Electrical properties of organic light emitting diodes with post fabrication heat and electric field treatments

Taher M. El-Agez[1,2], Mohammed S. Al-Qrinawi[1,2], Monzir S. Abdel-Latif[2,3], and Sofyan A. Taya[1,2]*,

[1]Physics Department, Islamic University of Gaza, Gaza, Palestinian Authority

[2]Renewable Energy Center, Islamic University of Gaza, Gaza, Palestinian Authority

[3]Chemistry Department, Islamic University of Gaza, Gaza, Palestinian Authority

***Corresponding Author:**
Sofyan A. Taya
Email: staya@iugaza.edu.ps

Abstract
The current work presents post-fabrication heat treatment and a combined external electric field-heat post-fabrication treatments for organic light emitting diodes (OLEDs). The devices were fabricated in the same run with a standard device without annealing for comparison, with an identical structure of ITO/PVK/Rhodamine B/Pb. After depositing the Rhodamine B layer on the PVK film, the samples were thermally annealed at different temperatures before depositing Pb. Some of the samples were thermally annealed without any external electric field while others were treated by an external electric field during heating. It is found that the annealing temperature of PVK/Rhodamine B layers increases the turn-on voltage of the device. On the other hand, in the electric field-heat treatment, the turn-on voltage is observed to decrease and the maximum current density of the device is dramatically enhanced.

Keywords: OLEDs, J-V curves, turn-on voltage.

1. Introduction

Recent research has focused on the development of organic materials and device structures for use in organic light-emitting devices (OLEDs), with the aim of realizing cost-efficient, light weight, and large-area flat panel displays. The main interests to researchers are improved efficiency, stability, and simplicity of the device fabrication process.

In general, the basic OLED structure consists of a stack of fluorescent organic layers sandwiched between a transparent conducting anode and metallic cathode. When an appropriate bias is applied to the device, holes are injected from the anode and electrons from the cathode. Some of the recombination events between holes and electrons result in electroluminescence.

In 1987, C. Tang and S. Slyke created the first multilayer organic device using small Alq_3 and diamine as a hole transport layer, and they used a transparent indium tin oxide (ITO) as an anode and Mg: Ag as a cathode [1].

In the last few decades, large developments in OLEDs industry have been conducted using different methods such as heat annealing, electric field annealing and other methods to increase the efficiency of OLEDs.

In 2008, A. Osman and S. Mutlu studied the influence of the electric field and heat treatment on polymer light emitting diodes (PLEDs), with the structure ITO/poly(3,4-ethylene dioxythiophene), poly(styrenesulfonate), (PEDOT:PSS), poly [2-methoxy-5-(2\ -ethyl-hexyloxy)-1,4-phenylene vinylene] (MEH-PPV), and Aluminum [2]. They found that heat treatment restores the light emitting function of dysfunctional PLEDs and, on the other hand, causes a high turn-on voltage of 10 V. Electric field treatment utilizing

-1 V reduces this high turn-on voltage to 3 V [2].

In 2011, Z. Chunlin et at. studied the effect of annealing of the ITO substrates and the organic layers in OLEDs with the structure of ITO/NiO/TPD:PVK/Alq_3 /Al [3]. They found that the fabricated OLED shows obvious performance improvement in brightness and efficiency.

This paper presents a two-step post-fabrication treatment of OLEDs. The fabricated OLEDs have the structure ITO/PVK/Rhodamine B/Pb. The first treatment process was thermal annealing of the PVK/Rhodamine B layers. The second treatment process was applying an electric field during the thermal annealing of the two layers. The influence of the two step post-fabrication treatments on the J-V characteristic curves of the fabricated device was studied.

2. Experiment

2.1. Fabrication

All fabrication steps were performed in standard room conditions at a temperature of 26°C. ITO-coated glass (Delta Technologies, USA) was used as substrates. The substrates were chemically cleaned using acetone, isopropanol and aquarequi solution with concentration of 3:1 at 60°C for 5 min. The substrates were then cleaned by distilled water and placed in an oven at 60°C for 24 hours in order to remove the residual solvents. The fabricated OLEDs have the structure ITO/PVK/Rhodamine B/Pb as shown in Fig 1. A mass of 15 mg of PVK powder, with an average molecular weight of 11×10^5, was weighed using a sensitive electrical balance (ESJ182-4) with a resolution of 10^{-4} gm. The PVK was dissolved in mixed solvents consisting of 5 ml tetrahydrofuran (THF) and 1 ml toluene. A homogenous solution was then deposited on the ITO substrate to form a thin film with thickness of about 44.8 nm. The thickness was measured using FILMETRICS F20 UVX Thin-Film Analyzer. The PVK film was obtained by placing a small amount of the homogenous solution on the substrate. The substrate was inclined at an angle of 45° for several minutes. The solution spreads on the surface of the substrate due to gravity forming a thin film. This process is sensitive to the variation in temperature due to different evaporation rate of solvents [4]. After PVK layer formation, the substrate was placed in an oven at 60°C for 24 hours in order to remove the residual solvents.

A 30 nm Rhodamine B layer is then deposited on the PVK layer by thermal vacuum deposition method using Minilab 080 made by Moorfield Associates, UK. Finally, a 35 nm Pb layer was deposited as cathode electrode on Rhodamine B layer. The negative terminal of the applied voltage was connected to the Pb electrode through a drop of Hg whereas the positive terminal was connected to the ITO substrate through silver paste.

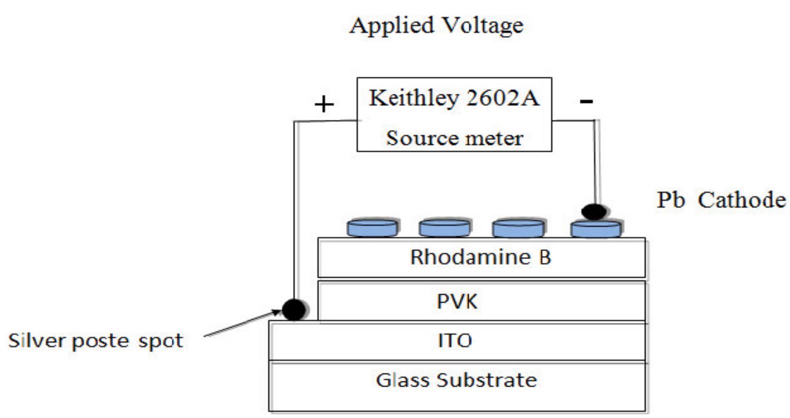


Fig. 1. Schematic drawing of the fabricated OLED.

2.2 Post processing treatment

After depositing the Rhodamine B layer on the PVK film, the samples were thermally annealed at different temperatures (90°C, 100°C, 110°C and 120°C) using a hot plate for 15 min under the atmosphere environment. After annealing, the Pb film was thermally evaporated on top of the Rhodamine B layer as the second electrode. Some of the samples were thermally annealed without any external electric field. Other samples were treated by an external electric field during heating. During the thermal annealing, these samples were exposed to high voltage of +10 KV applied to Cu disc with radius of 2.5 cm located 2 cm above the organic surface while the ITO electrode was grounded. The heater was turned off while the applied voltage is still on for another 15 min, then the electric field was turned off. The electric field setup is depicted in Fig 2. Finally, a 35 nm Pb film was thermally vacuum evaporated on top of the organic layers as a second electrode.

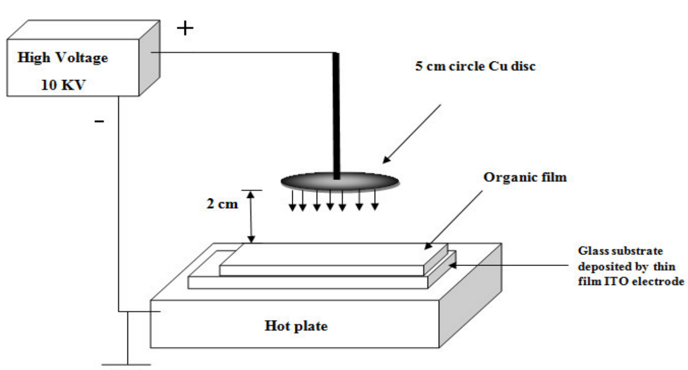


Fig 2. The electric field treatment setup

3. Results and discussion

Fig. 3 (a) and (b) shows the J-V and L-V, where L is the relative light intensity, characteristic of a standard device without annealing for comparison. The turn-on voltage (V_t) of this device is about 7.8 volt from the J-V curve. As can be seen from Fig. 3 (b), the voltage at which the light is detected is about 14 volt.

Four different temperatures of 90^{o}C, 100^{o}C, 110^{o}C and 120^{o}C were investigated in the heat treatment process. The J-V characteristic curves of the treated devices were recorded by Keithely 2602A source meter and are shown in Fig. 4(a) and (b). Fig. 4(a) represents the J-V characteristic curves for the heat treated OLEDs, and Fig. 4(b) shows the semi-log current density-voltage curves. As can be seen from the figure, as the annealing temperature of PVK/ Rhodamine B layers increases the turn-on voltage increases except at 90°C. On the other hand, all devices treated by heating didn't emit light compared to the standard device without any annealing. Maybe, the temperature process can cause dye aggregation which in turn leads to significant luminance drop [5]. Table 1 presents the turn-on voltages and maximum current densities of the treated devices at the different annealing temperatures. The best annealing temperature was 110°C which corresponds to the highest current density. The maximum current density was measured just before the device damage.

A set of samples were treated by applying an external field during heating. The same voltage of 10 KV was applied for the different annealing temperatures of 90^{o}C, 100^{o}C, 110^{o}C and 120^{o}C. The J-V characteristic curves of these samples are shown in Fig. 5(a) where a semi-log current voltage curves are shown in Fig. 5(b). As can be seen from the figure, when the annealing temperature increases the turn-on voltage decreases and the current flowing in the device is enhanced except at 110^{o}C. For devices treated at temperatures of 90^{o}C, 100^{o}C, 110^{o}C and 120^{o}C the turn-on voltages were 11.87 V, 6.26 V, 5.38 V and 4.73 V, respectively. The improved performance of OLEDs with organic layers annealed at elevated temperature was due to reduced defects and improved interface structures of organic and organic/ITO interface [5]. Table 2 presents the turn-on voltages and maximum current densities of the devices treated by applying an electric field during the annealing process.

On the other hand, all devices were treated by applying an external field during heating didn’t emit light compared to the standard device without any annealing.

The results obtained for OLEDs treated with applying an electric field during the annealing process revealed that there was a significant reduction in the turn-on voltage and a considerable current enhancement compared to the samples treated with only thermal annealing without any electric field as can be seen in Fig. 6.

The turn-on voltages and maximum current densities of the devices thermally annealed with and without an electric field are presented in Table 3. Moreover, the table shows the values obtained for the fabricated devices without any treatment. It should be point out that the maximum current density was recorded just before the device damage.

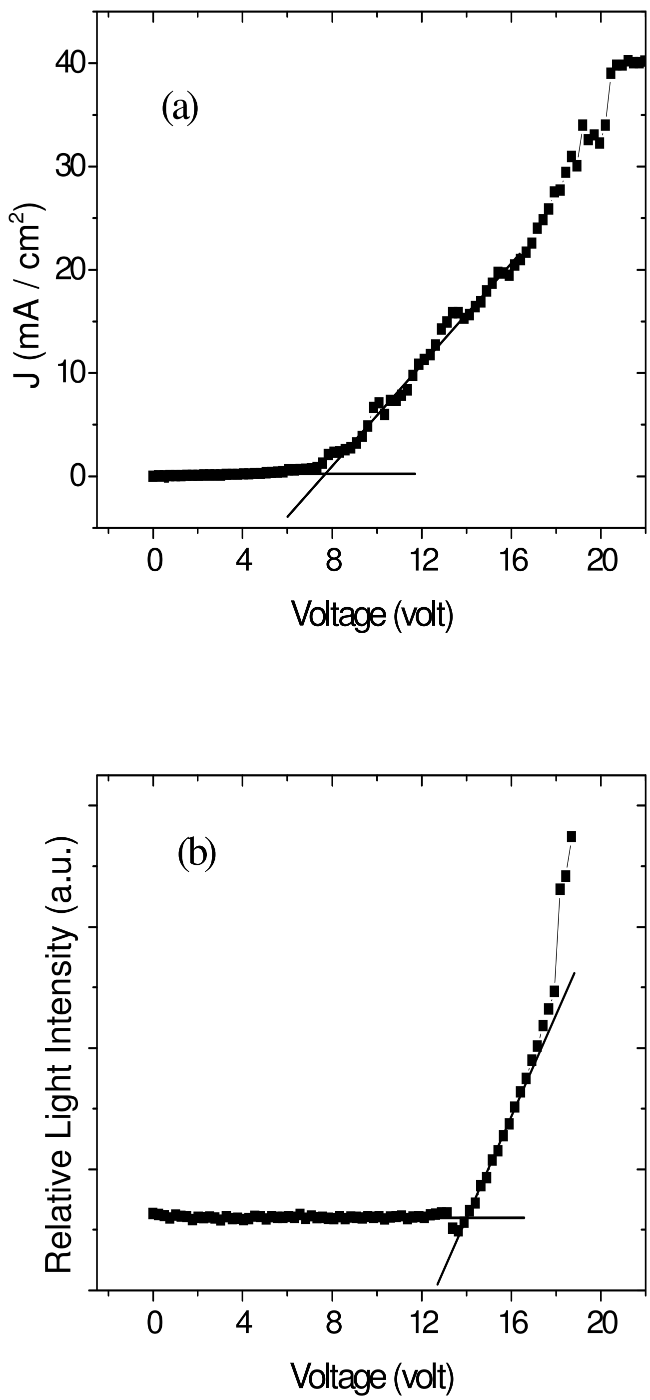
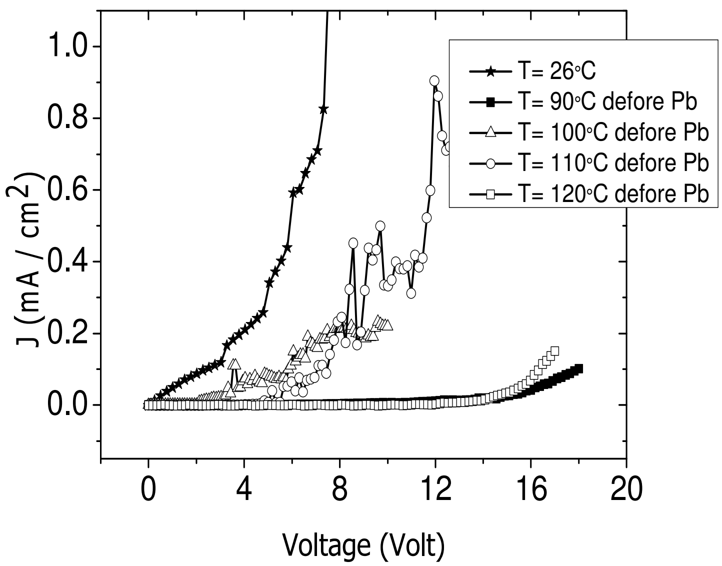


Fig. 3. Current density-voltage (a) and relative light intensity-voltage (b) characteristic curves of the device consisting of ITO/44.8nm PVK/ 30nm Rhodamine B/ 35nm Pb.



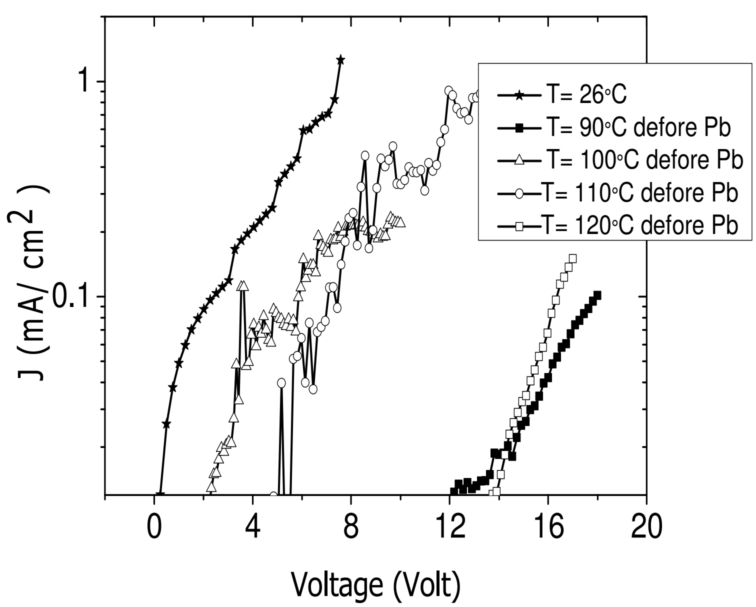
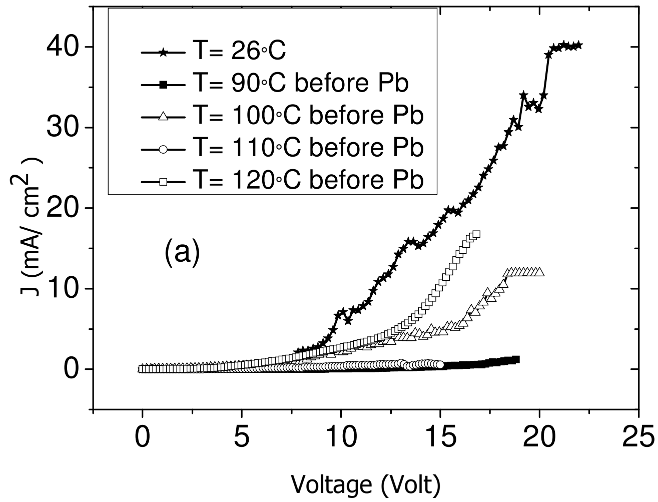


Fig. 4. Current density-voltage (a) and semi-log current density- voltage (b) characteristic curves of the heat-treated devices at different annealing temperatures.



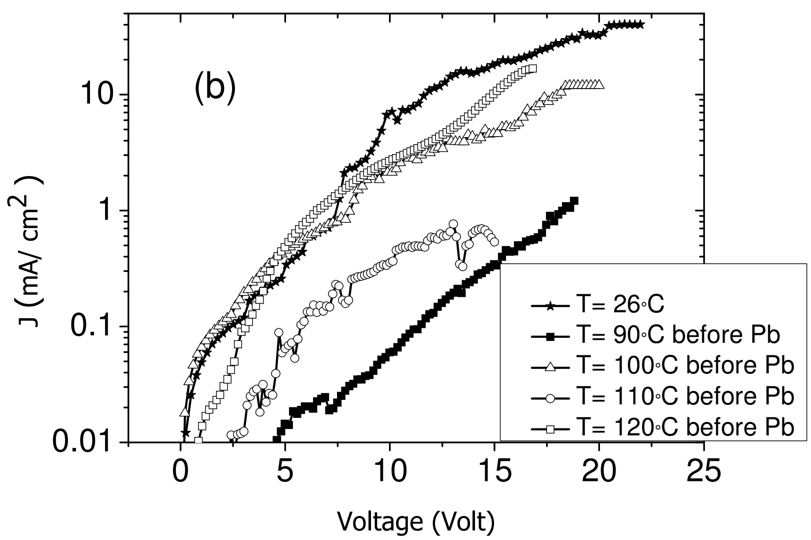


Fig. 5. Current density-voltage (a) and semi-log current density- voltage (b) characteristic curve of the OLEDs treated with an external electric field during heating.

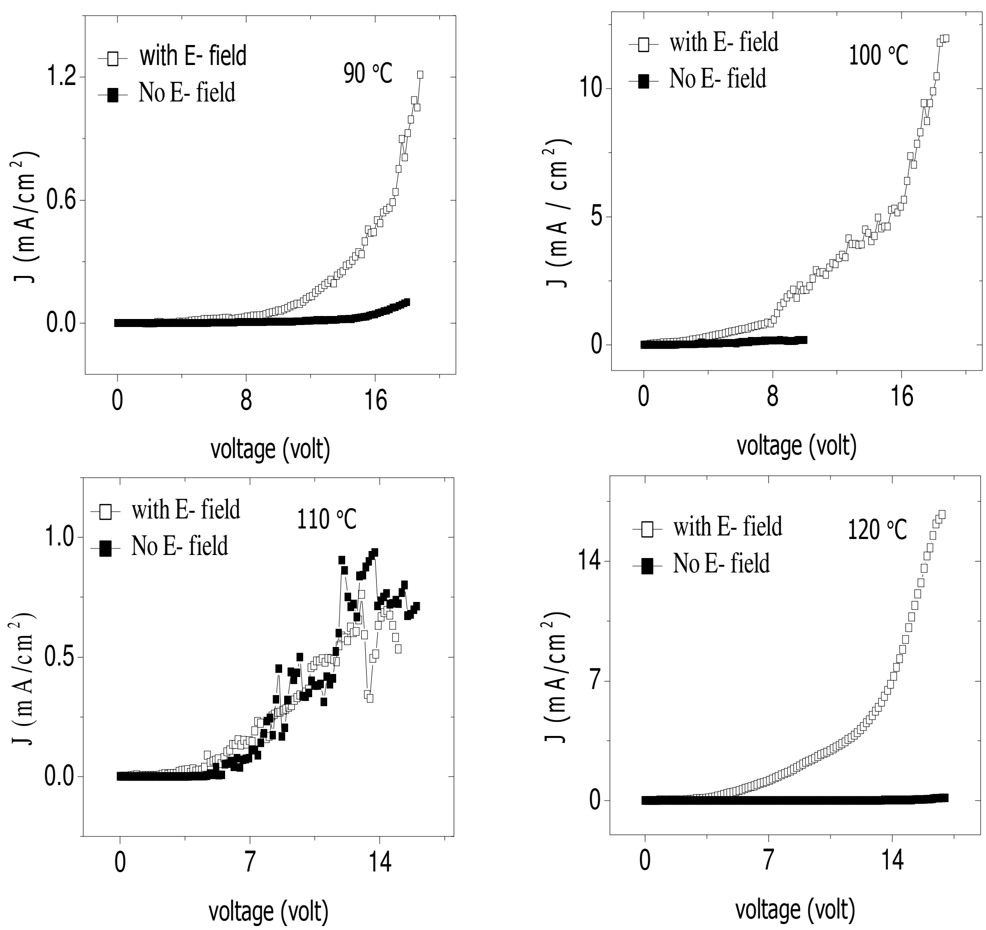


Fig. 6. Current density-voltage characteristic curves of the OLEDs thermally treated with and without an electric field.

Table 1. Turn-on voltages and maximum current densities of the devices after heat treatment

Temperatures	90°C	100°C	110°C	120°C	Standard device
V_t (Volt)	14.26	2.53	5.53	13.60	7.80
J_{max} (mA/cm^2)	0.10	0.23	0.93	0.15	39.92

Table 2. Turn-on voltages and maximum current densities of devices treated by an external electric field during annealing.

Temperature	90°C	100°C	110°C	120°C	Standard device
V_t (Volt)	11.87	6.26	5.38	4.73	7.80
J_{max} (mA/cm^2)	1.20	11.94	0.76	16.74	39.92

Table 3. Turn-on voltages and maximum current densities for OLEDs treated by heating with and without an electric field

Temperature	Heat treatment				Heat-external E-field treatment				Standard device
	90°C	**100°C**	**110°C**	**120°C**	**90°C**	**100°C**	**110°C**	**120°C**	
V_t (Volt)	14.26	2.53	5.53	13.60	11.87	6.26	5.38	4.73	7.80
J_{max} (mA/cm^2)	0.10	0.23	0.93	0.15	1.20	11.94	0.76	16.74	39.92

Conclusions

In this work, the effects of post-fabrication heat treatment and heat treatment associated with an applied electric field treatment on the J-V characteristic curves of OLED devices were investigated. OLEDs with the structure ITO/PVK/Rhodamine B/Pb were fabricated under ambient atmosphere without taking any preventive measures against exposure to oxygen and water vapors. Heat treatment of PVK/Rhodamine B layers significantly increased the turn-on voltage as the annealing temperature was increased except at 90°C. The best annealing temperature was 110°C which corresponds to the highest current density. By applying an external electric field to the PVK/Rhodamine B layers during annealing, it was observed that when the annealing temperature increased, the turn-on voltage was decreased and the current was dramatically increased expect at 110°C. The best annealing temperature in the presence of an electric field was 120°C which corresponds to the highest current density. We may conclude that thermal treatment in the presence of an electric field is much better that thermal treatment only.

Acknowledgement

The authors would like to express gratitude to the ministry of higher education (scientific research council) for the financial support of this work.

References

[1] Tang, C. W., & Van Slyke S. A., (1987). 'Organic electroluminescent diodes, Appl. Phys. Lett. 51, 913-915.

[2] Osman, A. & Mutlu S. (2009). Post-fabrication electric field and thermal treatment of polymer light emitting diodes and their photovoltaic properties, Organic Electronics, 10, 18-26.

[3] Chunlin, Z., Yong, Z., Haixia, ., Fangcong, L., Guobing, Z., Da C., Xiaoyun, J., & Su L. (2011). Enhancing the Performance of the Organic Light-Emitting Device (OLED) by Thermal Treatment, Chinese Journal of Electronics, 20, 55-57.

[4] El-Agez, T., Taya, S., Tayyan, A., Abdel-Latif, M. & Afghjani, A. (2013). Electroluminescence from Single PVK Layer Organic Light Emitting Diode Using Different Dyes at Different Concentrations, Physical Review & Research International, 3, 306-320.

[5] Chen, B., Sun, ., & Sarma, K. (2007). Phosphorescent organic light-emitting devices with in situ post-growth annealed organic layers, Material Science and Engineering B, 139, 192-196.