P-128: Inverted Top-Emitting Organic Light-Emitting Devices Using Vanadium Pentoxide as Anode Buffer Layer

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Abstract

Inverted top-emitting organic light-emitting devices (ITOLEDs) employing thin film of vanadium pentoxide (V_2O_5) capped with vacuum deposited semitransparent silver layer as top anode were studied. The devices consisted of C-545T doped in Alq_3 as emitting layers exhibited a maximum external current efficiency of ~11cd/A and a turn on voltage of ~6.4V.We attribute the good performance of the devices to the high work function of V_2O_5 which provides efficient hole injection into the devices.

1. Introduction

Recently, top-emitting OLEDs (TOLEDs) have attracted considerable attention due to their potential application in high resolution displays [1-4]. TOLED has the advantage that most of the pixel can be utilized in the emission process while the pixel transistors can be hidden underneath the OLED.

For TOLED, there is a choice of having the anode, usually ITO, on the substrate or on top of the device (inverted). ITO is usually obtained by sputtering. If the ITO is on top of the device, then one has to do sputtering on the OLED, which causes damage to the underlying organic layer. This will lead to a reduction of the performance even with protective buffer layers [1-4]. Thus ITO is usually placed on the substrate and a regular OLED stack with the cathode as the outermost layer. In this case the cathode has to be thin and semi-transparent.

However an inverted top-emitting OLEDs [5,6] are more preferable from the standpoint of integration of OLEDs to drivers, because n-channel Si or organic transistors have higher mobilities. So it better to have the cathode of the OLED on the substrate. Thus the problem is to find a good transparent anode material that can be evaporated on the OLED without causing any damage. Semitransparent silver [7-9] is a good candidate due to its lower resistivity and less absorption in the visible light region compared with other metals. However, its work function does not match that of the hole injection organic layer, leading to less than efficient carrier injection.

In this paper, we study an inverted TOLED (ITOLED) where the anode is the top layer. We employed thin films of V_2O_5, which has been used by other groups as an anode modification layer [10] to improve holes injection, capped with a semitransparent Ag as the top anode. Devices with different thicknesses of V_2O_5 were fabricated and compared, The best performance device has a turn on voltage of ~6.4 V and a maximum current efficiency of ~11cd/A, with 3nm of V_2O_5.

2. Experiment details

The substrate used here is commercial glass cleaned in the standard manner. The structure of the OLEDs studied is shown in Fig 1. 70nm Al thin films were fabricated onto the glass using vacuum thermal evaporation, capped with 9nm Ca as bottom cathode. The organic layers, consisting of 20nm 2,9-dimethyl-4,7 diphenyl-1,10-phenanthroline (BCP), followed by 30nm tris-(8-hydroxyquinoline) aluminum (Alq_3) doped with 2wt% 2,3,6,7-tetrahydro-1H, 5H, 11H-10-(2-benzothiazolyl)quinolizino-[9, 9a, 1gh] Coumarin (C-545T), and 50nm 4,4-bis[*N*-(1-naphthyl)-*N*-phenyl-amino] biphenyl (NPB). The BCP film served as electron transport layer and hole/exciton blocker. C-545T doped Alq3 layer was used as the emitting layer. NPB served as a hole transport layer. V_2O_5 capped with 25nm Ag were deposited on NPB as the top anode. All the films were formed by thermal evaporation in a vacuum chamber with a base pressure of less than 1.5 x 10^{-4} Pa.

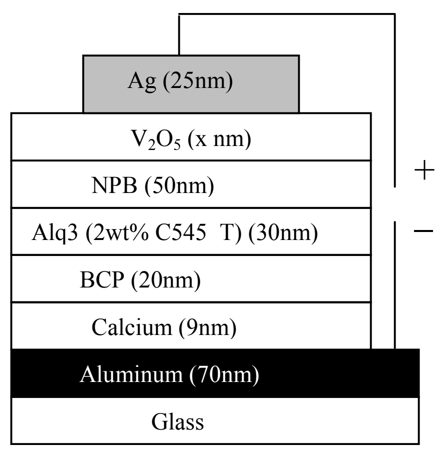

FIG 1. Schematic structure of inverted TOLEDs

The typical deposition rate was 0.1-0.2nm/s, 0.2-0.4nm/s and 0.02-0.04nm/s for organic materials, metal and V_2O_5, respectively. The thickness was monitored by quartz crystal oscillators in situ. The active area of the device was $7mm^2$ as defined by a shadow mask. The current density-voltage (J-V) and luminance-voltage (L-V) characteristics of the EL devices were measured simultaneously with parameter analyzer (HP4145B) and silicon photodiode calibrated by PR650.

3. Results and discussion

The key characteristic parameters of the EL devices are listed in Table I. It can be seen that the characteristics of devices are strongly dependent on V_2O_5 thickness. Device with 0.5nm V_2O_5 exhibits highest turn on voltage and poor J-V, L-V characteristics. With the increase of thickness of V_2O_5 from 0.5 nm to 3 nm, both the turn on voltage and V_{2000} (the voltage at 2000 cd/m^2) decrease greatly. Actually, a device without V_2O_5 layer was also fabricated. But it turned on at very high voltage and was broken down immediately.

TABLE I. Performance of ITOLEDs with different V_2O_5 thickness

V_2O_5 Thickness (nm)	turn on voltage (V)	voltage (V) at 20mA/cm^2	voltage (V) at 2000cd/m^2
0. 5	9.0	13.4	16.4
1	7.0	13.0	13.3
3	6.4	12.5	12.7
7	6.6	12.5	12.8

The J-V and L-V characteristics of devices with 1nm, 3nm, 7nm V_2O_5 thin films versus different operation voltages are shown in Fig. 2. Devices with 3nm and 7nm V_2O_5 can achieve a luminance of 10,000cd/m^2 at ~14.5V and increase rapidly to 70,000cd/m m^2 at about ~17V. The corresponding voltages for devices with 1nm V_2O_5 are ~15V and ~18.5V, respectively. Although the device with 1nm V_2O_5 exhibits relatively poor J-V and L-V characteristics, it can reach a similar current efficiency (See Fig. 3) as the device containing 3nm V_2O_5. However, the device with 7nm V_2O_5 shows the poorest external current efficiency.

The fact that the performances of devices are depending on the presence and different thickness of V_2O_5 can be understood in this way. There exists a big barrier (~1.2 eV) for hole injection at the Ag/NPB interface due to a mismatch between the work functions of Ag (~4.3eV) and the high occupied molecules orbital (HOMO) of NPB (~5.5eV). Insertion of a thin layer of high work function V_2O_5 greatly enhances holes injection from Ag to NPB. Consequently, the turn on voltage of devices decreases and the J-V, L-V characteristics are greatly improved in the meanwhile.

The performance of devices with 0.5nm V_2O_5 is the poorest among the devices listed in Table I because it is believed that the ultrathin V_2O_5 film does not form a continuous film. Devices with 7nm V_2O_5 exhibit comparable J-V and L-V characteristics to those containing 3nm V_2O_5, while the current efficiency is lower. We believe that thicker V_2O_5 film provides a lower sheet resistance so that more holes are injected under the same applied voltage. However this will induce an imbalance in the injection of holes and electrons leading to a lower recombination probability and therefore lower luminous efficiency.

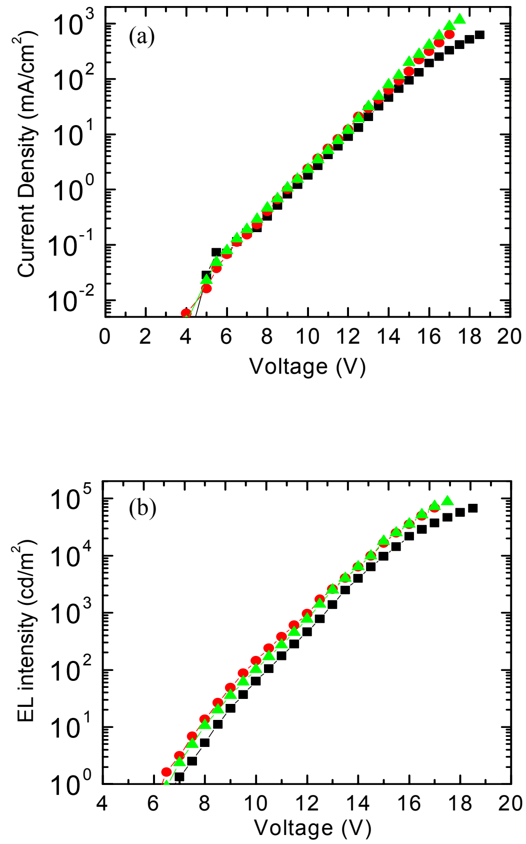

FIG. 2. (a) J-V and (b)L-V characteristics of ITOLEDs with different V_2O_5 thickness (□:1nm; ○:3nm; △:7nm)

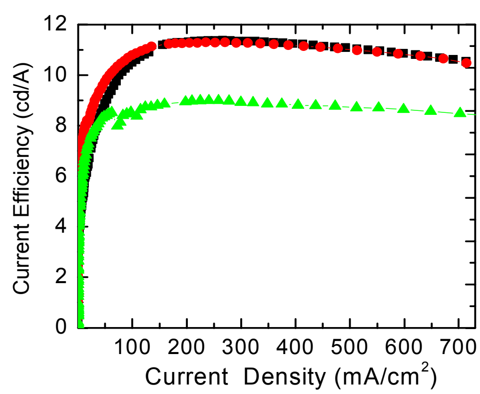

FIG. 3. Current efficiency characteristics of ITOLEDs with different V_2O_5 thickness (□:1nm; ○:3nm; △:7nm)

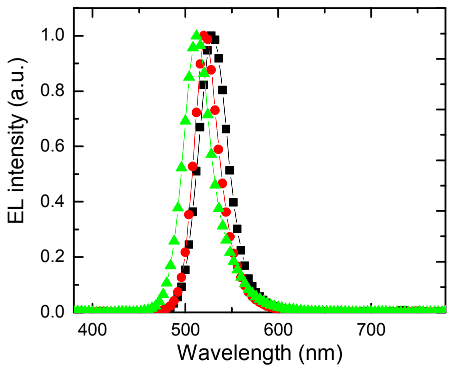

FIG. 4. EL spectra at different view angles (□:0; ○:20°; △: 60° off normal surface)

Fig. 4 shows the EL spectra of devices at different view angles. The variation of spectra is obviously caused by microcavity effects due to the two opposite metal electrodes [7,9]. Presumably this can be minimized by optimizing the thickness of devices through optical simulation [11].

4. Conclusions

We studied inverted TOLEDs using different thickness V_2O_5 thin layers as top anode buffer layers. The insertion of an optimal thickness V_2O_5 thin layer can greatly decrease the turn-on voltage and significantly improve the EL performance of the devices. We attribute the improvement to high work function of V_2O_5 that can greatly enhance the hole injection from top anodes. The results indicate that this type of top anode is a good candidate for ITOLEDs.

5. Acknowledgement

This research was supported by the Hong Kong Government Innovation and Technology Fund.

6. References

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