

Current-Voltage-Luminance Characteristics Depending on a Direction of Applied Voltage in Organic Light-Emitting Diodes

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(Received 18 January, Accepted 25 February 2002)

We have investigated current-voltage-luminance characteristics of organic light-emitting diodes based on TPD/Alq₃ organics depending on the application of forward-backward bias voltage. Luminance-voltage characteristics and luminous efficiency were measured at the same time when the current-voltage characteristics were measured. We have observed that the current-voltage characteristics shows a reversible current maxima at low voltage, which is possibly not related to the emission from Alq₃. Current-voltage-luminance characteristics imply that the conduction luminance mechanism at low voltage is different from that of high voltage one.

Keywords : Organic light-emitting diodes, Current-voltage-luminance characteristics, Negative differential resistance

1. INTRODUCTION

In 1987, Tang and VanSlyke reported a bilayer organic electroluminescent (EL) cell structure, which has a quantum efficiency of about 1% and a luminance of 1,000 cd/m² for green light under the low-operating voltage below 10V[1]. Organic light-emitting diodes (OLEDs) have been received attention due to their potential applications for full color flat-panel displays, low-driving voltage and capability of multicolor emission of many synthesized organics[2-6]. The obtained power and quantum efficiency as well as lifetime are already sufficient for commercial application. Electroluminescence in OLEDs occurs when the diode is biased for holes and electrons to be injected from anode and cathode. The injected carriers are transported through the organics and some of them are recombined. When the recombination occurs, there is a light emission. This is called electroluminescence.

Several models have been proposed to explain the electrical properties of OLEDs in terms of current-voltage (I-V) characteristics. According to Parker[7], the conduction mechanism could be explained by Fowler-Nordheim tunneling of both electrons and holes through the contact barriers arising from the band offset between the organics and the electrodes. However, Blom et al.[8]

described the I-V characteristics in terms of bulk properties of the organics rather than the charge injection mechanism. Thus, the understanding of mechanisms on charge carrier injection, transport and recombination is not yet fully understood. In addition, the I-V characteristics show an anomalous bump at low voltage, which gives a negative differential resistance (NDR). There are some reports on this NDR behavior in OLEDs[9-10]. Manca et al., observed anomalous I-V characteristics depending on the presence of oxygen in the surrounding atmosphere[9]. It shows that the anomaly strongly depends on the oxygen. When there is enough oxygen in the surrounding, the anomaly disappears. However, the implication of this behavior is not clearly understood yet.

In this paper, we present new observation of anomalous behavior at low voltage in the I-V characteristics of ITO/TPD/Alq₃/Al device with a direction of applied voltage.

2. EXPERIMENTALS

We have fabricated the OLEDs with a use of N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine(TPD) as a hole-transport and 8-hydroxyquinoline

aluminum(Alq_3) as an electron transport and emissive material. The ITO glass, having a sheet resistance of $15\Omega/\square$ and 170nm thick, was received from Samsung Corning Co.

A 5mm wide ITO strip line was formed by selective etching in solution made with hydrochloric acid (HCl) and nitric acid (HNO_3) with a volume ratio of 3:1 for 10~20 minutes at room temperature. And then the patterned ITO glass was cleaned by sonicating it in chloroform for 20 minutes at 50°C . And then the ITO glass was heated for 1 hour at 80°C in solution made with second distilled deionized water, ammonia water and hydrogen peroxide with a volume ratio of 5:1:1. We sonicated the substrate again in chloroform solution for 20 minutes at 50°C and in deionized water for 20 minutes at 50°C . After sonication, the substrate was dried with N_2 gas stream and stored it under vacuum. Fig. 1 shows molecular structures of TPD, Alq_3 and device structure. The organic materials were successively evaporated under 10^{-6} torr with a rate of about $0.5\sim 1 \text{ \AA/s}$.

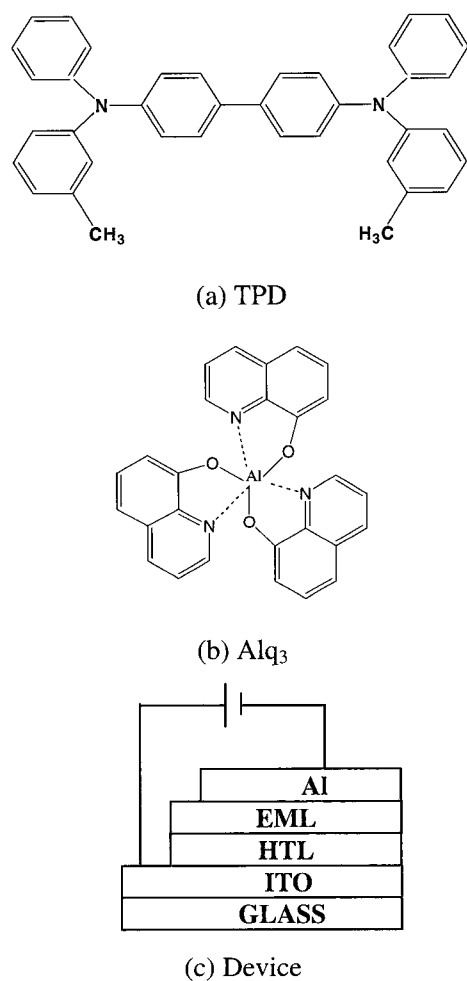


Fig. 1. Molecular Structure of (a) TPD, (b) Alq_3 and (c) device structures.

The film thickness of TPD and Alq_3 was made to be 40nm and 60nm, respectively. And Al cathode(150nm) was deposited at 1.0×10^{-5} torr. Light-emitting area was defined by using a shadow mask to be $0.3\times 0.5 \text{ cm}^2$.

Current-voltage-luminance characteristics of OLEDs were measured using Keithley 236 source-measure unit, 617 electrometer and Si-photodiode. Luminance-voltage characteristics were also measured at the same time when the current-voltage characteristics were measured. The efficiency of device was calculated based on the luminance, electroluminescent (EL) spectra and current densities. The EL spectra were measured using Perkin Elmer LS-50B spectrophotometer (Xenon flash tube).

3. RESULTS AND DISCUSSION

Figure 2 shows the semi-logarithmic plot of (a) current-voltage and (b) luminance-voltage characteristics of ITO/TPD/ Alq_3 /Al device.

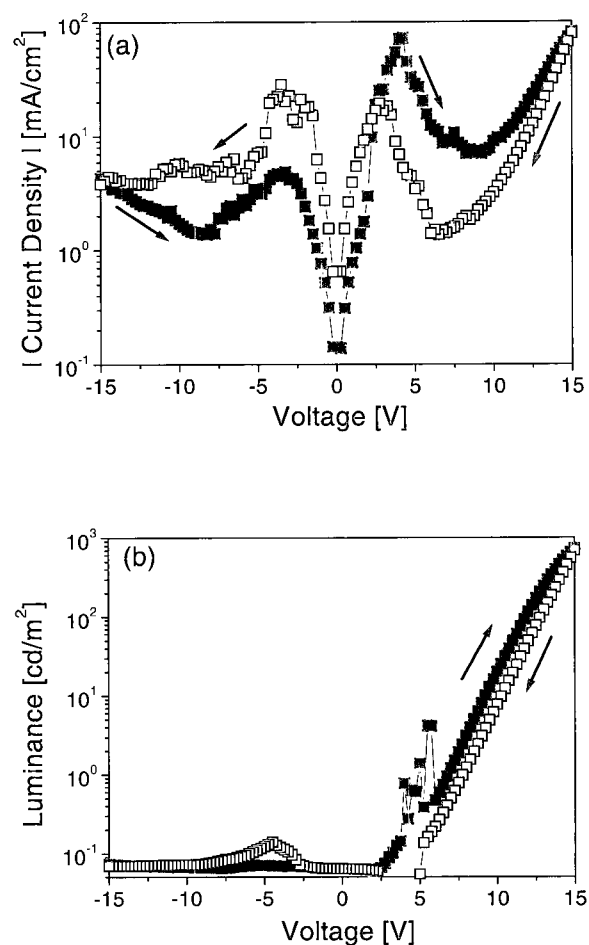


Fig. 2. (a) Current-voltage characteristics and (b) luminance-voltage characteristics in ITO/TPD/ Alq_3 /Al device.

The current and luminance were measured as the voltage is increasing from -15V to +15V continuously and then decreasing backwards from +15V to -15V with 100ms delay time at each measurement.

Figure 2(a) clearly shows that the curve follows different path depending on the direction of applied voltage. There are quasi-reversible current maxima at around ± 3.5 V and minima at approximately ± 8 V. Quite surprisingly, there exists negative differential resistance (NDR) region in between 3.5V and 8V. Even though the maximum current at about 3.5V is about the same as that at 15V, the luminance at 3.5V is much lower than that at 15V (see Fig. 2(b)). It indicates that even though there is a high current through a device, most of current does not contribute to the electroluminescence. There may be some other conduction route causing the high current without luminescence. We speculate this phenomenon to be related to the carrier trapping.

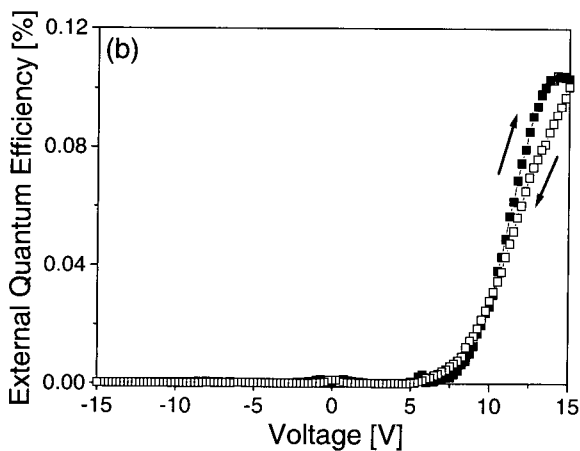
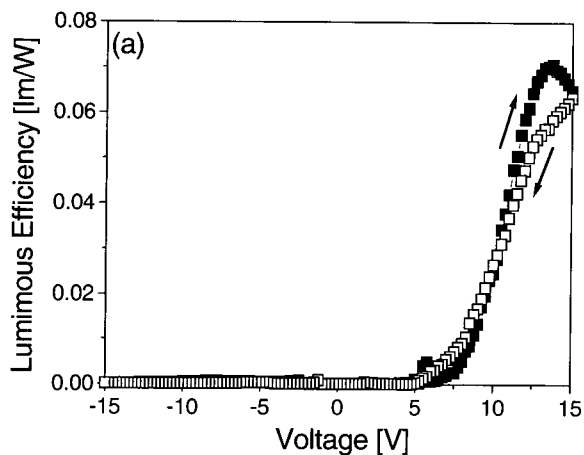


Fig. 3. (a) Luminous efficiency and (b) external quantum efficiency characteristics of ITO/TPD/Alq₃/Al device.

The carrier trapping site might be either interface or inside bulk. If we see Fig. 2(b), there is a very weak luminance of less than 1cd/m² at ± 5 V.

Figure 3 shows the (a) luminous efficiency and (b) external quantum efficiency of ITO/TPD/Alq₃/Al as a function of voltage. When the voltage is applied in forward direction, the luminous efficiency reaches a maximum at about 13V even though the current density and luminance increases further above 13V. When the voltage is decreased, it follows almost the same path as before. A little difference is that the variation of efficiency in forward direction is a little bit steeper than the other one. Maximum luminous efficiency and external quantum efficiency are 0.07lm/W and 0.10%, respectively. These low value of efficiency is not a big deal at this moment, because this measurement was done at ambient environment.

Figure 4 shows an electroluminescent(EL) spectra of ITO/TPD/Alq₃/Al device in the range of 3~10V.

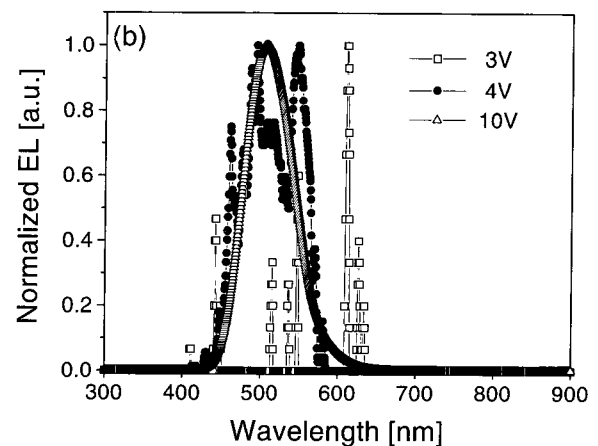
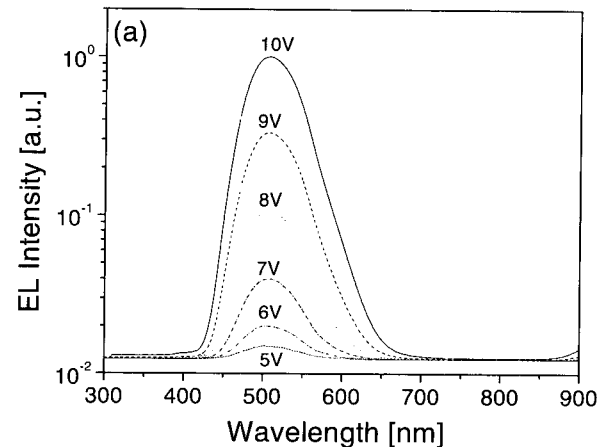


Fig. 4. (a) Electroluminescent spectra and (b) normalized electroluminescent spectra of ITO/TPD/Alq₃/Al devices.

It shows that there is a green light emission at 510nm when the voltage is greater than 5V. This peak wavelength is a typical one from Alq₃. No electroluminescence was observed below 2V.

If the applied voltage is 3V and 4V where the current anomaly occurs, there is a very weak and lousy luminescence. We can see in the experiment that the low-voltage luminescence comes from local spots rather than the whole surface emission. These local spots are not related to a burn-out of the device because this phenomenon is reproducible.

4. CONCLUSION

We have observed the anomalous behavior in current-voltage characteristics of ITO/TPD/Alq₃/Al device with the direction of applied voltage at ambient pressure. There is a reversible current maxima at low voltage and there is a NDR region in between 3.5V and 8V. It seems that the conduction mechanism at low voltage is totally different from the one at high voltage. We speculate this NDR behavior at low voltage comes from a carrier trapping. We have to study further what the source of carrier trapping is in the device.

ACKNOWLEDGMENTS

This work was supported by Grant No. R01-1999-00032 from the Korea Science & Engineering Foundation.

REFERENCES

- [1] C. W. Tang and S. A. VanSlyke, "Organic electroluminescent diodes", *Appl. Phys. Lett.*, Vol. 51, p. 913, 1987.
- [2] C. W. Tang, S. A. VanSlyke, and C. H. Chen, "Electroluminescence of doped organic thin films", *J. Appl. Phys.*, Vol. 65, p. 3610, 1989.
- [3] C. Adachi, T. Tsutsui, and S. Saito, "Blue light-emitting electroluminescent devices", *Appl. Phys. Lett.*, Vol. 56, p. 799, 1990.
- [4] S. W. Pyo, Y. M. Kim, H. S. Lee, S. H. Lee, Y. K. Kim, and J. S. Kim, "A study on the various organic electroluminescent devices using lanthanide chelate metal complexes", *J. of KIEEME* (in Korean), Vol. 13, No. 5, p. 437, 2000
- [5] J. S. Kim, J. U. Kim, and H. B. Gu, "Emission properties of white light emission organic electroluminescent device using exciplex emission", *J. of KIEEME*(in Korean), Vol. 14, No. 9, p. 762, 2001.
- [6] S. K. Kim, D. H. Chung, H. S. Lee, T. G. Chung, T. W. Kim, H. K. Min, J. W. Park, M. J. Song, and J. U. Lee, "Effects of buffer layer in organic light-emitting diodes", *Proc. 2001 Summer Conf. KIEEME*, Vol. 2, No. 1, p. 174, 2001.
- [7] I. D. Parker, "Carrier tunneling and device characteristics in polymer light-emitting diodes", *J. Appl. Phys.*, Vol. 75, p. 1658, 1994.
- [8] P. W. M. Blom, M. J. M. de Jong, and J.J.M. Vlegaar, "Electron and hole transport in poly(*p*-phenylene vinylene) devices", *Appl. Phys. Lett.*, Vol. 68, p. 3308, 1996.
- [9] J. Manca, W. Bijnens, R. Kiebooms, J. D'Haen, M. D'Olieslaeger, T.-Di Wu, W. De Ceuninck, L. De schepper, D. Vanderzande, J. Gelan, and L. Stals, "Effect of oxygen on the electrical characteristics of PPV-LEDs", *Optical Materials*, Vol. 9, p. 134, 1998.
- [10] S. Berleb, W. Brutting, and M. Schwoerer, "Anomalous current-voltage characteristics in organic light-emitting devices", *Synthetic Metals*, Vol. 102, p. 1034, 1999.