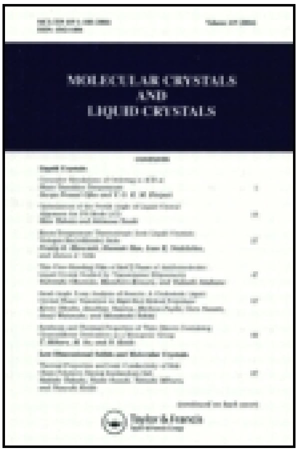

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Effect of Cathode and Anode Fabrication on Flexible Transparent OLED Based on PEN Film

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Among many display devices, organic light-emitting diodes (OLEDs) have been regarded most promising for the transparent flexible displays. In this work we fabricated transparent flexible OLEDs by adopting ITO/Ag/ITO multilayer as anode and Ag/Al thin film as cathode on PEN film and examined their performances.

Keywords Flexible OLED; Organic Light Emtting Diode; Transparent Anode; Transparent Cathode

Introduction

Transparent displays are promising candidates for the next-generation displays which could be integrated into daily lives in the ubiquitous society. Among many display devices, organic light-emitting diodes(OLEDs) have been regarded most promising for the transparent flexible displays. In achieving high-transparency OLEDs with a high efficiency, the role of transparent top cathode is especially important since metal cathodes are currently employed for the OLEDs due to efficient electron injection property. The dielectric-metal-dielectric type anode such as ITO-Ag-ITO has been reported to achieve a transparent effect in the visible region [1]. It was also suggested that the electrical conductivity and mechanical flexibility of OLEDs can be remarkably improved by using ITO-Ag-ITO type anode. In this work we fabricated transparent flexible OLEDs by adopting ITO/Ag/ITO multilayer as anode and Ag/Al thin film as cathode on PEN film and examined their performances from the view points of the sheet resistance and transmittance of the transparent electrodes.

Experimental

The ITO/Ag/ITO multilayer thin films were deposited on the PEN films by RF sputtering (ITO layer) and DC sputtering (Ag layer) utilizing roll-to-roll sputtering system at room

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Table 1. The operation conditions of roll-to-roll sputter for the ITO/Ag/ITO multiple anode

Film	Layer	RF[w]	DC[w]	B.P[torr]	Ar[sccm]	O2[sccm]
PEN	ITO	500	—	1.0E-0.5	100	0.3
	Ag	—	250		50	0
	ITO	500	—		100	0.3

temperature. Table 1 lists the deposition conditions for ITO/Ag/ITO multilayer on PEN films. The fabrication of OLED device on the PEN film with patterned ITO/Ag/ITO multilayer anode and insulator layer was carried out with the Sunic EL Plus 200, a cluster type OLED panel fabrication system.

Results and Discussion

Fabrication and Electro-optical Properties of Transparent Electrodes

The ITO/Ag/ITO multilayer anode was deposited on the PEN film with primer coating layer by magnetron sputtering method with the roll-to-roll sputtering system shown in Fig. 1 utilizing the operation conditions shown in Table 1. Before the multilayer anode deposition the PEN film roll was extensively degassed in the roll-to-roll sputter chamber for 24 hr at 70°C under 1×10^{-5} torr vacuum with illumination of mid-infrared lamp to remove the adsorbed moisture which could otherwise cause micro-cracks in the subsequent ITO/Ag/ITO thin film deposition. The roll speed for multilayer deposition and the sheet resistance(Rs) and transmittance(TT) of the resulting ITO/Ag/ITO-PEN films are shown in Table 2. The ITO/Ag/ITO-PEN(9) film exhibited low sheet resistance of 8.0 Ω/□ and 83.8% transmittance which could be well suited for the fabrication of transparent flexible OLED devices. The average thickness of the ITO/Ag/ITO anode was 50/17/50 nm, respectively, as reported in our previous work [2] and the work function of ITO/Ag/ITO anode was

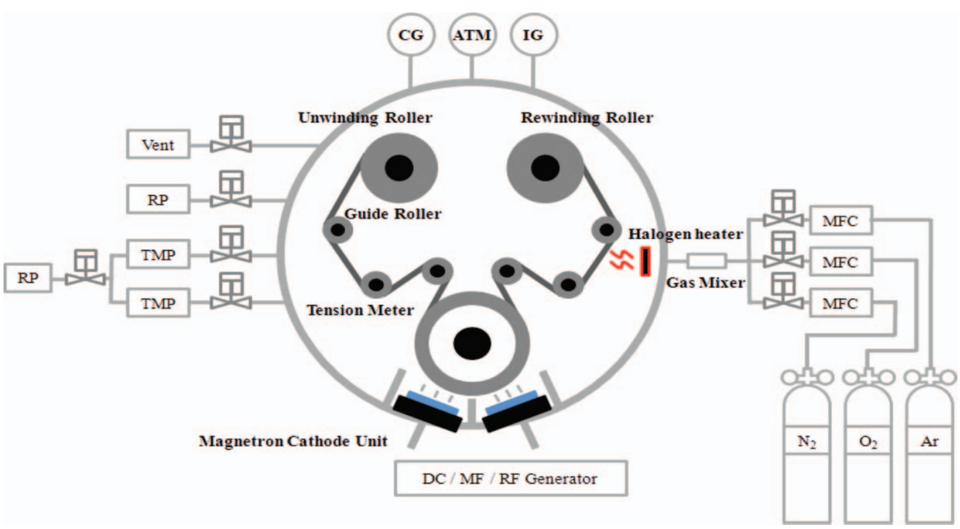

Figure 1. Schematic diagram of roll-to-roll sputtering system.

Table 2. The sputtering condition and electro-optical properties of ITO/Ag/ITO-PEN anode films

Sample No.	Speed [m/min]		Rs [ohms/sq]	TT[%]	Sample No.	Speed [m/min]		Rs [ohms/sq]	TT[%]
1	ITO	0.60	23.0	77.3	6	ITO	0.12	13.0	80.5
	Ag	1.10				Ag	1.00		
	ITO	0.60				ITO	0.12		
2	ITO	0.30	15.0	79.0	7	ITO	0.10	12.0	76.3
	Ag	1.10				Ag	1.00		
	ITO	0.30				ITO	0.10		
3	ITO	0.10	15.0	79.6	8	ITO	0.08	11.0	80.8
	Ag	1.10				Ag	1.00		
	ITO	0.10				ITO	0.08		
4	ITO	0.08	16.0	74.6	9	ITO	0.12	8.0	83.8
	Ag	1.10				Ag	0.90		
	ITO	0.08				ITO	0.12		
5	ITO	0.06	14.0	59.2	10	ITO	0.10	8.6	83.3
	Ag	1.10				Ag	0.90		
	ITO	0.06				ITO	0.10		

nearly same as that of ITO glass. As for the transparent cathode, the Al/Ag, Mg:Ag and Mg:Ag/Ag type double layers and codeposition layers were formed on the glass substrates first in order to check the relationship between the metal cathode thickness and sheet resistance vs. transmittance properties [3–5]. In case of Mg:Ag codeposition by thermal evaporation the deposition was controlled to 10:1 Å/sec rates. Here thin metal cathodes were deposited by vacuum thermal evaporation method in order not to damage the organic layers of OLED devices when actually deposited on the flexible PEN substrates. Table 3 shows that the thin film cathodes of Al/Ag = 5/110(Å) and Al/Ag = 10/100(Å) resulted in

Table 3. Sheet resistances and transmittances of double layer metal cathodes

Cathode	Thickness (Å)	Sheet resistance (Ω/□)	Transmittance (%)
Al/Ag	5/105	11.99	57.9
Al/Ag	5/110	8.72	58.2
Al/Ag	10/105	11.27	54.8
Al/Ag	10/110	9.83	53.3
Mg:Ag	90	112.4	66.0
Mg:Ag	100	95.37	60.2
Mg:Ag	110	86.14	60.1
Mg:Ag	120	60.18	50.9
Mg:Ag	130	38.41	42.0
Mg:Ag/Ag	30/80	90.93	67.9
Mg:Ag/Ag	30/90	52.13	67.3
Mg:Ag/Ag	30/100	34.73	67.0

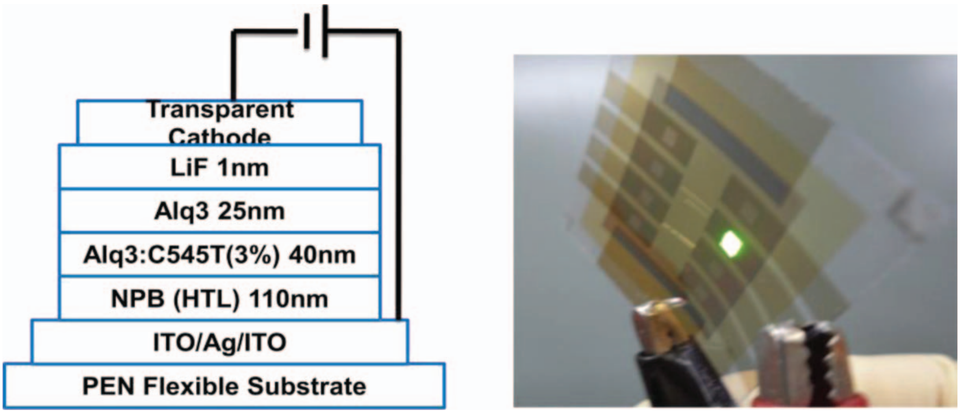

Figure 2. The structure(a) and operating picture(b) of flexible transparent OLEDs.

sheet resistance of lower than 10 Ω/□, normally required for the anodes of OLED devices, and relatively high transmittance over 50%.

Fabrication and Properties of Transparent Flexible OLEDs

After deposition of ITO/Ag/ITO transparent multilayer anode on PEN film, the flexible substrates were subjected to the OLED device fabrication. For the patterning of ITO/Ag/ITO multilayer anode on flexible substrates the photolithographic processes have to be modified from the usual ITO glass process used in the OLED device fabrication. First positive-PR (DS-i1000, Dongjin Chemical Co.) was spin coated stepwise under the condition of 200 rpm (10 sec), 1800 rpm (20 sec) and 2000 rpm (20 sec) followed by soft bake at 90°C for 3 min. The positive-PR thin film was subjected to UV exposure (MDA-12000, Midas System) at 6 mW/CM^2 for 15 sec followed by developing in TMAH 2.38 wt% solution (80 sec), D.I. water washing and hard bake at 100°C for 5 min. The ITO/Ag/ITO multilayer anode was then etched by dipping in an etchant solution (DA-300, Dongjin Chemical Co.) for 10 min followed by deionized water washing. After etching of ITO/Ag/ITO anode the remaining positive PR was stripped in an aqueous alkaline solution (Remover PG, Microchem Co.) by dipping for 5min followed by D.I. water washing. After patterning of ITO/Ag/ITO anode the insulator layer was also patterned by photolithographic process. Here we used a new insulator layer that is the same positive PR (DS-i1000, Dongjin Chemical Co.) used in the

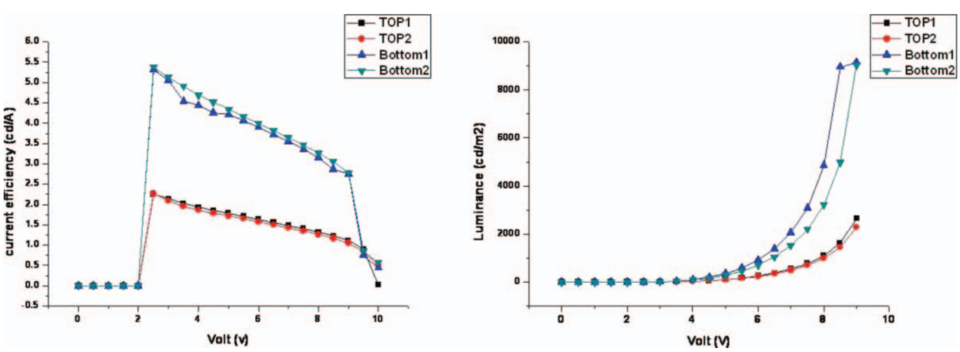

Figure 3. The performances of flexible transparent OLED devices.

Table 4. The performance of OLEDs measured from anode and cathode sides.

	Measured sides			
	Anode side		Cathode side	
OLED devices	OLED-1	OLED-2	OLED-1	OLED-2
Current efficiency(cd/A)	5.5	5.5	2.2	2.2
Luminance(cd/m^2)	9153	9041	2626	2285

ITO/Ag/ITO anode pattering instead of the usual polyimide PR due to the higher process temperature of the latter photoresist. The flexible transparent OLED device had configuration of PEN/ITO-Ag-ITO/HTL(NPB, 110 nm)/EML(Alq3:C545T(3%), 40 nm)/ETL(Alq3, 25 nm)/LiF/Transparent Cathode as shown in Fig. 2 with a picture of transparent flexible OLED device under operation. Here the transparent metal cathodes adopted were Al/Ag = 5/110(Å) and Al/Ag = 10/110(Å) for the transparent flexible OLED-1 and OLED-2 devices, respectively as explained in Table 3. The performances of the OLED-1 and OLED-2 devices are shown in Fig. 3. The notations TOP1/TOP2 and Bottom1/Bottom2 in Fig. 3 were used to represent the current efficiency vs. voltage and luminance vs. voltage plots of the OLED-1/OLED-2 devices measured from the top (cathode) and bottom (anode) sides, respectively. It was found that both current efficiency and luminance of the OLEDs were higher when they were measured from the ITO/Ag/ITO anode sides than from the Al/Ag thin film cathode sides due to the higher transmittance of the former transparent electrode as shown in Table 4. This reflects that the transmittance of the ITO/Ag/ITO anode was higher (83.8%) than that of the Al/Ag thin film cathode (58.2%). It was also observed from Table 4 that the OLED-1 device exhibited slightly higher luminance values from both anode and cathode sides than the ones from OLED-2 device. This seemed to be due to the lower sheet resistance of the transparent anode, that is, OLED-1 (8.72 Ω/□) than that of OLED-2 (9.83 Ω/□).

Conclusions

In this work we fabricated transparent flexible OLEDs by adopting ITO/Ag/ITO multilayer as anode and Ag/Al thin film as cathode on PEN film and examined their performances from the view points of the sheet resistance and transmittance of the transparent electrodes. It was noted that both current efficiency and luminance of the OLEDs were higher when they were measured from the ITO/Ag/ITO anode sides than from the Al/Ag thin film cathode sides due to the higher transmittance of the former transparent electrode. The OLEDs with lower sheet resistance in the transparent anode exhibited higher luminance.

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