Dynamic Response of Organic Right-emitting Diodes in ITO/Alq₃/Al Structure

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Dynamic response of organic light-emitting diodes were analyzed in ITO/Alq₃(100 nm)/Al device structure with a variation of voltage an frequency. At low frequency region, complex impedance is mostly governed by resistive component, and at high frequency region by capacitive component. Also, we have evaluated resistance, capacitance and permittivity of devices.

1. INTRODUCTION

Researches on organic light-emitting device have been briskly performed since Tang and VanSlyke had embodied green light-emitting with a low molecule material in 1987[1,2]. The analysis of conduction model and equivalent circuit is needed to develop the most optimized display device[3-5]. Sudipto Roy et al. analyzed the equivalent circuit of organic layer with resistive component and capacitive component[6], J. Pospisil et al. presented the experimental results that component elements of organic layer might be changed with frequency and applied voltage variation[7]. Resistive and capacitive components of complex impedance with a variation of frequency and voltage variation were compared by calculating permittivity of Alq₃ and varying the frequency and applied voltage of organic layer. From this study, we can establish an equivalent-circuit model of the device involving resistors and capacitors.

2. EXPERIMENTS

In this experiment, ITO(Indium-Tin-Oxide) known as transparent electrode was used as a positive anode. Al was used as a negative cathode, and the device structure of ITO/Alq₃(100 nm)/Al were manufactured. Surface resistance and thickness of ITO substrate used as positive anode were 15 Ω/□ and 170 nm, respectively. And it was manufactured by Samsung Corning Co.

The Alq₃ (tris (8-hydroxyquinolinate) aluminum) used as organic layer was purchased from TCI Co. And its molecular weight is 459.44. It was vacuum-evaporated at the base pressure of 5×10^{-6} torr. Al used as negative cathode was also vacuum-evaporated at the base pressure of 5×10^{-6} torr, whose thickness was 150 nm. Light-emitting area of the device was fixed to be 15 mm².

The current-voltage characteristics of the device was measured with Keithley 236 source-measure unit, 617 electrometer and Si-photo diode(Centronics Co. OSD100 -5T), and impedance was analyzed with Aglient 4294A of precision Impedance Analyzer.

The dependence of voltage and frequency was evaluated for the impedance analysis. To investigate the frequency dependence, the frequency was fixed to 100 Hz, 1 kHz, 10 kHz, and 100 kHz, and the voltage range was from -5 to 22 V.

To investigate the voltage dependence, the bias voltage was fixed to +4 V and +18 V and the frequency range was from 40 Hz to 100 MHz, and oscillation level was kept constant, 100 mV. The thickness and refractive index was measured by using PLASMOS ellipsometer.

3. RESULTS AND DISCUSSION

The equivalent electrical circuit with resistive component R_p and capacitive component C_p can be considered for the organic layer of organic light-emitting device. Figure 1 and 2 show the measured results for the impedance components of ITO/Alq₃(100 nm)/Al device.

Figure 1 represents the magnitude of impedance with frequency variation. The magnitude of impedance was revealed to be 110 kΩ ~200 kΩ at 100 Hz, 3.5 kΩ at 10 kHz and 350 Ω at 100 kHz.

Figure 2 shows phase angle Θ with frequency variation in ITO/Alq$_3$(100 nm)/Al device structure. The phase angle, Θ is about -74 ° at 0 V in case of 100 Hz, but it approaches to 0 ° as the voltage increases. Therefore, when the voltage is low, the capacitance characteristic is dominant. On the other hand, when the voltage becomes higher, the light is emitted, and the characteristic of resistance R_p appears.

In case of frequency of 1 kHz, the C_p characteristic appears in non light-emitting region, but both R_p and C_p characteristics appear in light-emitting region with a phase angle of about -45 °. But, the phase angle is constant, -89 °, at 100 kHz regardless of voltage variation.

As can be seen in Fig. 1 and Fig. 2, the effect of resistance R_p is dominant in low frequency region, but the effect of resistance R_p is nearly ignored and only the effect of C_p is dominant at high voltage of 100 kHz.
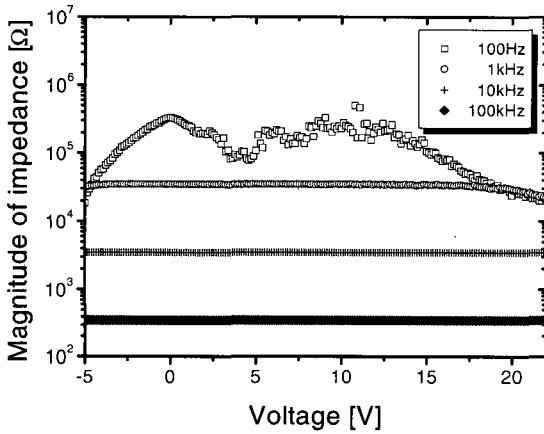

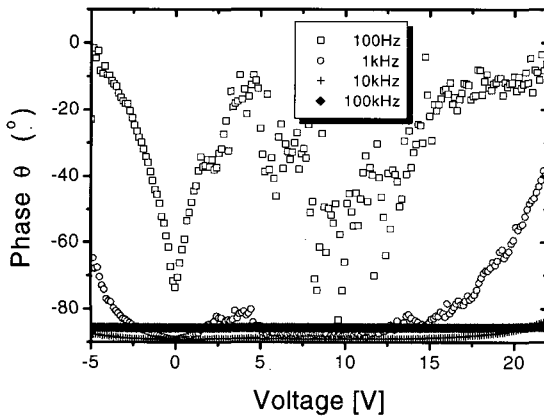Fig. 1. Magnitude of impedance with frequency variation in ITO/Alq$_3$(100 nm)/Al device structure.

Fig. 2. Phase angle, Θ with frequency variation in ITO/ Alq$_3$(100 nm)/Al device structure.

The combined impedance Z of Fig. 1 and Fig. 2 can be expressed by the following equation,

$$\frac{1}{Z} = \frac{1}{R_p} + j\omega C_p \tag{1}$$

The combined impedance of Eq. (1) can be rewritten as follows.

$$Z = \frac{R_p}{1+(\omega R_p C_p)^2} - j\frac{\omega R_p^2 C_p}{1+(\omega R_p C_p)^2} \tag{2}$$

Assuming $\tau = R_p C_p$, the impedance is

$$Z = \frac{R_p}{1+(\omega\tau)^2} - j\frac{\omega R_p \tau}{1+(\omega\tau)^2} \tag{3}$$

The magnitude of impedance, $|Z|$ and phase angle, θ can be obtained from equation (3) as the following expressions.

$$|Z| = \frac{R_p}{\sqrt{1+(\omega\tau)^2}} \tag{4}$$

$$\theta = -\tan^{-1}(\omega\tau) \tag{5}$$

The magnitude of impedance and phase angle for ITO/Alq$_3$(100 nm)/Al device evaluated by using Eqs. (4) and (5) are Fig. 1 and Fig. 2.

Figure 3 represents resistance R_p component with frequency variation for the equivalent circuit of Alq$_3$ organic compound in ITO/Alq$_3$(100 nm)/Al structure.

In low frequency region, the resistance has a peak value of 1 MΩ at 0 V, and it decreases with increasing voltage. As the frequency increases, R_p becomes low, which is about 4.5 kΩ at 100 kHz. Figure 4 shows capacitance C_p with frequency variation for the equivalent circuit of Alq$_3$ organic compound in ITO/Alq$_3$(100 nm)/Al structure. The capacitance C_p is not constant because R_p is more dominant than C_p at 100 Hz. But, the capacitance C_p is almost constant at high frequency more than 1 kHz.

The obtained capacitance was about $C_p \approx 4.5$ nF in this study. The capacitance can be expressed as a following equation, .

$$C = \varepsilon\frac{A}{d} \tag{6}$$

$$\varepsilon = \varepsilon_r \varepsilon_0 \tag{7}$$

, where A is area of Alq₃(15×10⁻⁶ m²), d is a thickness of Alq₃ later(112 nm), ε_r is a specific permittivity of Alq₃, and ε_0 is a permittivity of vacuum. The specific permittivity of Alq₃ was obtained by using Eqs. (6) and (7). The specific permittivity of Alq₃ is $\varepsilon_r = 3.79$ and the refractive index is, $n=1.94$. The refractive index measured by ellipsometer is 1.71, which accords with it.

Figure 5 shows current-voltage characterisitics with frequency variation. Compared with measured dc I-V characterisitics, the characterisitics are most similar at 100 Hz and the I-V characterisitics vary as the frequency increases. Especially, at 100 kHz, it show much different I-V characterisitics from measured dc I-V characterisitics. The parallel equivalent circuit of organic layer can be expressed by the following equations.

$$Z = Z' + jZ'' \qquad (8)$$

$$Z' = \frac{R}{1+(\omega\tau)^2}, \quad Z'' = -\frac{\omega\tau R}{1+(\omega\tau)^2} \qquad (9)$$

Figure 7 shows a real part Z' and imaginary part Z'' of impedance Z part with voltage variation at the bias voltage of 4 V. The absolute values of Z' and Z'' decrease as the bias voltage increases because the resistive component decreases. When the frequency increases, $1/\tau$ increases, therefore $1/\tau$ shifts to the higher frequency.
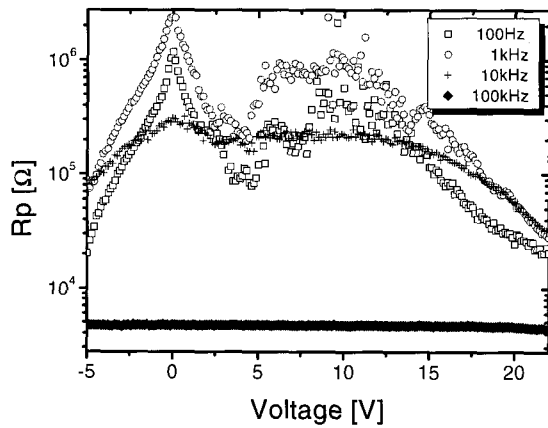

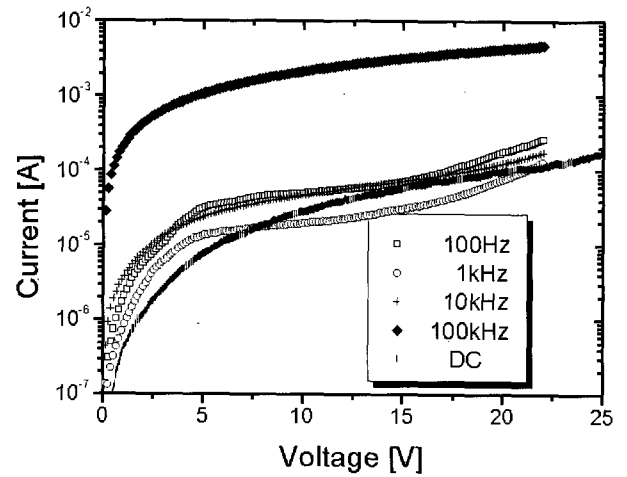Fig. 3. Resistive component R_p with frequency variation.

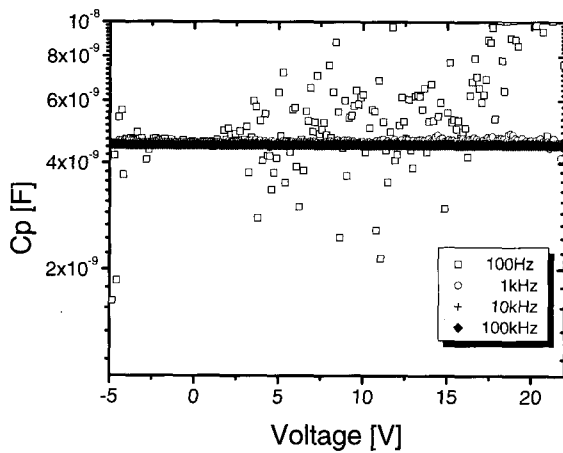Fig. 5. Current-voltage characterisitics with frequency variation.

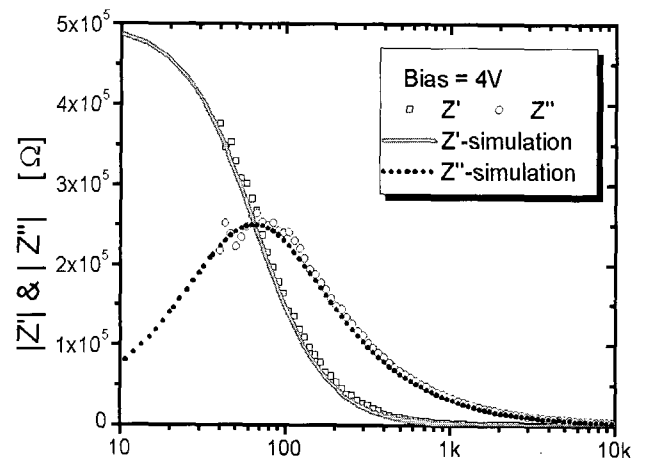Fig. 4. Capacitive component C_p with frequency variation.

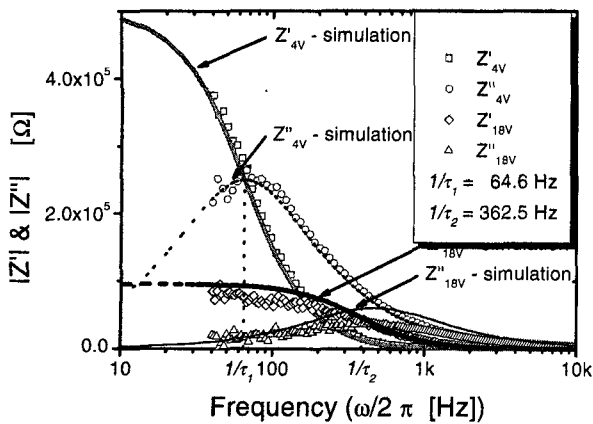Fig. 6. Parallel equivalent circuit with bias voltage.

Fig. 7. Real part and imaginary part with voltage variation.

From the Fig. 7, it can be seen that the magnitude of real part Z' is approximately 500 kΩ at the bias voltage of 4 V in low frequency region. Even though in low frequency region, the magnitude of real part Z' is approximately 100 kΩ at the bias voltage of 18 V, which is the reduced value to 1/5. The value of $1/\tau$ was 64.6 Hz at the bias voltage of 4 V, and it increases to 362.5 Hz at 18 V.

4. CONCLUSION

The equivalent circuit was considered through the impedance analysis of ITO/Alq$_3$(100 nm)/Al structure device. According to frequency dependence of parallel equivalent circuit, the characteristics of resistive component dominantly determines the I-V characteristics of the circuit at 100 Hz. But, as the frequency increases, the characteristics of capacitive component dominantly determines the characteristics of the circuit. The permittivity by impedance analysis was calculated and compared by the permittivity measured with ellipsometer. It was confirmed that as the bias voltage increases, impe-

dance of parallel equivalent circuit decreases, while $1/\tau$ increases, which means that $1/\tau$ shifts to right side.

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