Admittance Spectroscopic Analysis of Organic Light Emitting Diodes with a LiF Buffer Layer

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Abstract
Admittance Spectroscopic analysis was applied to study the effect of LiF buffer layer and to model the equivalent circuit for ITO/Alq_3/LiF/Al device structure. The admittance spectroscopic analysis of the devices with LiF layer shows reduction in contact resistance (R_C), parallel resistance (R_P) and increment in parallel capacitance (C_P).

1. Introduction
In organic light emitting diodes, both the electron and the hole should be injected efficiently for best device performance. It means that a small injection barrier height at the cathode/organic interface is required. Insertion of an insulating layer between the cathode and the organic layer leads to a significant improvement in the charge injection and electroluminescence output [1]. The enhancement is due to increased charge carrier density near the cathode/organic interface that results from enhanced electron tunneling, and removal of exciton-quenching gap states that are intrinsic to the cathode/organic interface [2-5]. Insertion of a LiF layer at the cathode/organic interface shifts the lowest unoccupied molecular orbital level and the vacuum level of the organic layer as a result the barrier height for electron injection at the cathode/organic interface is reduced [6].

Admittance Spectroscopy is one of the powerful tools to study the equivalent circuit models, the charge carrier dynamics, and dielectric properties of organic devices [7]. The single layer device with ITO/Alq_3/Al structure can be modeled as a simple parallel combination of resistor and capacitor [8].

2. Results
ITO, tris-(8-hydroxyquinoline) aluminum (Alq_3), Aluminum (Al) and LiF were used respectively as a bottom anode, an emitting layer (EML), a top cathode and a buffer layer as shown in Fig. 1. The ITO-coated glass with a sheet resistance of 10 Ω/sqaure was used for OLEDs. For the preparation of OLEDs, the ITO glass was cleaned sequentially in ultrasonic bath of trichloroethylene, acetone, and methanol. Finally, the ITO glass was sonicated in deionized water and then blown dry with N_2 gas. The Alq_3 layer was prepared sequentially by thermal evaporation on the substrate. The cathode with 1-nm-thick LiF and 100-nm-thick Al was deposited by thermal evaporation. The Impedance measurement was done by using LF 4192A Impedance analyzer. The impedance was measured for the devices with and without LiF layer for a range of 10 Hz to 10 MHz to find the effect of LiF layer. The amplitude test signal was 50 mV. A Keithley 2400 electrometer was used for measuring J-V characteristics as a voltage source and current measurement equipment.

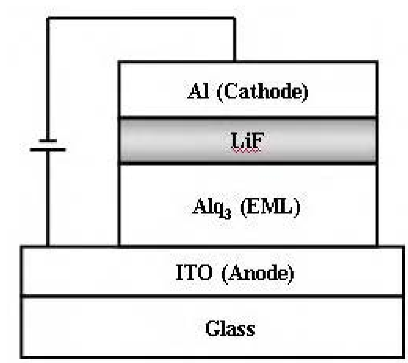

Figure 1. The device structure of OLEDs with LiF buffer layer

Figure 2 shows the capacitance versus frequency(C-F) characteristics for the device with ITO/Alq_3/Al and ITO/Alq_3/LiF/Al structures.

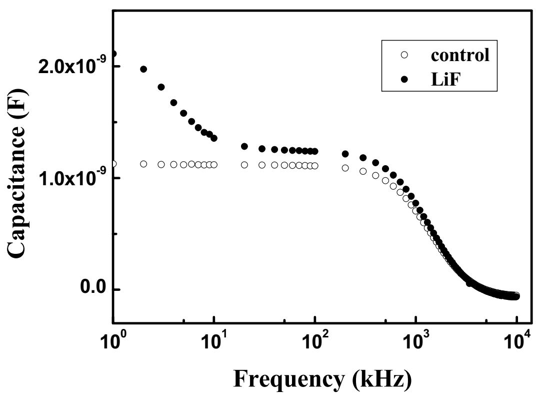

Figure 2. The capacitance vs. frequency plot for the devices with and without LiF layer

For the high frequency region, the values of capacitances with and without LiF layer are almost equal, but for the low frequency region, there is an increment in the capacitance with the introduction of the LiF layer, which is related to the enhancement of carrier injection and space charge formed by the injected carriers [9].

Figure 3 shows the quantum efficiency of the device with and without LiF layer.

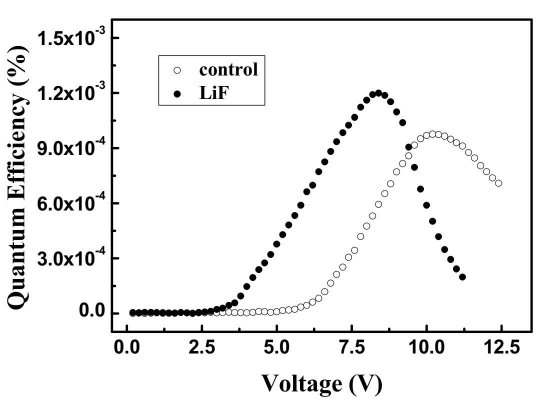

Figure 3. Variation in Quantum efficiency with bias voltage with and without LiF as a buffer layer between cathode and organic interface

The Insertion of a LiF layer at the Al/Alq_3 interface brings change in external quantum efficiency [10] of the device from 0.975×10^{-3} % to 1.199×10^{-3} % with a net increase of 0.224×10^{-3} % as shown in Figure 3. By inserting LiF layer, the unbalance between holes and electrons in the emitting layer is reduced.

For the device modeling, the impedance was measured for the devices with and without LiF layer for a rage of 10Hz to 10MHz for zero bias voltage.

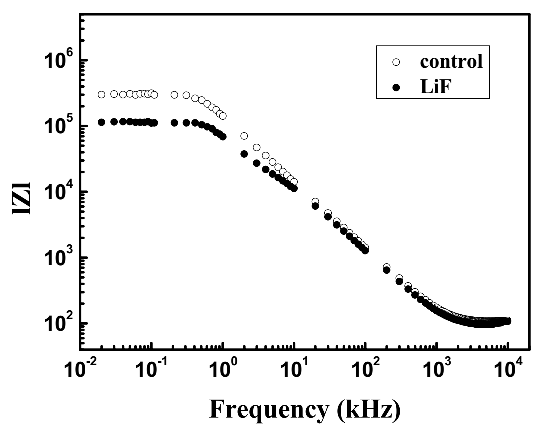

Figure 4. The impedance vs. frequency plot for the devices with and without LiF layer

Figure 4 shows the impedance variation with frequency in the devices with and without LiF layer. Impedance of the device decreases for the low and high frequency region when the LiF layer is inserted into the cathode/organic interface, which is basically caused by carrier injection enhancement, as mentioned early.

The results were analyzed by the complex admittance equation [11]

$$Y = \frac{1}{Z} = G + jB = G + jwC = Y' + jY'' \cdots (1)$$

Where Y, Z, G, B and C are the admittance, impedance, conductance, susceptance and capacitance of the device, respectively. Figure 5 shows the Cole-Cole plots of the device with and without LiF layer. The horizontal and vertical axes represent the real (Y') and the imaginary (Y") parts of the admittance of the devices, respectively.

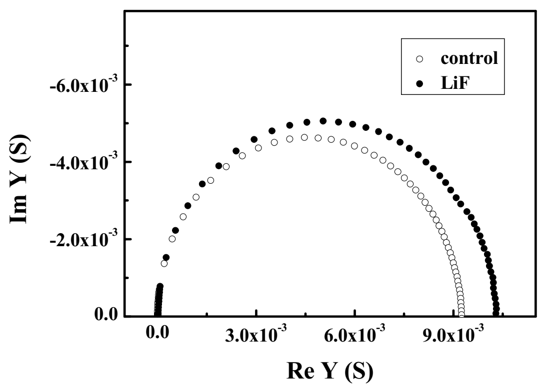

Figure 5. The cole-cole plot for the devices with and without LiF layer

The values of contact resistance (R_C), parallel resistance (R_P) and increment in parallel capacitance (C_P) extracted from the cole-cole plot for the devices with and without LiF layer is summarized in Table 1.

Table 1. Comparison of values of Resistance and Capacitance for the devices with and without LiF layer

	Without LiF layer	With LiF layer
$R_C(\Omega)$	111	100
$R_P(k\Omega)$	298	114
C_P (nF)	1.1	2.1

Fowler-Nordheim tunneling equation is given as [12-14]

$$I \propto AF^2 \exp(\frac{-k}{F}) \cdots\cdots\cdots\cdots\cdots (2)$$

Simplifying the equation 1. by taking log on both sides, we get the equation 2.

$$\ln(\frac{I}{F^2}) \propto -\frac{k}{F} \cdots\cdots\cdots\cdots\cdots (3)$$

where I is the current, F is the electric-field strength, and k is a parameter that depends on the barrier shape.

Figure 6 shows the plot of ln (I/F^2) versus (1/F). The curve seems to be very close to linear and the slope of which gives the value of k. The values of k were calculated to be 1.217×10^9 and 2.314×10^8 from the plots of Figures 6 for the case without and with LiF as a buffer layer, respectively. The slope decrease after the insertion of LiF as a buffer layer. Smaller value of k gives lower barrier height [14] as a result of which the turn on voltage of the device becomes lower.

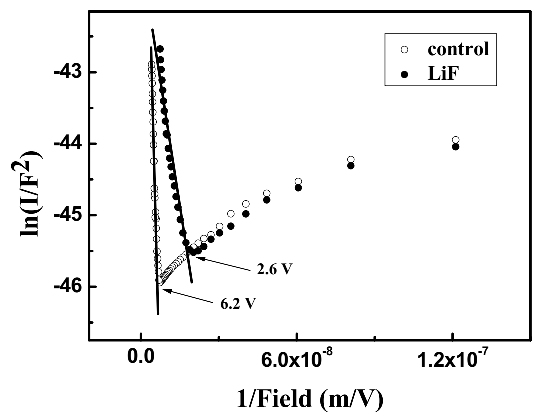

Figure 6. Fowler-Nordheim tunneling plot with and without LiF between cathode and organic interface

Insertion of a LiF layer at the Al/Alq_3 interface shifts the lowest unoccupied molecular orbital level and the vacuum level of the Alq_3 layer, as a result, the barrier height for electron injection at the Al/Alq_3 interface is reduced, which leads to reduction in the driving voltage of the device with LiF layer. The reduction of barrier height is attributed to the increment in C_P and the reduction of driving voltage is attributed to the reduction of the R_P of the devices with LiF layer which is well supported by our impedance measurement.

3. Conclusion

The device with the LiF cathode buffer layer at the Al/Alq_3 interface can be expressed as a simple parallel combination of resistor and capacitor with a reduced value of resistance and increased value of capacitance than that of the device without the LiF cathode buffer layer. The lowering of the barrier height in OLEDs with thin LiF layer is attributed to the increment in device capacitance and the lowering of the driving voltage in OLEDs with a thin LiF.

4. Acknowledgements

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5. References

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