Fabrication of Organic Light Emitting Diodes on Nano-structured Indium Tin Oxide

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We have fabricated Organic Light Emitting Diodes (OLEDs) on nano-structured indium tin oxide films. The enhancement in extraction efficiency by a factor of 30% was found comparable to other expansive techniques for the fabrication of indium tin oxide layer. The electroluminescence spectra at viewing angles from normal to the substrates up to 60^0 off normal remain almost unchanged and does not show the angle dependence observed for other extraction efficiency enhancement techniques. The emission spectrum was also found to be stable with time for these OLEDs. The spectral uniformity with angle and time with enhanced extraction efficiency and cheap deposition technique could be of great interest for the application of down converted OLED.

Keywords: Organic Light Emitting Diodes (OLEDs), Electroluminescence (EL) spectra.

1. INTRODUCTION

Organic light emitting diodes (OLEDs) have attracted considerable interest due to their potential applications in flat panel displays [1] and solid state lighting [2]. OLEDs have many advantages over conventional displays, such as, light weight, low power consumption and their ability to grow on flexible substrate [3]. Though electro-phosphorescent OLEDs with an internal quantum efficiency of near 100% is approaching the efficiency of fluorescent lamps [4], only about 20% of the generated light can escape from the OLEDs due to total internal reflection in the glass substrate and wave guiding [5].

Till date, several light extraction techniques [5] have been reported to increase the light extraction efficiencies of OLEDs e.g. incorporation of textured surfaces [6], use of mesa shaped substrates [7], micro cavities [8], surface plasmons [9], ordered structures or photonic crystals [10] and a low refractive index silica aero gel layer [11]. However, these methods often possess problems such as undesirable angle dependent emission spectra and complex fabrication process [12] and high cost. Most of these techniques [6-13] cause the change in EL spectrum with the change in viewing angle e.g. use of micro cavity [8] changes the CIE coordinates from (0.38, 0.61) to (0.31, 0.65) for the change in viewing angle from 0^0 to 40^0. It was observed by many authors that the use of scattering medium such as micro lens [14] and phosphor [15,16] to enhance light out-coupling efficiency simply redirect the light without introducing micro cavity or other parasitic optical effects. Still, the deposition technique for these mediums is very expansive like other techniques for light extraction efficiency enhancement. In this paper we have deposited indium tin oxide layer consisting of indium tin oxide particles by using spin coating technique on backside of OLED and characterized OLEDs for light emission, light extraction efficiency enhancement and angle dependency of EL spectrum and also characterized the time dependency of the EL spectrum.

2. EXPERIMENTAL

The OLEDs were fabricated on ITO coated glass substrates. We have fabricated two OLEDs, one the control device and the other with an indium tin oxide layer. The device structure for fabricating OLED was ITO (120 nm)/0.4 wt % F4-TCNQ doped α-NPD (30 nm)/5 wt % Alq3 doped CBP (35 nm)/BCP (6 nm)/Alq3 (28 nm)/LiF (1 nm)/Al (150 nm). Tris (8-hydroxyquinoline) aluminum (Alq3) (Sigma Aldrich) and N,N'-Di-[(1-naphthalenyl)-N,N'-diphenyl]-(1-1'-biphenyl)-4,4'-diamine (α -NPD) (Sigma Aldrich) were used as the electron and hole transporting layers. 2,9 dimethyl 4,7 diphenyl 1,10 phenanthrolene (BCP) (Sigma Aldrich) which has a high ionization potential (6.5 eV) has been used as hole blocking layer and lithium floride (LiF)/aluminum (Al) and ITO has been used as cathode and anode respectively. After the fabrication, the OLEDs were sealed by a top encapsulating cover glass. The used indium tin oxide was Nanostructures. Indium tin oxide was first mixed with PVAc in 1:1 ratio in methanol. The used amounts of indium tin oxide, PVAc, methanol were 60 mg, 60 mg, 1.5 ml respectively. After mixing this solution properly, a film of this solution was spin coated on to the backside of glass substrate at 1000 rpm for 2 min. OLEDs were then further dried in high vacuum (~10-5 torr) at 50^0C for one hour to remove the residual solvent. PVAc serves the purpose of a binder for nanophosphor particles.

3. RESULT AND DISCUSSION

Figure 1(a) (curve a) shows the EL spectrum of OLED. The CIE coordinates for OLED were (0.18, 0.20). EL spectrum of OLED has peaks at 440 nm and 475 nm. Inset of Figure 1 (a) shows the absorption and photoluminescence spectrum of Nano indium tin oxide films coated on glass substrates. Peak absorption wavelength for indium tin oxide is 460 nm and peak emission wavelength is 600 nm. Since the indium tin oxide is coated on the backside of the OLED, this can excite the indium tin oxide, which can then re-emit in yellow region of visible spectrum and the superposition of unabsorbed light from OLED and the yellow light of phosphor re-emission produces light. Curve b of Figure 1(a) shows the EL spectrum of indium tin oxide coated OLED. From the figure, it can be seen that the intensity of the peak at 440 nm is reduced, while a new peak appears at 590 nm. This new peak corresponds to the indium tin oxide re-emission. The measured CIE coordinates were (0.29, 0.33), which lies well within the region of visible spectrum.

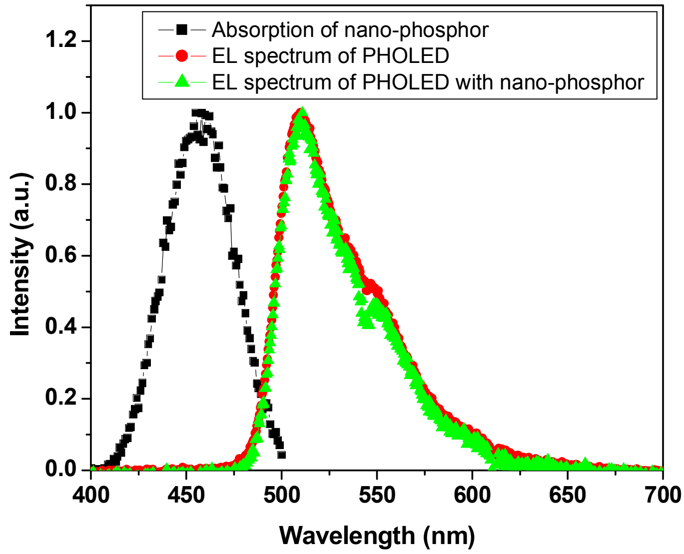

Fig. 1: (a) Electroluminescence spectrum of OLED (curve a) and OLED with indium tin oxide layer (curve b). Inset shows the absorption and emission spectrum of indium tin oxide particles.

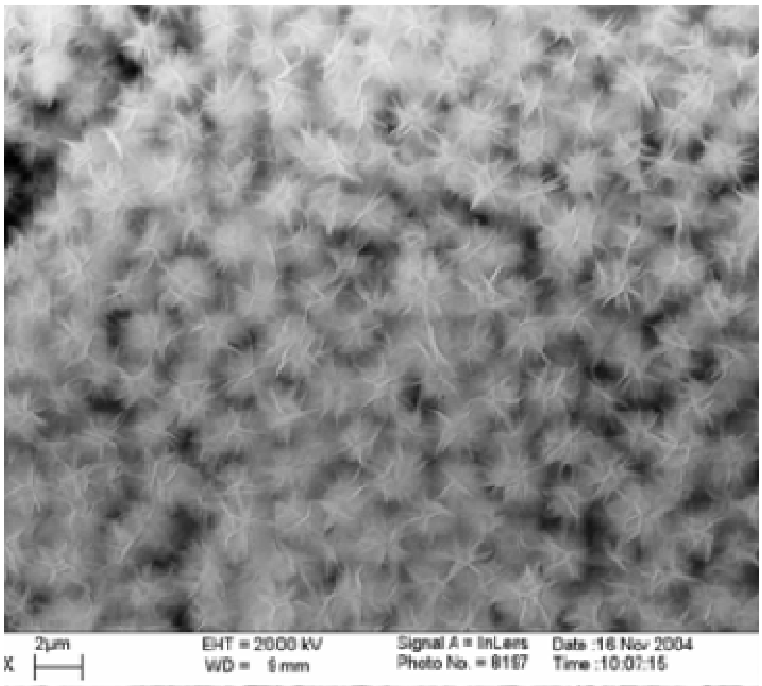

Fig. 1 (b): SEM image of the spin coated film of indium tin oxide layer.

Figure 1(b) shows the SEM image of the film of Nanostructures on glass substrate fabricated as described earlier. The average size of the indium tin oxide particles is 180 nm with an average spacing of 200 nm.

In an OLED, about 25 % of light generated inside the emissive layer is lost at glass/air interface due to total internal reflection. Indium tin oxide coated on the backside of glass substrates also works as scattering centers for the light incident on glass/air interface and the condition of total internal reflection relaxes for these scattering centers. Hence, indium tin oxide coated on backside of the substrate can enhance the light extraction efficiency. To measure this effect, the luminescence of indium tin oxide coated OLED has been measured in the normal direction and compared with the luminescence of reference OLED. Figure 2 shows the current density-luminescence characteristics of indium tin oxide coated OLED and reference OLED.

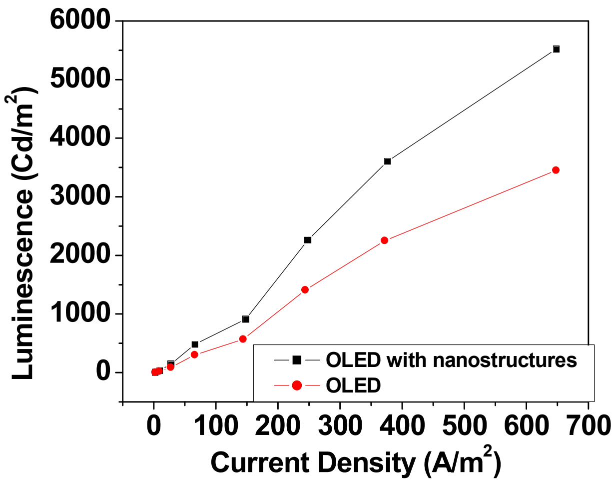

Fig. 2: Current density-luminescence characteristics of indium tin oxide coated OLED and reference OLED in the normal direction.

It can be seen that the luminescence has been enhanced for the whole range of current densities. At a current density of 100 A/m^2, the luminescence has been enhanced from 400 Cd/m^2 to 650 Cd/m^2 showing about 32% enhancement of luminescence. Inset of Figure 2 shows the plot of enhancement ratio with current density for the indium tin oxide coated OLED in comparison to the OLED. The average enhancement over the current density range of 0-700 A/m^2 was about 1.6. The measured refractive index of PVAc films were 1.47, which almost matches with the refractive index of glass (~1.5). Thus the indium tin oxide layer breaks the sudden change of refractive index at glass/ air interface reducing the loss and scattering from indium tin oxide particles couples the light out from the indium tin oxide layer/air interface. Generally, the techniques used for the enhancement of light extraction efficiencies are very expansive, such as, insertion of ordered structures or photonic crystals [10] and insertion of nano-imprinted low refractive index layer [13]. But spin coating of indium tin oxide particles has an advantage of low cost fabrication over the other techniques and is found effective in increasing the out coupling efficiency.

4. CONCLUSIONS

In conclusion, we have fabricated an OLED with an indium tin oxide layer. Indium tin oxide layer was deposited by very low cost spin coating technique. Indium tin oxide layer provides a 60% enhancement of light extraction with angle independent EL spectrum. The light source was found to follow nearly the Lambertion profile of luminescence. Color stability of OLED with indium tin oxide layer has been monitored and found that CIE coordinates remained invariant with time.

REFERENCES

[1] S.R. Forrest, P.E. Burrows, Z. Shen, G. Gu, V. Bulovic and M.E. Thompson; “The stacked OLED (SOLED): a new type of organic device for achieving high-resolution full-color displays”, Synth. Met., Vol. 91, pp. 9-13, 1997.

[2] Y. Sun and S.R. Forrest; “Enhanced light out-coupling of organic light-emitting devices using embedded low-index grids”, Nat. Photonics, Vol. 2, pp. 483-487, 2008.

[3] A.N. Krasnov; “High-contrast organic light-emitting diodes on flexible substrates”, Appl. Phys. Lett., Vol. 80, pp. 3853-3855, 2002.

[4] S. Reineke, F. Lindner, G. Schwartz, N.Seidler, K. Walzer, B. Lussem and K. Leo; “White organic light-emitting diodes with fluorescent tube efficiency”, Nature (London), Vol. 459, pp. 234-238, 2009.

[5] K. Saxena, V. K. Jain and D. S. Mehta; “A review on the light extraction techniques in organic electroluminescent devices”, Opt. Mater., Vol. 32(1), pp. 221-233, 2009.

[6] I. Schnitzer, E. Yablonovitch, C. Caneau, T. J. Gmitter and A. Scherer; “30% External quantum efficiency from surface textured, thin-film light-emitting diodes”, Appl. Phys. Lett., Vol. 63, pp. 2174-2176, 1993.

[7] G. Gu, D.Z. Garbuzov, P.E. Burrows, S. Venkatesh, S.R. Forrest and M.E. Thompson; “High-external-quantum-efficiency organic light-emitting devices”, Opt. Lett., Vol. 22(6), pp. 396-398, 1997.

[8] R.H. Jordan, L.J. Rothberg, A. Dodabalapur and R.E. Slusher; “Efficiency enhancement of microcavity organic light emitting diodes”, Appl. Phys. Lett., Vol. 69(14), pp. 1997-1999, 1996.

[9] J. Feng, T. Okamoto and S. Kawata; “Enhancement of electroluminescence through a two-dimensional corrugated metal film by grating-induced surface-plasmon cross coupling”, Opt. Lett., Vol. 30(17), pp. 2302-2304, 2005.

[10] B.J. Matterson, J.M. Lupton, A.F. Safonov, M.G. Salt, W.L. Barnes and I.D.W. Samuel; “Increased efficiency of a polymer light-emitting diode by wavelength scale microstructure”, Adv. Mater., Vol. 13(2), pp. 123-127, 2001.

[11] T. Tsutsui, M. Yahiro, H. Yokogawa, K. Kawano and M. Yokoyama; “Doubling Coupling-Out Efficiency in. Organic Light-Emitting Devices Using a Thin Silica Aerogel Layer”, Adv. Mater., Vol. 13(15), pp. 1149-1152, 2001.

[12] N.C. Greenham, R.H. Friend, D.D.C. Bradley; “Angular dependence of the emission from a conjugated polymer light-emitting diode: implications for efficiency calculations", Adv. Mater., Vol. 6, pp. 491-494, 1994.

[13] S.M. Jeong, F. Araoka, Y. Machida, Y. Takanishi, K. Ishikawa, H. Takezoe, S. Nishimura and G. Suzaki; “Enhancement of normally directed light outcoupling from organic light-emitting diodes using nanoimprinted low-refractive-index layer”, Appl. Phys. Lett., Vol. 92(8), pp. 083307, 2008.

[14] Y. Sun and S.R. Forrest; “Organic light emitting devices with enhanced outcoupling via microlenses fabricated by imprint lithography”, J. Appl. Phys., Vol. 100(7), pp. 073106, 2006.

[15] A. Duggal, J.Shiang, C. Heller and D. Faust; “Organic light-emitting devices for illumination quality white light”, Appl. Phys. Lett., Vol. 80(19), pp. 3470-3472, 2002.

[16] B.C. Krummacher, V.E. Choong, M.K. Mathai, S.A. Choulis, F.So, F. Jermann, T. Fiedler and M. Zachau; “Highly efficient white organic light-emitting diode”, Appl. Phys. Lett., Vol. 88(11), pp. 113506, 2006. http://dx.doi.org/10.1063/ 1.2186080

[17] Y. Li, F. Li, J. Zhang, C. Wang, S. Zhu, H. Yu, Z. Wang and B. Yang; “Improved light extraction efficiency of white organic light-emitting devices by biomimetic antireflective surfaces”, Appl. Phys. Lett., Vol. 96(15), pp. 153305, 2010.