The effect of GO buffer layer insertion on OLED electroluminescence

Aziz, T.H.T., Salleh, M.M., Yahya, M., Umar, A.A., Rahman, M.Y.A, Dee, C.F. & Yap, C.C., Majlis, B.Y.M.
Institute of Microengineering and Nanoelectronics (IMEN),
Universiti Kebangsaan Malaysia,
43600 Bangi, Selangor, MALAYSIA
Email: mms@ukm.edu.my

Abstract — **In this paper, we report a spin coated graphene oxide serve as electron buffer layer for OLED devices with structure of ITO/PEHF/GO/Al where PEHF is poly[9,9-di-(2-ethylhexyl)-fluorenyl-2,7-diyl] emitting polymer. It is predicted that the large band gap of graphene oxide can improve the electron injection into the polymer to balance the injected hole charges leading to higher electroluminescence. Preliminary results show insertion of GO layer reduced the turn-on voltage (Von) from 11.0 V to 8.0 V and at the same time increased the brightness from 179 cd to 380 candela. We discovered that the brightness enhancement is caused by exciplex at the GO/polymer interface.**

Keywords — OLED, electroluminescence, graphene oxide, exciplex

I. INTRODUCTION

It was estimated that about 20–30% of global electricity consumption is used for lighting [1]. The generation of electricity is mostly based on fossil fuel burning which results in releases of CO_2 into the atmosphere causing global warming [2]. To reduce the consumption of electricity for lighting, we required efficient solid state lighting device such as conventional inorganic semiconductor light emitting diode, LED and recently develop organic light emitting diode, OLED [3]. The application for OLED as a lighting device is still under improvement for its lifetime, stability and brightness [4]. Researchers have used several methods to achieve high-performance OLED by using high-efficiency material like TADF [5]or improve the charge carrier injection by inserting additional metal oxide layer [6]. The latter method showed promising route for exploration as many metal oxide can be manipulated including graphene oxide (GO).The use of GO as hole injection layer in OLED has been reported by Shi et al., 2013 and Yang et al., 2014. However, current research showed that the hole charges normally dominate the OLED device, and electron injection from the metal cathode are limited due to the barrier at the electrode/polymer interface [9]. In this paper, we report a spin coated GO serve as electron buffer layer for OLED devices with structure of ITO/PEHF/GO/Al where PEHF is poly[9,9-di-(2-ethylhexyl)-fluorenyl-2,7-diyl] emitting polymer. It is predicted that the high band gap of graphene oxide can improve the electron injection into the polymer to balance the injected hole charges leading to higher electroluminescence. Preliminary results show insertion of GO layer reduced the turn-on voltage (Von) from 11.0 V to 8.0 V and at the same time increased the brightness from 179 cd to 380 candela. We discovered that the brightness enhancement is caused by exciplex at the GO/polymer interface.

II. METHODOLOGY

OLED devices were prepared with the structure of ITO/PEHF/Al and ITO/PEHF/GO/Al. The OLED of ITO/PEHF/Al is considered as a control device. The PEHF and GO layers were prepared by spin coating. The OLED devices were characterized by current density-voltage (J-V) curves and electroluminescence spectra. The highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) value for each PEHF and GO layers were measured using cyclic voltammetry while the exciton lifetime was estimated using Ultrafast Luminescence Spectrometer.

III. RESULTS AND DISCUSSION

Fig. 1 shows the OLED structure with a configuration of ITO/PEHF/Al and ITO/PEHF/GO/Al. The indium tin oxide (ITO) and aluminum (Al) were used as cathode and anode electrode, respectively. PEHF acted as emitting layer while GO served as electron buffer layer and hole blocking layer.

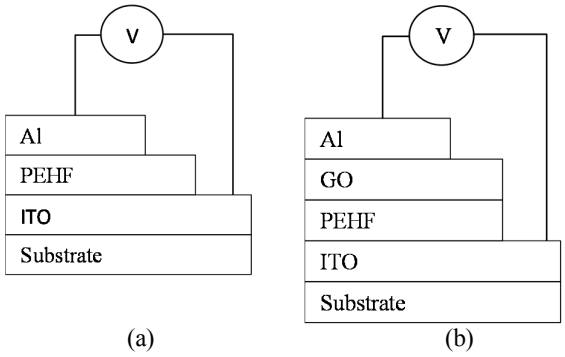


Fig. 1 OLED structure for (a) control device (b) insertion of GO layer

The current densities versus voltage (JV) curve are presented in Fig. 2. The performance of control OLED is comparatively lower compared to the device with an insertion of GO layer. For OLED with GO layer, the Von is 8.0 V while the control OLED is 11.0 V. The different in Von indicated that the device with GO layer requires less

energy to inject the electron into the polymer compare to the control OLED.

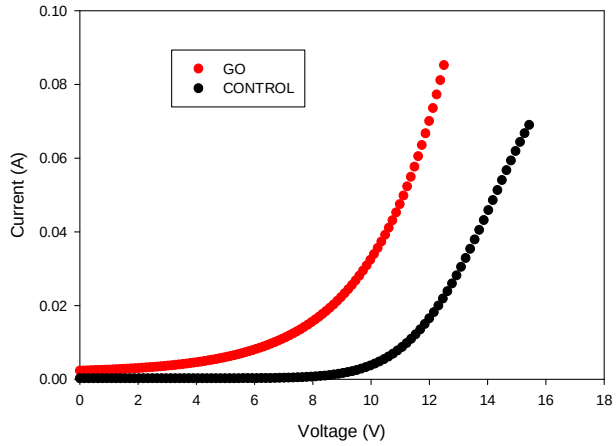


Fig. 2 Current-density voltage (JV)

The electroluminescence spectra for both devices are presented in Fig. 3, while the emission properties are presented in Table 1. The spectra are almost similar excluding the difference in intensity and width. The peak for both devices was at the wavelength of 511 nm. It is observed that the peak intensity is higher wider for OLED with the GO layer. The device electroluminescence data are summarized in Table 1.

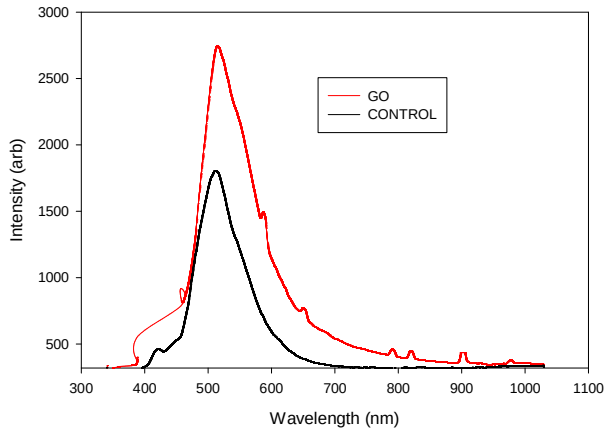


Fig. 3 Electroluminescence spectra of fabricated OLEDs

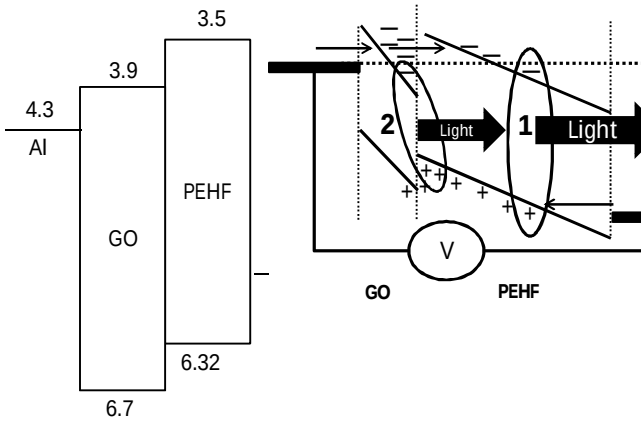
Table 1 Comparison of OLED performance

Device	Von	Electroluminescence	Peak (nm)
Control	11.0	179	511
GO	8.0	380	511

To understand the enhancement mechanism, we measured and estimated the important parameter such as highest occupied molecular orbital (HOMO), lowest unoccupied molecular orbital (LUMO) and the Electron-excited lifetime. The calculated value for HOMO, LUMO and excited electron lifetime is presented in Table 2. By using the calculated value, the energy diagram for OLED device with GO buffer was illustrated in Fig. 4 (a).

Table 2 Optoelectronic value for thin films

Layer	HOMO (eV)	LUMO (eV)	Electron excited lifetime
PEHF	6.32	3.5	1.0-1.1 ns
GO	6.7	3.9	0.17-0.19 ns



(a) (b)

Fig. 4 Energy diagram for (a) OLED with insertion of GO layer (b) layer device mechanism

The enhancement mechanism begins when then bias applied to the OLED device as shown in Fig. 4(b). The ITO will inject hole charges while the Al inject the electron charge through the GO layer. The presence of GO layer will improve the electron injection as the electron excited lifetime is very short (0.17-0.19 ns) and the GO layer have to transport the electron immediately into the polymer. The GO layer will also block hole charges from recombining with electron charges at the Al interface due to its barrier at the GO/PEHF interface. As the exciton (electron-hole pair) process that produces light is happening entirely inside the PEHF, the electroluminescence will increase significantly. At the same time the blocked hole charges at the GO/PEHF interface will accumulate and parts of the accumulated electron at the GO/PEHF interface will form exciton and produce light. This process is known as exciplex [10], [11] and the light produced by this process explained higher electroluminescence and wider spectrum for OLED with an insertion of GO layer.

It is clear from the summarize data in Table 1 that the performance for OLED device improves with an insertion of GO layer data. A further understanding of the mechanism involving the GO structure and electrical properties is outside the scope of this paper, and will be addressed in our upcoming work.

IV. CONCLUSIONS

In summary, we demonstrate higher electroluminescence and lower Von OLED device by inserting a spin coated GO layer between the cathode and the emitting layer. The improved device performance is mostly caused by the

insertion of GO layer which facilitates the electron injection while the block the holes charge at the GO/PEHF interface to optimize the exciton formation. The formation of exciplex at GO/PEHF interface also increased the electroluminescence properties and causing wider spectrum for the OLED devices.

ACKNOWLEDGEMENT

This study was supported by the Malaysian Ministry of Higher Education (MOHE) and Universiti Kebangsaan Malaysia under grant LRGS/2015/UKM-UKM/NanoMITE/04/04.

REFERENCES

[1] P. Chiradeja, a. Ngaopitakkul, and C. Jettanasen, "Energy savings analysis and harmonics reduction for the electronic ballast of T5 fluorescent lamp in a building's lighting system," *Energy Build.*, vol. 97, pp. 107–117, 2015.

[2] S. Fujita and A. Suzuki, *Electrical conduction in graphene and nanotubes*. 2013.

[3] N. Thejo Kalyani and S. J. Dhoble, "Organic light emitting diodes: Energy saving lighting technology - A review," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 2696–2723, 2012.

[4] Y.-S. Tyan, "Organic light-emitting-diode lighting overview," *J. Photonics Energy*, vol. 1, no. 1, p. 011009, 2011.

[5] S. Reineke, "Organic light-emitting diodes: Phosphorescence meets its match," *Nat. Photonics*, vol. 8, no. 4, pp. 269–270, Mar. 2014.

[6] H. J. Bolink, H. Brine, E. Coronado, and M. Sessolo, "Hybrid organic-inorganic light emitting diodes: effect of the metal oxide," *J. Mater. Chem.*, vol. 20, no. 20, p. 4047, 2010.

[7] S. Shi, V. Sadhu, R. Moubah, G. Schmerber, Q. Bao, and S. R. P. Silva, "Solution-processable graphene oxide as an efficient hole injection layer for high luminance organic light-emitting diodes," *J. Mater. Chem. C*, vol. 1, no. 9, p. 1708, 2013.

[8] Y. Yang, X. Yang, W. Yang, S. Li, J. Xu, and Y. Jiang, "Ordered and ultrathin reduced graphene oxide LB films as hole injection layers for organic light-emitting diode.," *Nanoscale Res. Lett.*, vol. 9, no. 1, p. 537, 2014.

[9] B. A. Al-asbahi, M. Hafizuddin, H. Jumali, C. C. Yap, and M. M. Salleh, "Influence of TiO 2 Nanoparticles on Enhancement of Optoelectronic Properties of PFO-Based Light Emitting Diode," vol. 2013, 2013.

[10] W. E. B. Shepherd, A. D. Platt, M. J. Kendrick, M. A. Loth, J. E. Anthony, and O. Ostroverkhova, "Energy transfer and exciplex formation and their impact on exciton and charge carrier dynamics in organic films," *J. Phys. Chem. Lett.*, vol. 2, no. 5, pp. 362–366, 2011.

[11] X. K. Liu, Z. Chen, C. J. Zheng, C. L. Liu, C. S. Lee, F. Li, X. M. Ou, and X. H. Zhang, "Prediction and design of efficient exciplex emitters for high-efficiency, thermally activated delayed-fluorescence organic light-emitting diodes," *Adv. Mater.*, vol. 27, no. 14, pp. 2378–2383, 2015.