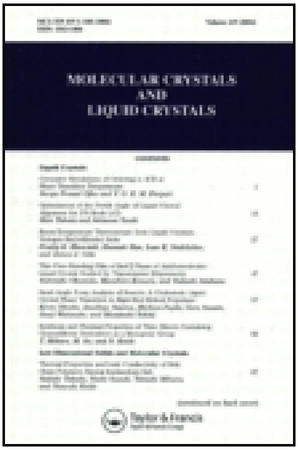


Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Application of High Work Function Anode for Organic Light Emitting Diode

Ji-Yun Chun [a], Jin-Woo Han [a] & Dae-Shik Seo [a]

[a] Department of Electrical and Electronic Engineering, Yonsei University, Seodaemun-gu, Seoul, Korea

Version of record first published: 10 Nov 2009

To cite this article: Ji-Yun Chun, Jin-Woo Han & Dae-Shik Seo (2009): Application of High Work Function Anode for Organic Light Emitting Diode, Molecular Crystals and Liquid Crystals, 514:1, 115/[445]-121/[451]

To link to this article: http://dx.doi.org/10.1080/15421400903232149

Mol. Cryst. Liq. Cryst., Vol. 514, pp. 115/[445]–121/[451], 2009

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400903232149

Application of High Work Function Anode for Organic Light Emitting Diode

Ji-Yun Chun, Jin-Woo Han, and Dae-Shik Seo
Department of Electrical and Electronic Engineering, Yonsei University, Seodaemun-gu, Seoul, Korea

We fabricated bottom emission organic light emitting diode (OLED) by using high work function material anode with sputtering method and investigated their electrical properties. Nickel oxide (NiO) was found to reach about 5.2 eV, much higher than those of other oxide metal and indium tin oxide (ITO). The bottom emission OLED using a thin oxidation of nickel oxide layer upon ITO as an anode and an Al layer as a cathode has been fabricated. Device performance was found to improve greatly due to an efficient hole injection from nickel oxide; moreover, the transmittance of NiO-ITO was nearly same as the transmittance of ITO.

Keywords: multi-stacked anode; nickel oxide; OLED

INTRODUCTION

OLED can exhibit many advantages such as fast response, wide viewing angle, low power consumption, thin and light body, comparing to liquid crystal displays (LCDs). Moreover, the OLEDs show superior performance to other displays so that have attracted considerable interests as a future display with high potentiality [1–3].

Recently, the OLEDs have been widely investigating and various applications have been developed. Among them, the material fields are dramatically advancing with high-end techniques. Especially, improving performance of material is being reported intensively because effectiveness of material decides lifespan of panel and amount of power consumption [4–8].

Address correspondence to Prof. Dae-Shik Seo, Department of Electrical and Electronic Engineering, Yonsei University, 262 Seongsanno, Seodaemun-gu, Seoul 120-749, Korea (ROK). E-mail: dsseo@yonsei.ac.kr

The efficiency of the OLED panel can be classified into internal and external efficiency. The external efficiency is influenced by the structure of devices [9–11].

Indium tin oxide (ITO) has been widely used, because of its transparency in the visible light region and high conductivity, as an electrode for several electronic devices, such as OLEDs, LCDs, and solar cells. Various methods have been reported for preparing ITO, such as sputtering, chemical vapor deposition, electron beam deposition, and spray pyrolysis. The work function of pyrosol ITO is usually lower, by approximately 1 eV, than the highest occupied molecular orbital (HOMO) of the organic layer of OLEDs [12–15]. The larger energy difference between the ITO and the organic layer makes the interfacial Schottky barrier larger, which results in a smaller injected current at the interface. Raising the work function of ITO to a level close to the HOMO of the organic layer, therefore, would minimize the Schottky barrier, and resultantly enhance hole injection from the ITO to the organic layer of OLED, reducing the required voltage of the OLED [16–22].

Several methods, such as plasma treatments, UV treatments and grafting of molecules, have been reported for treating ITO, in an effort to increase its work function. Among them, the oxygen plasma treatment is known as the most effective technique in increasing the work function of ITO prepared by sputtering [23–28].

In this study, we prepared nickel-oxide (NiO) thin film on ITO with high work function and hole transfer and injection properties using the radio frequency (RF) sputter. NiO is well-known p-type transparent conducting oxide, which should exhibit a higher work function and is more favorable for hole injections into the organic than ITO. NiO has a higher work function ($\sim$5.2 eV) than ITO ($\sim$4.6 eV) [12].

In the materials of anode for the OLED, the efficiency gets better as the work function is higher. In this paper, the nickel oxide, which has higher work function than the ITO generally used in industry, is applied to anode of the OLED.

EXPERIMENTAL

The cross-sectional structure of a bottom emission OLED is schematically shown in Figure 1. ITO and NiO were used for the anode, which was deposited sequentially on a glass substrate by using radio frequency sputter (RF-sputter) at a pressure of about $3 * 10^{-3}$ Torr and was patterned by using the lift-off method. O_2 plasma was treated for 3 min to improve the surface roughness of the anode and emissive

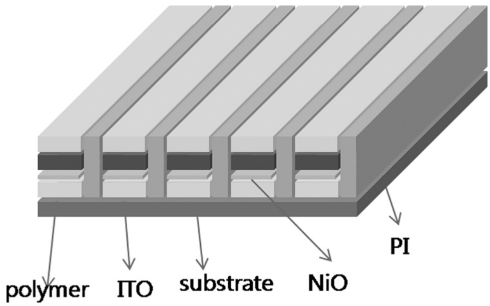


FIGURE 1 Schematic cross-section of the nickel-oxide (NiO) based OLED fabricated in this study.

efficiency. The surfaces of anode layer were studied by atomic force microscopy (AFM) and the result is Figure 2.

The structure of organic layers was composed with 15 nm thick 4,4′, 4″-tris[N-(1-naphthyl)-N-phenylamino]-triphenylamine) (2-TNATA) as

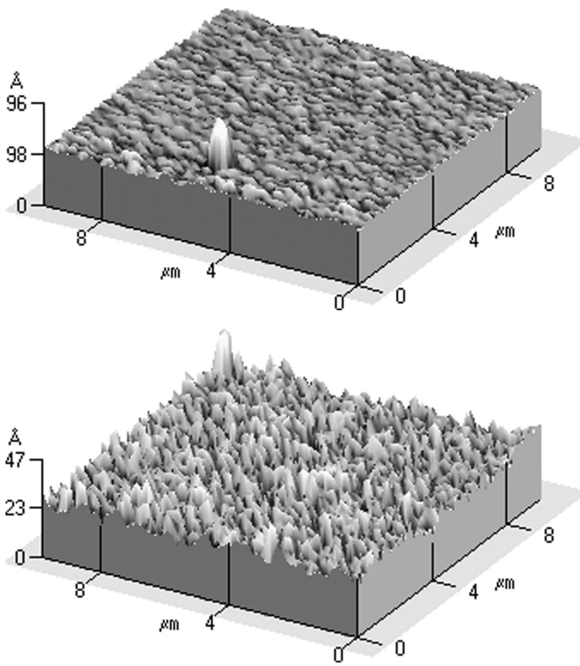


FIGURE 2 AFM images of the anode surface (a) without nickel-oxide (NiO) layer, and (b) with nickel-oxide (NiO) layer.

a hole injection layer, 30 nm thick N,N′-Diphynyl-4N,N′-bis(1--naphthalyl),benzidine (a-NPD) as a hole transfer layer, 40 nm thick tris(8-hydroxyquinoline)aluminum (Alq_3). The cathode was 10 nm Al. The organic thin films were deposited at the rate of 0.5 Å/sec and the cathode was 2–3 Å/sec.

RESULTS AND DISCUSSION

NiO is well-known p-type transparent conducting oxide, NiO has a higher work function (~5.2 eV) than ITO (~4.6 eV). However, NiO is a transition metal; its resistivity is quite high. When the thickness increases, the resistivity is decreased. While, the transmittance goes down to below 65% at the thicknesses above 100 nm so that there are difficulties employing nickel oxide solely as for compositing anode.

So, we make multi-stacked anode using NiO and ITO multi stacked anode improved resistivity and transmittance. The transmittance of NiO-ITO and ITO is shown in Figure 3. In this paper, the ITO and NiO electrode were successively deposited and lifted off for patterning Though it has been reported that the NiO can be applied to hole injection layer, applying it to anode has never been investigated.

I-V characteristics of the OLED devices with ITO and NiO are shown in Figure 4. The turn-on voltage of the device is effectively

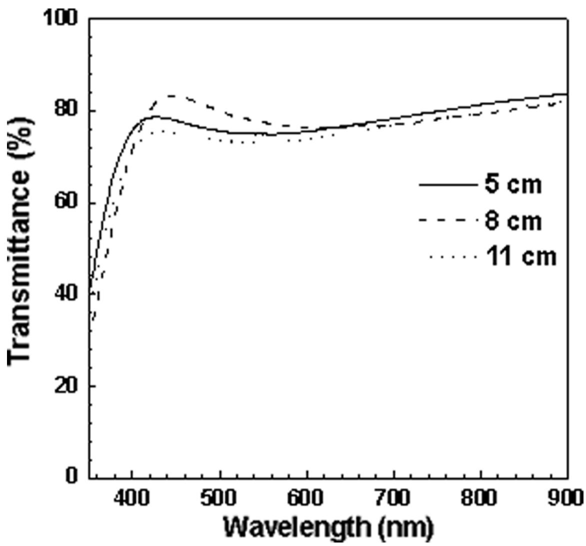
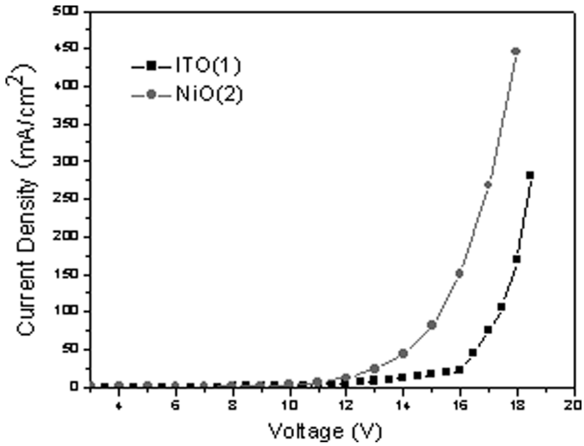
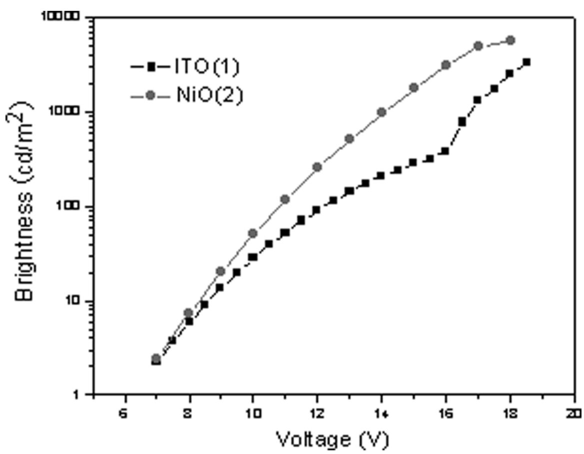


FIGURE 3 Optical Transmittance of NiO-ITO anode.



(a)



(b)

FIGURE 4 (a) I-V characteristics, and (b) L-V characteristics of OLEDs with ITO anode (1), and with NiO-ITO anode (2).

reduced by NiO-ITO anode. Figure 4 shows the luminescence intensity versus the applied voltage (L-V). The device with the deposition of NiO-ITO has the lower voltage than ITO anode for the same emission intensity. It is clearly seen that the mobility increases as the work function of the metal electrode increases.

The reduction of the turn-on voltage by the NiO-ITO anode might be attributed to the increase of the anode work function, which reduces the energy barrier of hole injections into the organic layer.

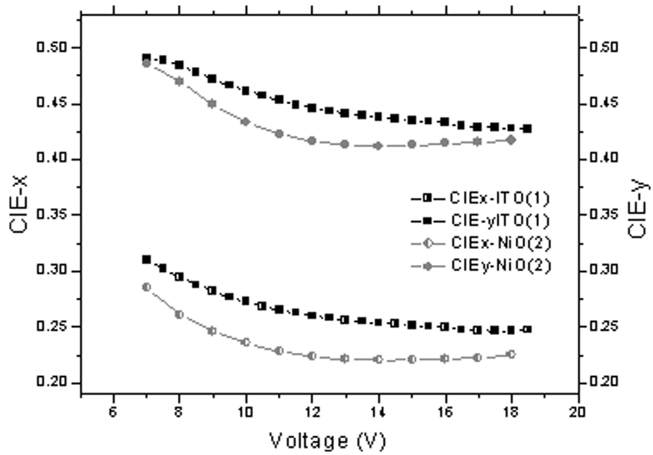


FIGURE 5 Commission internationale de l'Eclairage color model (CIE) graph of OLED using nickel oxide (NiO).

Figure 5 shows the commission internationale de l'Eclairage color model (CIE) graph.

As the injection current increases as depicted in this graph, it was observed that the color-shift biased to blue hue happened. As CIE-x and CIE-y approaches to (0.15, 0.15), the emitting efficiency was improved.

That means the performance of emission layer was favorably implemented. It was also exhibited that the OLED device employing NiO-ITO anode was closer to 0.15 as shown in Figure 5.

CONCLUSIONS

In conclusion, the NiO-ITO is an excellent material for anode of OLED. While the anode employing only NiO solely shows dramatically decreased transmittance above certain thickness so that there is a problem fabricating pixel electrode, the anode with successive deposition of the NiO on the ITO displays much better performance and solve the problem of transmittance. The device with the deposition of NiO-ITO has the lower voltage than ITO anode for the same emission intensity. These characteristic improvements are consistent with lowering the barrier for carrier injection. As a result, more charges can be injected into the organic layer from the ITO anode through a lower injection barrier, which suggests that turn-on voltage can be lowered and more current can flow during the OLED operation. It can be concluded that in OLED, a work function of anode with higher is preferable in achieving better electrical properties. The fabrication of effective organic devices may be important for realizing future applications in organic electronics.

REFERENCES

[1] Tang, C. W. & Van Slyke, S. A. (1987). *Appl. Phys. Lett.*, *51*, 913.
[2] Kwon, S. H., Paik, S. Y., Kwon, Kwon, O. J., & Yoo, J. S. (2001). *Appl. Phy. Lett.*, *79*, 4450.
[3] Chang, A. B., Rothman, M. A., Mao, S. Y., Hewitt, R. H., Weaver, M. S., Silvernail, J. A., Haek, M., Brown, J. J., Chu, X., Moro, Krajewski, L. T., & Rutherford, N. (2003). *Appl. Phys. Lett.*, *83*, 413.
[4] Gelinck, G. H., Geuns, T. C. T., & Leeuw, D. M. (2000). *Appl. Phys. Lett.*, *77*, 1487.
[5] Hamada, Y. Y., Adachi, Tsutsui, C. T., & Saito, S. ((1992)). *Jpn. J. Appl. Phys.*, *31*, 1812.
[6] Granström, M. & Ingan, O. (1996). *Appl. Phys. Lett.*, *68*, 147.
[7] Dodabalapur, A., Rothberg, L. J., & Miller, T. M. (1994). *Appl. Phys. Lett.*, *65*, 2308.
[8] Van Slyke, S. A., Chen, C. H., & Tang, C. W. (1996). *Appl. Phys. Lett.*, *69*, 2160.
[9] Han, S., Feng, X., Lu, Z. H., Johnson, D., & Wood, R. (2003). *Appl. Phys. Lett.*, *82*, 2715.
[10] Chen, B. J., Sun, X. W., & Tan, S. C. (2005). *Opt. Exp.*, *13*, 937.
[11] Wu, C. C., Lin, C. L., Hsieh, P. Y., & Chiang, H. H. (2004). *Appl. Phys. Lett.*, *84*, 3966.
[12] Hsu, C. M., Liu, C. F., Cheng, H. E., & Wu, W. T. J. (2006). *Electo. Materials*, *35*, 3.
[13] Monkade, M., Fuliang, Z., Martinot-Lagarde, P., & Durand, G. (1987). *Appl. Phys. Lett.*, *50*, 856.
[14] Fan, J. C. C. & Goodenough, J. B. (1975). *J. Electron. Soc.*, *122*, 1719.
[15] Liversey, R. G., Lyford, E., & Moore, H. (1968). *J. Phys.*, *E 1*, 947.
[16] Hamberg, I. & Granqvist, C. G. (1986). *J. Appl. Phys.*, *60*, 11.
[17] Blandenet, G., Court, M., & Lagarde, Y. (1981). *Thin Solid Films*, *77*, 81.
[18] Pommier, R., Grill, C., & Marucchi, J. (1981). *Thin Solid Films*, *77*, 91.
[19] Zhou, Z. B., Cui, R. Q., Pang, Q. J., Wang, Y. D., Meng, F. Y., Sun, T. T., Ding, Z. M., & Yu, X. B. (2001). *Appl. Surf. Sci.*, *172*, 245.
[20] Maki, K., Komiya, N., & Suzuki, A. (2003). *Thin Solid Films*, *445*, 224.
[21] Park, N. G., Kwak, M. Y., Kim, B. O., Kwon, O. K., Kim, Y. K., & Kim, Y. S. (2002). *Jpn. J. Appl. Phys.*, *41*, 1523.
[22] Adachi, C., Nakajima, Y., & Oyamada, T. (2003). Data book on work function of organic thin films..
[23] Lee, K. H., Jang, H. W., Kim, K. B., Tak, Y. H., & Lee, J. L. (2004). *J. Appl. Phys.*, *95*, 586.
[24] Mason, M. G., Hung, L. S., Tang, C. W., Lee, S. T., Wong, K.W., & Wang, M. (1999). *J. Appl. Phys.*, *86*, 1688.
[25] Sugiyama, K., Ishi, H., Ouchi, Y., & Seki, K. (2000). *J. Appl. Phys.*, *87*, 295.
[26] Ganzorig, C., Kwak, K., Yagi, K., & Fujihira, M. (2001). *Appl. Phys. Lett.*, *79*, 272.
[27] Chan, I. M., Hsu, T. Y., & Hong, F. C. (2002). *Appl. Phys. Lett.*, *81*, 1899.
[28] Hsua, C. M. & Wu, W. T. (2004). *Appl. Phys. Lett.*, *85*, 840.