to be ~ 1×10^{-5} cm^2/Vs in the vacuum-deposited PPP film.

Introduction

The organic electroluminescent devices (OELDs) with thin films of small molecules or polymers as the active emissive layers become very attractive for their potential applications in large-area, full-color, flat-panel displays [1,2]. Electroluminescence (EL) results from the radiative recombination of electrons and holes injected from the cathode and anode, respectively. Upon the application of short rectangular voltage pulses in the forward bias the EL arises with a delay time τ_d and then saturates when the electron and hole distributions have reached the steady-state condition [3-5]. At the end of the voltage pulse, the EL decays to zero as the injected charge carriers deplete. The delay time τ_d of the EL onset is considered as the time for the leading edges of the packets of injected electrons and holes to meet and undergo radiative recombination [3-5]. Therefore, one can study charge carrier dynamics as well as estimate the charge carrier mobility from the temporal response of the transient EL signal. In this paper, we will present the result of the transient EL measurements in blue OELDs fabricated with the vacuum-deposited poly(p-phenylene) (PPP) thin film [6].

Experimentals

The details of the synthesis and characterization of poly(p-phenylene) used in this study has been previously reported [7]. The chemical structure of PPP and the device configuration are shown in Figure 1. The PPP thin film was deposited onto the pre-cleaned ITO substrate (sheet resistance of ~10 Ω/□, Samsung Corning Co., Ltd.) by heating the PPP powder to 500 °C under a vacuum of about 2×10^{-6} Torr. From the IR spectrum analysis, we found that the average phenylene chain lengths of the vacuum-deposited PPP thin film was about n=8-9 [6-8]. On top of the PPP layer, the Al electrode was deposited with the active area of about 4 mm^2. The current-voltage-EL (I-V-EL) characteristics were measured using a Keithley 2400 SourceMeter. and a Keithley 2000 multimeter equipped with a calibrated Si photodiode. The transient EL signal detected by a fast PMT, the voltage pulse from the pulse generator (HP 214B) and the voltage across the current-limiting resistor (50 Ω) were simultaneously digitized with a 500 MHz digital storage oscilloscope (Tektronix TDS 644B). The overall RC time constant of the system was estimated to be less than 50 ns.

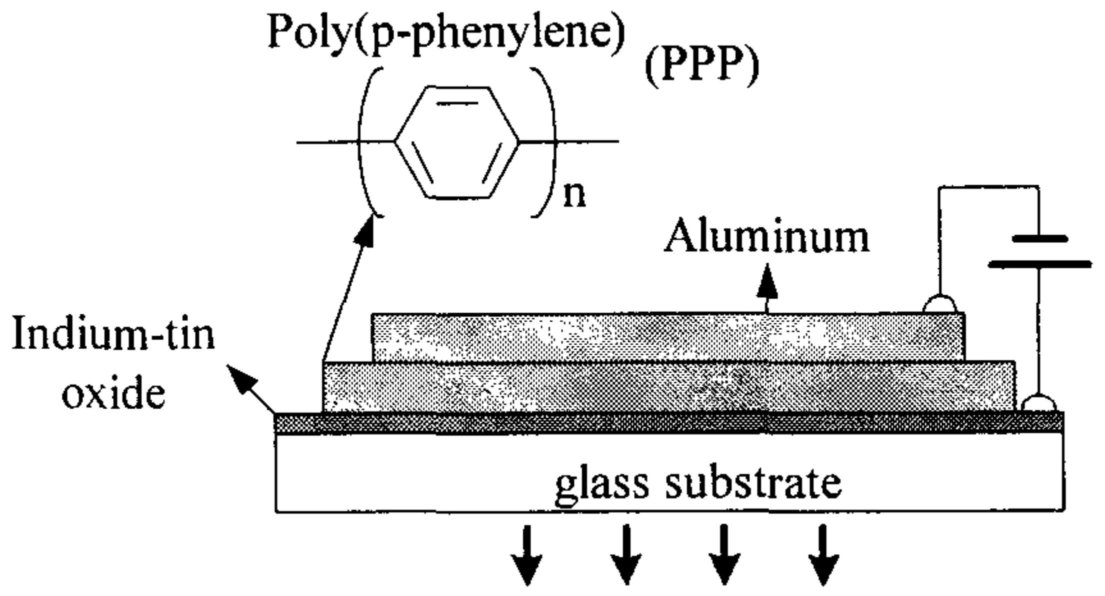

Fig. 1. Configuration of the ITO/PPP/Al device and the chemical structure of PPP

Results and Discussion

Figure 2 shows the current-voltage-EL (I-V-EL) characteristics of the ITO/PPP/Al device at 290 K. The I-V characteristics show the rectifying behavior with the forward bias defined as positive voltage applied to the ITO electrode. The inset shows the EL-current (EL-I) characteristics of the same device.

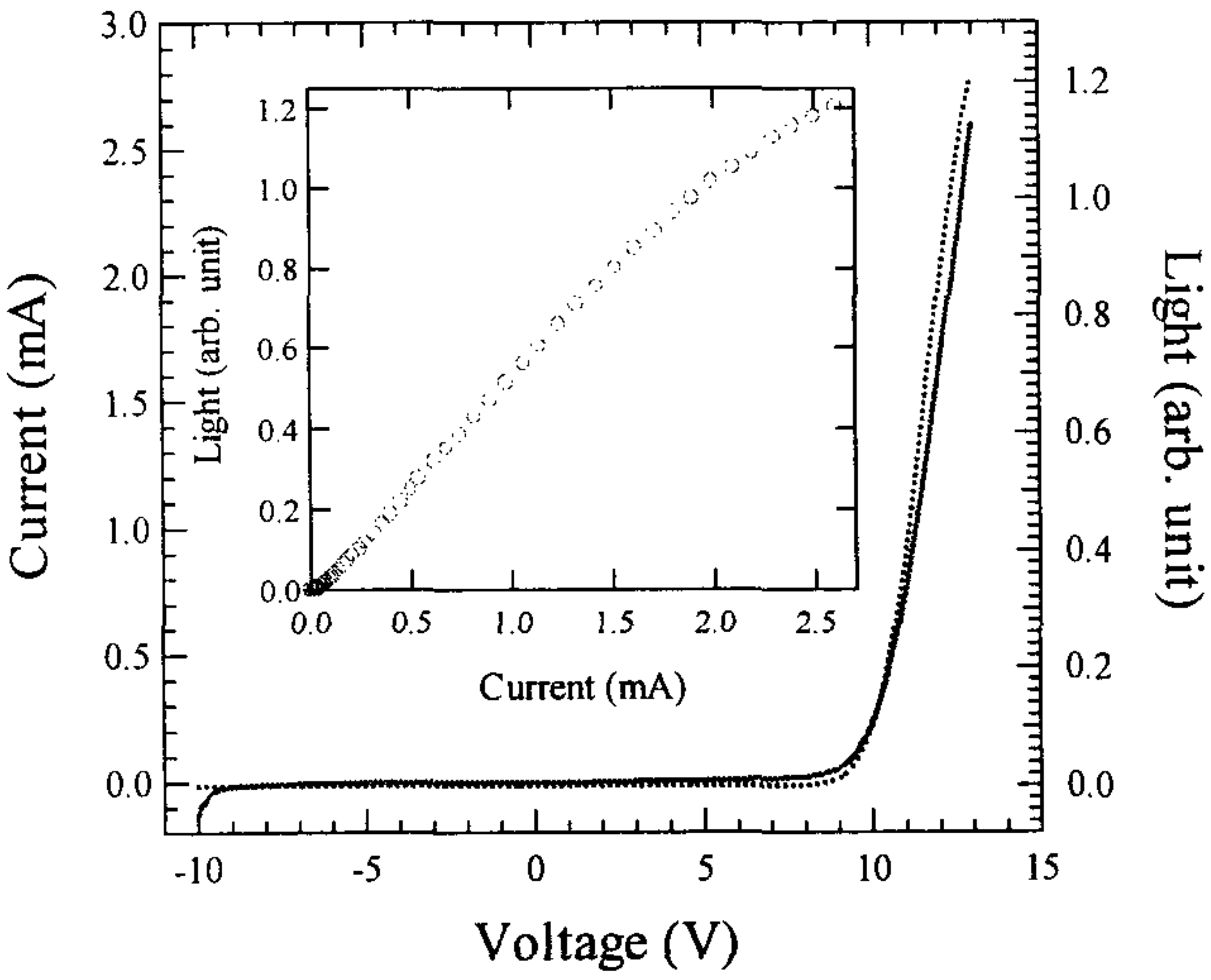

Fig. 2. The I-V (solid) and EL-V (dotted line) characteristics of the ITO/PPP (d=120 nm)/Al device at T=290 K. The inset shows the EL-I characteristics of the same device.

The ITO/PPP/Al LED device in Fig. 2 turned on at ~ 8 V with a blue emission (peak at ~ 450 nm). The EL intensity increases linearly with the current. The external quantum efficiency, proportional to the slope of the EL-I curve, is estimated of about 0.02 %. From the detailed analysis of the I-V-EL characteristics we found that the charge carrier injection was dominated by a tunneling process through an energy barrier of about 0.7 eV in the ITO/PPP/Al devices [6].

Figure 3 shows the typical transient EL response of the ITO/PPP/Al device in comparison with the voltage pulse shape of the pulse generator and the voltage response, V_L, across the current-limiting resistor (50 Ω) in series with the device. The voltage spikes in V_L at the rise and fall of the pulse is due to the inductive effect in the circuit. The EL emission arises with the time delay of about 0.2 µs after the onset of the bias voltage pulse and then saturates at about 0.5 µs. The fast response time (<µs) is an important feature of the OELDs or the high-resolution display [9].

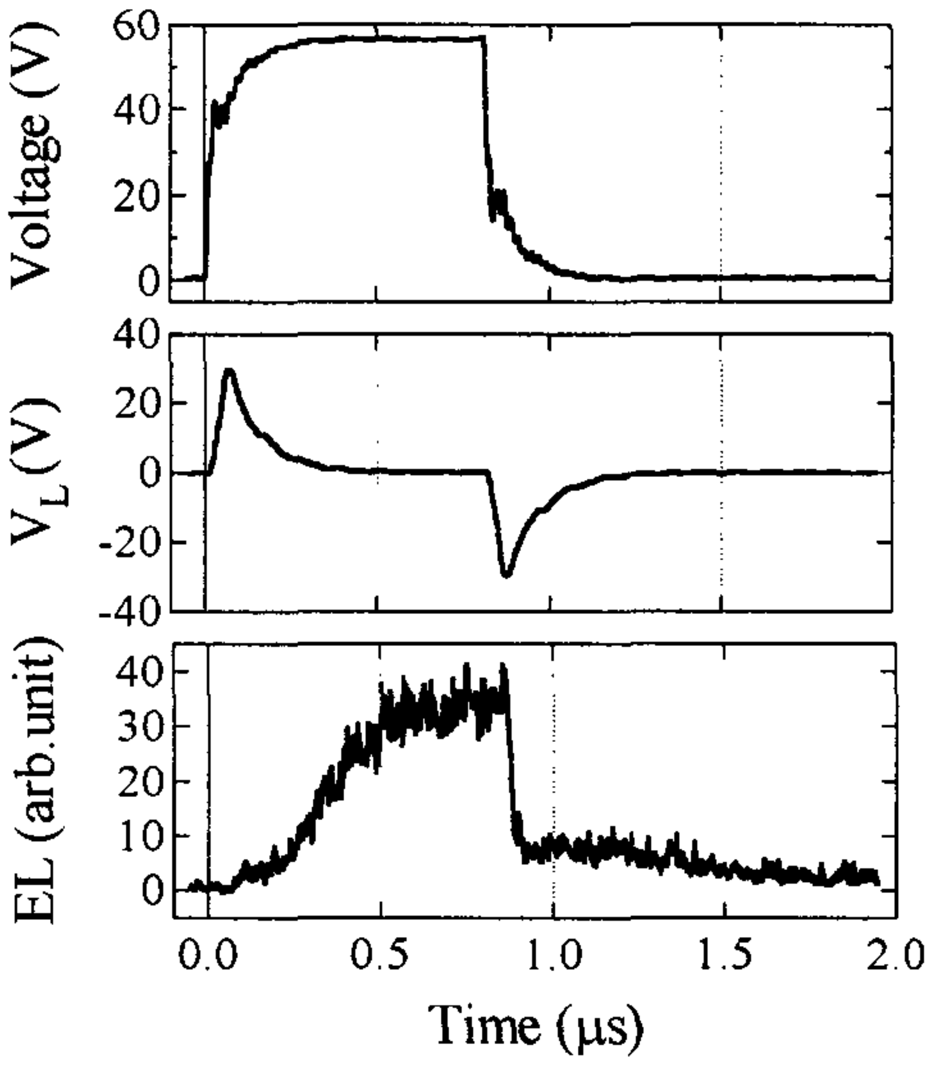

Fig. 3. Typical transient EL response of the ITO/PPP/Al device, compared with the pulse shape of the pulse generator and the voltage V_L across the current-limiting resistor (50 Ω) in series with the device.

Figure 4 shows the EL time delay as a function of 1/V in the ITO/PPP/Al devices with different PPP layer thicknesses of about d_1=120 nm and d_2=260 nm. The EL delay time is considered as the transit time of holes in the PPP thin film since the hole mobility is much larger than the electron mobility in PPP [3]. Then the time delay is given by $\tau_d \cong d/(\mu_n + \mu_p)F \cong d/\mu_p F$, where d is the thickness of the PPP layer, μ_n and μ_p are the electron and hole mobilities, respectively, at an average electric field F. Thus, we can calculate the hole mobility from the slope of the straight-line approximation and the thickness of the PPP film. The hole mobility is obtained to be μ_p ~ $1\text{x}10^{-5}$ cm^2/Vs in both devices. This hole mobility value is consistent with that recently reported in organic El devices based on para-hexaphenyl film [10].

Conclusion

The transient EL response has been studied in blue OELDs fabricated with the vacuum deposited PPP thin film. The ITO/PPP/Al devices turned on at ~ 8 V with an external quantum efficiency of ~ 0.02 %, and they had a fast response time less than microsecond. The dependence of the transient EL response on the amplitude of voltage pulses and the film thickness indicates that the EL time delay results from the transit of holes across the PPP layer. The hole mobility is estimated to be ~ $1\text{x}10^{-5}$ cm^2/Vs in the vacuum-deposited PPP film.

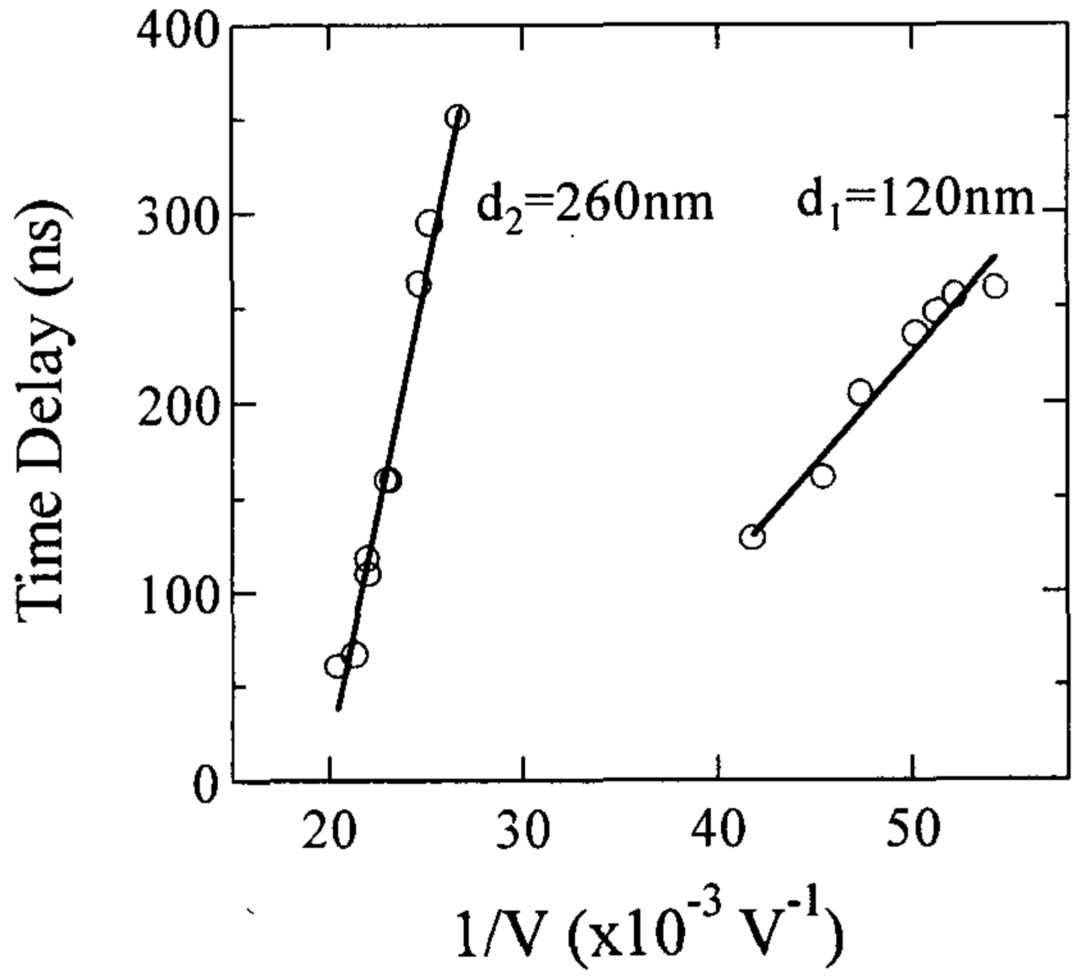

Fig. 4. The EL time delay as a function of 1/V in the ITO/PPP/Al devices with PPP layer thicknesses of about d_1=120 nm and d_2=260 nm.

Acknowledgements

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