$ITO/Alq_3/Al$ 소자의 주파수 의존 응답을 이용한 유기발광소자의 등가회로 분석

안준호, 정동회, 허성우*, 이준웅, 송민종**, 이원재***, 김태완*
광운대학교, 홍익대학교*, 광주보건대학**, 경원전문대학***

Equivalent-Circuit Analysis of Organic Light-Emitting Diodes using Frequency-dependent Response of $ITO/Alq_3/Al$ Device

Joon-ho Ahn, Dong-Hoe Chung, Sung-Woo Hur*, Joon-Ung Lee, Min-Jong Song**, Won-Jae Lee***, and Tae Wan Kim*
Kwangwoon University, Hongik University*, Kwangju Health College**, Kyungwon College***

Abstract

We have investigated equivalent-circuit analysis of organic light-emitting diodes using frequency-dependent response of $ITO/Alq_3(60nm)/Al$ device at two different bias voltages. Complex impedance Z of the device was measured in the frequency range of 40Hz~1MHz. A Cole-Cole plot shows that there are two dielectric relaxations at the bias below turn-on voltage, and one relaxation at the bias above turn-on voltage. We are able to interpret the frequency-dependent response in terms of equivalent-circuit model of contact resistance R_s in series with parallel combination of resistance R_p and capacitance C_p. We have obtained contact resistance R_s around 90Ω, mainly from the ITO anode.

keyword : impedance, frequency-dependant response

1. Introduction

There was a breakthrough in the area of organic light-emitting diodes due to a report of Tang and VanSlyke's work in Eastman Kodak[1]. A light emission from the device occurs due to a recombination of injected electrons and holes in the molecules. Hence, an injection mechanism, transport mechanism, and recombination process are important in organic light-emitting diodes. A dc current-voltage characteristic of the device gives a resistive response to the applied voltage. However, an ac current-voltage characteristic gives a resistive and capacitive response to the applied voltage. Roy et al., analyzed the organic layer in terms of resistive and capacitive component[2]. And Pospisil et al., reported that the impedance of organic layer depends on the frequency and the applied voltage[3].

In this paper, we report dielectric response of the organic light-emitting diodes through a study of frequency- and voltage-dependent impedance of the $ITO/Alq_3/Al$ device. From this study, we can establish an equivalent-circuit model of the device involving resistors and capacitors.

2. Experimental

Organic light-emitting diodes were fabricated with the Alq_3 emissive layer sandwiched between ITO anode and Al cathode. A thermal evaporation was employed to evaporate the powder of Alq_3 at a base pressure of 5×10^{-6} torr with a deposition rate of about 0.7Å/s. A thickness of organic layer was made to be 60nm. And then the aluminum was thermally evaporated to a thickness of 150nm at a base pressure of 5×10^{-6} torr. A deposition rate of aluminum was 0.5Å/s up to 10nm thick, and 10 Å/s in 10nm~150nm thickness range. A light-emitting area was made to be $15mm^2$(3mm×5mm). A surface resistance of ITO substrate is 15Ω/□ and a thickness is 170nm.

To characterize the organic light-emitting diodes, complex impedance of the device was measured as a function of frequency at ambient environment. Precision impedance analyzer of Agilent 4294A was used to measure the frequency-dependent response in the range of 40Hz and 1MHz.

3. Results and Discussion

A complex impedance Z can be expressed such as

$$Z = Z' + jZ'' = |Z| e^{j\theta} \qquad (1)$$

Figure 1 shows (a) a magnitude of impedance |Z| and (b) phase θ of the device as a function of frequency from 40Hz to 1MHz at a bias voltage of 2V and 12V.

As is seen in Fig. 1(a), the magnitude of impedance |Z| at 2V bias decreases from 40Hz to
As is seen in Fig. 1(a), the magnitude of impedance |Z| at 2V bias decreases from 40Hz to
100Hz in the beginning, and stays almost constant from 100Hz to 3kHz, and then gradually decreases as the frequency increases further. The corresponding phase θ at 2V bias is about zero below 1kHz, and

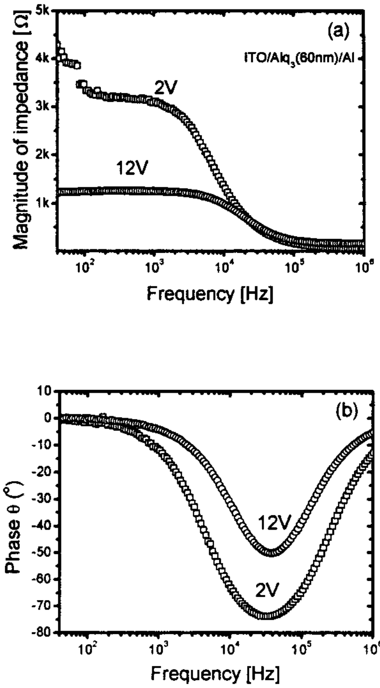

Fig. 1. (a) Magnitude of impedance |Z| and (b) phase θ as a function of frequency at a bias voltage of 2V and 12V in ITO/Alq_3(60nm)/Al organic light-emitting diodes.

decreases to about -75 near 30kHz, and then gradually approaches zero in the high frequency region(see Fig. 1(b)). A behavior of |Z| and θ measured under 12V bias is similar to that of 2V bias, except the magnitude of impedance |Z| is lower by a factor of one third to the previous one.

The complex impedance Z can be expressed in terms of real and imaginary part of impedance Z' and Z'' instead of |Z| and θ using Eq. (1) and Fig. 1. Figure 2(a) shows an absolute value of real and imaginary part of impedance |Z'| and |Z''| as a function of frequency measured at 2V, which is well below turn-on voltage. And Fig. 2(b) is the impedance measured at 12V, which is above the turn-on voltage. The real part of impedance |Z'| is almost constant below 1kHz and gradually decreases

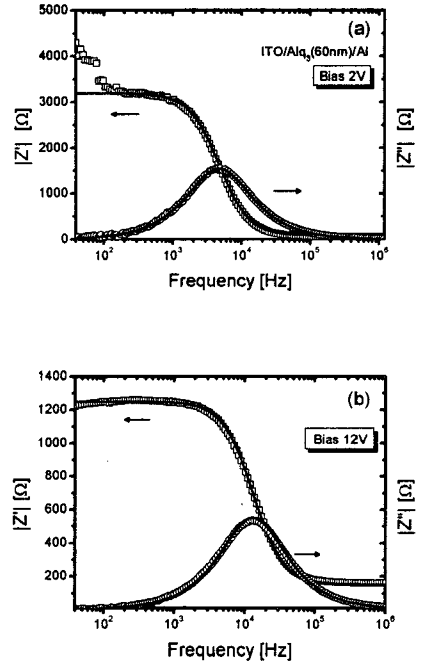

Fig. 2. Absolute value of real and imaginary part of impedance as a function of frequency at a bias voltage of 2V and 12V in ITO/Alq_3(60nm)/Al organic light-emitting diodes.

as the frequency increases.

A Cole-Cole plot was made as shown in Fig. 3. Bigger half circle in Fig. 3 is the one measured at 2V, and the smaller one at 12V. It is thought that there are two relaxations in the complex impedance measured at 2V; the first one is a big half circle which is supposed to be due to a molecular orientational polarization, and the second one is a low-frequency response(below 100Hz) possibly due to an interfacial polarization. However, the Cole-Cole plot at 12V shows only one relaxation due to a molecular orientational polarization.

We can employ an equivalent-circuit model of the device such as shown in Fig. 4 for the analysis of Cole-Cole plot. Then, the complex impedance Z in this model is

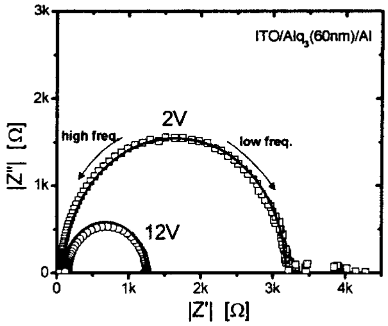

Fig. 3. Cole-Cole plot of the complex impedance Z of a single layer ITO/Alq_3(60nm)/Al organic light-emitting diodes at different bias voltages.

$$Z = Z' + jZ'' = R_s + \frac{R_p}{1 + j\omega\tau} \quad (2)$$

, where τ is given by R_pC_p. Then, the real and imaginary part of impedance are the following.

$$Z' - R_s = \frac{R_p}{1 + (\omega\tau)^2}$$
$$Z'' = -\frac{\omega\tau R_p}{1 + (\frac{1}{\omega\tau})^2} \quad (3)$$

The solid lines in Fig. 2 are fitted ones using Eq. (3). It implies that this equivalent-circuit model is appropriate in this device structure. We can show that the Z' and Z'' satisfy the following relation.

$$[Z' - (R_s + \frac{R_p}{2})]^2 + [Z'']^2 = (\frac{R_p}{2})^2 \quad (4)$$

In Z'-Z'' plane, this is an equation of circle, having a center at $(R_s + R_p/2, 0)$ with radius of $R_p/2$. The solid lines in Fig. 3 are fitted ones using Eq. (4). From this analysis, it gives a contact resistance of R_s around 90Ω. And the

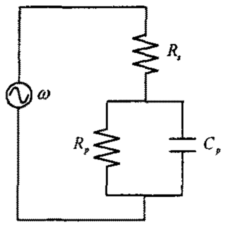

Fig. 4. Equivalent-circuit model of organic light-emitting diodes in terms of contact resistance R_s in series with parallel combination of resistance R_p and capacitance C_p.

radius gives a resistance R_p around 3,100Ω and 1,170Ω for 2V and 12V, respectively.

Using Eq. (2), we can express frequency-dependent R_p and C_p in terms of Z' and Z''.

$$R_p=(Z'-R_s)+\frac{(Z'')^2}{(Z'-R_s)}$$

$$C_p=-\left(\frac{1}{\omega R_p}\right)\cdot\left(\frac{Z''}{(Z'-R_s)}\right) \qquad (5)$$

Figure 5 shows a calculated resistance R_p and capacitance C_p of the device as a function of frequency at two bias voltages by applying the equivalent-circuit model of Fig. 4. A capacitance C_p is almost constant to be about 10nF in the measured frequency range irrespective of the bias voltages.

4. Conclusion

We have studied frequency-dependent response of organic light-emitting diodes using ITO/Alq_3(60nm)/Al device at two different bias voltages; one above and one below turn-on voltage. We are able to interpret the organic light-emitting diodes in terms of the equivalent-circuit model of contact resistance R_s in series with parallel combination of resistance R_p and capacitance C_p..

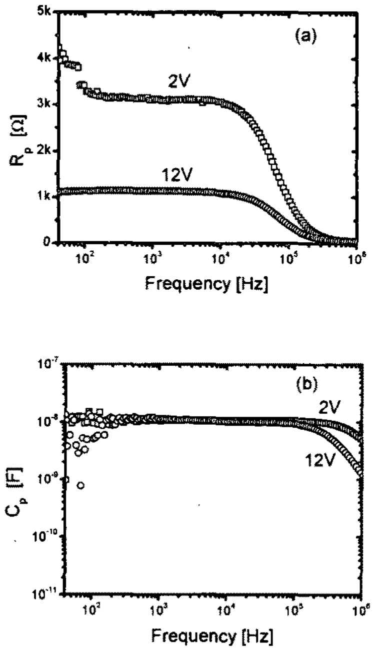

Fig. 5. Frequency-dependent R_p and C_p at the bias voltage of 2V and 3V in ITO/Alq_3(60nm)/Al organic light-emitting diode.

Acknowledgment

This work was support by Grant from Korea Ministry of Commerce, Industry and Energy(2004).

Reference

[1] C. W. Tang, S.A. VanSlyke, "Organic Electroluminescent Diodes", Appl. Phys. Lett. Vol 51. p. 913, 1987.

[2] Sudipto Roy, S. Kundu, S.K. Roy, Amlan J. Pal, "Impedance characteristics of layer-by-layer electrostatic self-assembled films of evans blue", Mater. Chem. Phys. Vol. 77, p. 784, 2002.

[3] J. Pospisil, J. Honskus, J. Fahnrich, P. Hlidek, P. Toman, "Optical and electrical properties of poly(p-phenylene vinylene) light emitting diodes", J. Lumin., Vol. 72, p. 522, 1997.