Analysis on electrical transport characteristic of 8-hydroquinoline aluminum film

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Abstract The current-voltage and capacitance-voltage characteristic of the organic single-layered electroluminescent diode utilizing 8-hydroquinoline aluminum as active layer have been measured under bias ranging from − 5 V to 28 V in this work. A simple model for charge transport process of 8-hydroquinoline aluminum layer is proposed to illuminate the conductivity characteristic of the diode.

Keywords: **8-hydroquinoline aluminum, current-voltage characteristic, capacitance-voltage characteristic.**

WITH high luminescence and fine amorphous film, 8-hydroquinoline aluminum (Alq) becomes one of the materials used widely in organic electroluminescence (OEL)[1-5]. It is usually utilized as emission layer or electron transporting layer materials in OEL diodes[4, 5]. Alq single-layer diode-adopting proper metal cathode also can yield electroluminescence[6].

In this note, conductivity characteristic of Alq film is studied by means of current-voltage and capacitance-voltage characteristic measurement, and a simple model is proposed for the transport process of Alq film.

1 Experiment results

The single-layer structure cell (ITO/Alq/Mg/Ag) was fabricated by vacuum deposition. Alq, magnesium and silver were deposited in turn on ITO (SnO_2: In_2O_3)/glass whose resistance was 150 Ω/□ under a vacuum of 4×10^{-3} Pa (for Alq) and 3×10^{-3} Pa (for Mg and Ag) respectively. The thickness of Alq film was about 150 nm, and the effective area of metal electrode was 0.1 cm^2. Current-voltage characteristic was measured on a WYJ-3B DC stabilizing voltage supply and an X-Y recording meter. Capacitance-voltage characteristic was measured on a Botton 72BD capacitance meter, whose signal frequency was 1 MHz. Hereafter, the forward bias is defined as ITO contact on anode and Mg/Ag on cathode.

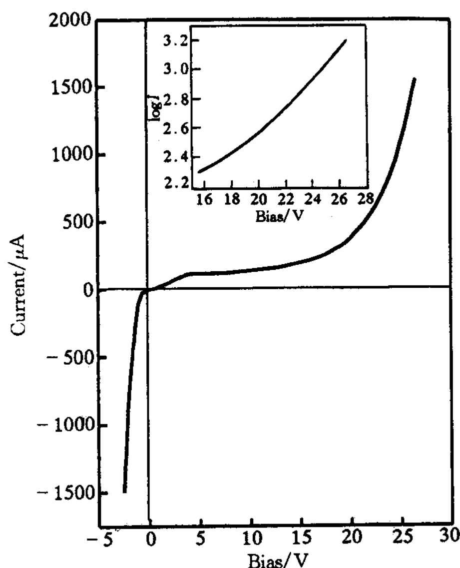

Fig. 1. The current-voltage characteristic of the cell ITO/Alq/Mg. Inset shows the logarithm of current dependence on bias at high forward bias.

Current-voltage characteristic (I-V) of the cell is shown in fig. 1. When reverse bias was less than 1.5 V, it was found from fig. 2(a) that the current-voltage relation nearly satisfied the following function:

$$I = I_0(\exp(-\alpha V) - 1). \tag{1}$$

Here α is ranged between 4 and 6 (V^{-1}). When reverse bias was more than 1.5 V, square root of current was linear with the reverse bias in fig. 2(b), so current-voltage relation can be expressed as

$$I \propto (V - V_\alpha)^2. \tag{2}$$

Here V_α could be determined from experiment.

When forward bias was less than 15 V, the current was very small and hardly affected by operating bias. But when the bias increasesd over 20 V, the logarithm of current was directly proportional to bias as the following function:

$$I = I_0\exp(\beta V). \tag{3}$$

Here β was about 0.23 V^{-1} which was estimated from experiment result. Meanwhile, electrolumi-

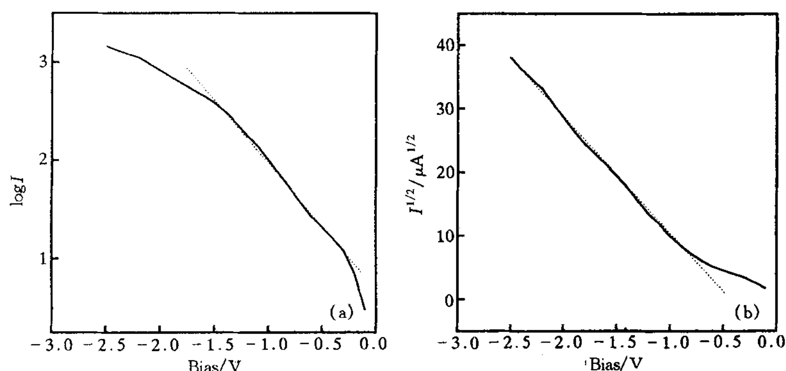

Fig. 2. (a) Logarithm of current dependence on reverse bias; (b) square root of current dependence on reverse bias. Dash line shows linear fit in a range of voltage.

nescence was achieved and radiance brightness was in direct proportion to the forward current.

It was revealed from current-voltage characteristic of the cell that different charge transport processes in Alq single-layer cell transferred under various biases.

Figure 3 shows the capacitance-voltage characteristic of the cell. A transferring point of capacitance appeared at reverse bias of about 1.5 V. The capacitance decreased with bias under small reverse bias, but when the reverse bias was in excess of 1.5 V, it increased with bias and gradually tended to the capacitance unbiased. The transferring point bias was close to the bias corresponding to the change of current-voltage relation.

When the cell was operated by forward bias less than 10 V, a small fluctuation and a slight drop of the capacitance of the cell appeared with increase of bias.

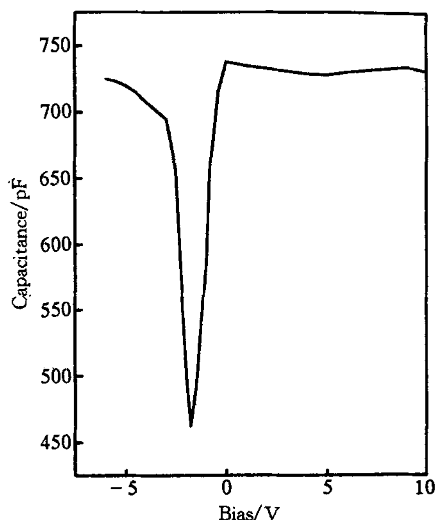

Fig. 3. Capacitance of the cell dependence on bias.

2 Analysis and discussion

Alq film is high-resistance N-type semiconductor, and the density of donor and acceptor caused by defect or other factors in film is low. Electrons are two orders of magnitude more mobile than holes in Alq film[7], so it can be supposed that the conductance of Alq film is mainly dependent on electrons transport. According to optical energy gaps and work function of Alq and ITO as well as work function of magnesium[4, 8, 9], the energy band diagrams under various biases are obtained and shown in figure 4.

When a reverse bias is applied to the cell, a portion of bias falls on the organic film, and electrons and holes in the film layer drift to the interfaces by the electrical field and accumulate at the interfaces. Under a small bias, the fermi level of organic layer can be assumed to be consistent, so current is determined by thermal emission of carriers through interfaces. At the interface of Alq/Mg, the current caused by emission of electrons from Alq to magnesium under V bias is given by

$$J_{\text{Alq-Mg}}(V) = n_{\text{Alq}} e \bar{\nu}. \tag{4}$$

Here n_{Alq} is the electron density on the interface; ν is the average velocity of electrons in the direction perpendicular to the interface. According to Boltzmann distribution in the system, we can obtain

$$N_{\text{Alq}} = N_c \exp((E_f - E_c + eV_i + eV_d)/kT) = n_{0i} \exp(eV_d/kT). \tag{5}$$

Here N_c is the state density at conduct band bottom; n_{0i} the electron density unbiased at the interface, V_i the built-in potential at the interface of Alq/Mg, and V_d is the potential caused by external bias on the in-

terface. Meanwhile, the current caused by emission of electrons from magnesium to Alq film is given by

$$J_{\text{Mg-Alq}} = J_{\text{Alq-Mg}}(0) = n_{0i}e\bar{\nu}. \quad (6)$$

Because of large mismatch of value bands between Alq and ITO, the current caused by hole emission from Alq to ITO can be negligible under reverse bias. So total current is given by

$$J = J_{\text{Alq-Mg}}(V) - J_{\text{Mg-Alq}} = n_{0i}e\bar{\nu}(\exp(eV_d/kT) - 1) = j_0(\exp(eV_d/kT) - 1). \quad (7)$$

Taking the distribution of bias drop on the cell into consideration, $V_d = -V/\eta$ (here V is bias and $\eta > 1$), the current follows $J = j_0(\exp(-eV/\eta kT) - 1)$. Comparing that with eq. (1), we can obtain $\alpha = e/(\eta kT)$, and $\eta \approx 8$ at room temperature.

Under a fairly large reverse bias, the bias mainly falls on the film layer, and electron current is determined by space charge-limited current of organic film[10]:

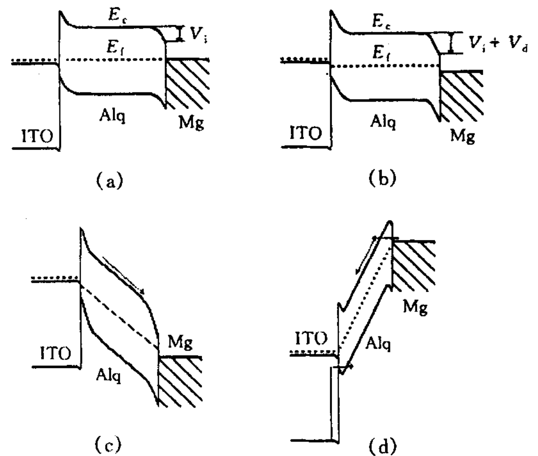

Fig. 4. Energy band diagrams of ITO/Alq/Mg structure under various bias. (a) Energy diagram corresponding to no bias; (b) corresponding to small reverse bias; (c) corresponding to fairly high reverse bias, (d) under high forward bias.

$$J = n(x)e\mu_n E(x). \quad (8)$$

Here $n(x)$ is the density of electron injected at x point; μ_n is electron mobility. And electrical field $E(x)$ obeys $\frac{\mathrm{d}E(x)}{\mathrm{d}x} = en(x)/\varepsilon_0\varepsilon$, where $\varepsilon_0\varepsilon$ is the dielectric constant of organic film, so it can give

$$J = \varepsilon_0\varepsilon\mu_n E(x)\mathrm{d}E(x)/\mathrm{d}x. \quad (9)$$

According to $E(x) = \frac{\mathrm{d}V(x)}{\mathrm{d}x}$ and the boundary condition of electrical field in film, we can obtain

$$J = \frac{9}{8}\varepsilon_0\varepsilon\mu_0 V_m^2/L^3. \quad (10)$$

Here V_m is the voltage drop in organic film layer, and L is the thickness of organic layer. Voltage drop on contact interface is nearly a constant under large reverse bias. Supposing that the total voltage drop on interfaces is V_a, $V_m = V - V_a$.

Under small forward bias, current of the cell is also determined by thermal emission of electrons on the interface. As a result, the current satisfies $J = j_0(\exp(-eV/\eta kT) - 1)$. When V is large enough, $J = -j_0$.

When the forward bias is more than 20 V, the potential barrier at the interface of Alq/Mg becomes very thin so that electrons can tunnel into Alq layer. Owing to the effect of high electrical field, electrons make strong drift movement and cannot accumulate at the interface, so current is determined by the tunneling current through Alq/Mg. According to tunneling process through Schottky junction[11], the current satisfies the function $J = j_s\exp(eV/E_0)$. Comparing that with eq. (3), we can obtain $e/E_0 = \beta = 0.23\ \text{V}^{-1}$, and E_0 is about 4.3 eV. Considering the distribution of bias drop on the cell, E_0 should be less than 4.3 eV.

The capacitance (C) of the cell of ITO/Alq/Mg consists of two parts: capacitance (C_m) of dielectric film and that (C_s) of space charge zone at the interface, neglecting the diffusion capacitance of surface free carriers because free carriers accumulating at the interfaces are limited in the surface zone. The two parts of capacitance are in series

$$1/C = 1/C_m + 1/C_s, \quad (11)$$

and

$$C_m \approx \varepsilon_0\varepsilon S/L, \ C_s = \varepsilon_0\varepsilon S/W, \quad (12)$$

where S is the effective area of metal electrode, and W is the thickness of space charge region. Here W

is far less than L. External bias has little effect on C_m. Under small bias, W increases with reverse bias increasing, leading to simultaneous change of C_s.

Under small forward bias or unbiased, $L >> W$, so $C \approx C_m$.

Under small reverse bias, $W = W_0(1 + V_d/V_i)^{1/2}$, and W_0 is the thickness of space charge region unbiased. Referring to eq. (11), the capacitance of the cell is given by

$$C = C_m/(1 + W_0(1 + V_d/V_i)^{1/2}/L). \tag{13}$$

So the capacitance of the cell reduces with reverse bias increasing.

But under fairly large reverse bias, the bias mainly falls on organic dielectric layer, and the space charge zone hardly changes with bias. As a result, the capacitance of the cell is dominated by the capacitance of dielectric layer (C_m).

In summary, in the cell with ITO/Alq/Mg/Ag structure, the current is determined by the electrical transporting and contact properties of organic film under various biases.

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Photoluminescence from Si-based SiN_xO_y films

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Abstract B^+, C^+, Si^+, and As^+ with dose of 5×10^{16} cm^{-2} were implanted into SiN_xO_y films grown on crystalline silicon by plasma-enhanced chemical vapor deposition. The ion-implanted samples exhibit their photoluminescence with different intensities and different peak wavelengths after thermal annealing. Especially, the C^+-implanted SiN_xO_y films show very intense photoluminescence at green-yellow color region.

Keywords: silicon-based light-emitting materials, photoluminescence, ion implantation.

IN order to realize Si-based optoelectronic integration, people are trying to search for some suitable Si-based light-emitting materials. SiO_2 films, due to their wide use in Si integrated circuits as passivation layers or dielectric layers, are being investigated as one of such light-emitting materials. Some good results from the investigation of light-emitting SiO_2 films have been reported[1–4]. As is well known, besides SiO_2 films, SiN_xO_y films are also used in Si integrated circuits as passivation layers or gate insulators. Be-