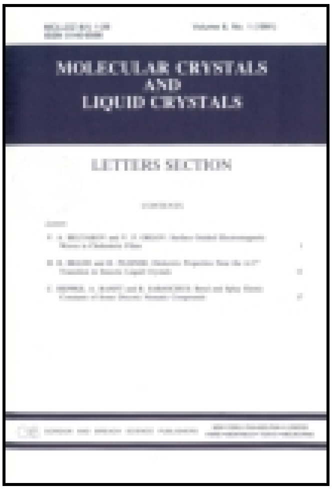

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Flexible OLED Fabricated on Glass Fabric Reinforced Film and Performance

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The efficiency and life time of flexible OLED are still major problem to overcome compared to the OLED devices based on glass substrate. The short life time of flexible OLEDs are attributed to the increased penetration of oxygen and water vapor to the thin organic layer of OLED device through the flexible polymer film substrate.

In this work, we prepared glass fiber reinforced polymer film (GFRF) for use as substrate of flexible OLED. The glass fabric was immersed in the UV curable resin and packed between the transparent glass templates followed by UV irradiation for conversion to GFRF. The optical and mechanical properties of the GFRF films were examined and optimized for use as substrate of flexible OLEDs. The gas barrier layers were formed on the GFRF films. The deposition of ITO/Ag/ITO transparent conduction anode was carried out by using roll-to-roll sputter followed by fabrication of flexible OLEDs. The effect of process conditions on the property of flexible OLEDs were studied from the view point of application to the OLED lighting and signage of flexible OLEDs.

Keywords Flexible OLED; glass fiber; toughness; roll-to-roll sputter; transparent film; multi-layer

1. Introduction

Organic light-emitting diodes (OLEDs) have drawn much attention due to their potential application in next-generation flat-panel displays and lighting fixtures [1–5]. The efficiency and life time of flexible OLED are still major problem to overcome compared to the OLED devices based on glass substrate. The short life time of flexible OLEDs are attributed to the increased penetration of oxygen and water vapor to the thin organic layer of OLED device through the flexible polymer film substrate. Additionally, because of their simple, organic

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

Layer	RF[w]	DC[w]	B.P[torr]	Ar[sccm]	O_2[sccm]
ITO	500	-	1.0E-0.5	100	0.3
Ag	-	250		50	0
ITO	500	-		100	0.3

thin-film design, OLEDs can be easily built on flexible substrates [6]. The plastic substrate suitable for an OLED display must satisfy numerous requirements : high optical quality, substrate smoothness in the nanometer range to prevent protrusions into subsequent barrier and device layers, a good barrier to moisture and oxygen and good dimensional stability [7].

Flexible OLEDs have been reported utilizing transparent plastic films such as poly(ethylene terephthalate), polycarbonate and polyimide. In this work, we have made a glass fabric reinforced film (GFRF) as a substrate for flexible OLEDs. The fabrication process of GFRF and the performance of the resulting flexible OLEDs were examined.

2. Experiment Details

2.1. Preparation and Characterization of Glass Fabric Reinforced Film (GFRF)

The materials used in the fabrication of GFRF are as following. The glass fabric was obtained from Nittobo Co., Japan, which had thickness of about 30 μm. The UV resin were also supplied from the companies, PM-472 and SR-33 (CC Tech Co. Korea) and Mins-311RM (Minuta Co., Japan). Monofunctional UV monomer, 2-hydroxyethyl methacrylate (HEMA), was purchased from Aldrich Chemical Co. (U.S.A.) and used as received.

The glass fabric was washed by soaking for 3 min. in solvents such as ethanol and acetone. After drying at room temperature, the glass fabric was soaked in UV resin or UV resin diluted with HEMA monomer, followed by lamination on the flat glass substrate up to three layers. The resulting composite layers were cured by exposure to the UV curing equipment. The cured GFRF flexible substrate was peeled off the glass [8]. The GFRF samples were subjected to the optical and mechanical measurements by using UV-vis. spectrophotometer (CM-3600d, Konica Minolta, Japan) and UTM (M 4465, Instron Co., U.S.A.), respectively.

2.2. Flexible OLEDs on GFRF Substrates

The AlNx thin film as gas barrier layer on GFRF flexible substrate was formed by reactive sputtering method with Al target under control of N2 partial pressure using roll-to-roll sputter. The ITO/Ag/ITO multilayer thin films as anode of OLED device were deposited on AlNx /GFRF substrate by RF sputtering (ITO layer) and DC sputtering (Ag layer) utilizing roll-to-roll sputtering system at room temperature [9]. Table 1 lists the deposition condition for ITO/Ag/ITO multilayer on top of the AlNx/GFRF films. The fabrication of OLED device on the GFRF 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

Table 2. Optical property of GFRF film and glass fabric

UV Resin	Thickness(μm)	Transmittance	Haze	a* (green-red)	b* (blue-yellow)	L* (black-white)
MINUTA	120	85.02	53.64	0.01	1.09	93.77
PM-472	110	89.05	11.83	-0.82	3.02	95.86
SR-33	90	85.75	51.32	0.00	1.42	94.08
Glass Fabric	30	72.80	88	0.01	0.21	88.06

system. The flexible OLEDs fabricated on GFRF substrate had configuration of HTL(NPB, 1000Å)/EML(Alq3;C545T, 400 Å)/ETL(Alq3, 250 Å)/EIL(LiF, 10 Å)/Cathode(Al, 1000 Å). The film encapsulation of the flexible OLEDs on GFRF substrate was carried out by using the same GFRF film with AlNx gas barrier layer utilizing optically clear adhesive (OCA) 8146–2 from 3M Co., U.S.A. The surface treatment in the rectangular edge of AlNx/GFRF encapsulation film was conducted with UV/Ozone cleaner (UVC-30, Jaesung Eng. Co., Korea).

2.3. Measurement

The thickness of the gas barrier layers and the light transmittance of the substrate film with gas barrier layers were measured by Nanoview (Nanosystem, NV-E1000) equipment and UV-vis. spectraphotometer (CM-3600d, Konica Minolta Co., Japan). The surface of gas barrier thin film was examined by both scanning electron microscope (SEM, Hitachi s-4800, Japan). The electro-optical performance of the flexible OLED device was measured by using Spectroscan PR-650 (Photoresearch Co., U.S.A.) with a DC power supply (Keithley 2400) connected with model 8092A digital multimeter [10].

3. Results and Discussion

3.1. Fabrication of GFRF Substrate and Properties

After wahing and drying on layer of the glass fabric (thickness $\sim 30\mu$m) was soaked with UV resin and then sandwitched between two sheets of glasses on which thin layer of UV resin was coated. After UV exposure, the GFRF composite film was peeled off the glasses and then optical property was checked. The ITO/Ag/ITO/AlNx/GFRF film exhibited low sheet resistance of 8.0 Ω/γ 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, and the work function of ITO/Ag/ITO anode was nearly same as that of ITO glass. As shown in Table 2, the GFRF film exhibited much higher transmittance and lower haze than the glass fabric. This seemed to be due to the higher scattering of light from the glass fabric than the GFRF film. The glass fabric had a lot of air void in the fabric structure. The GFRF, however, had higher density and smoother surface compared to the glass fabric. The GFRF film made with UV resin PM-472 exhibited high transmittance to visible light and low haze compared to other UV resin samples. This could be explained by good wetting property of PM-472 UV resin on the glass fabric and

Table 3. Optical and deformation properties of GFRF films made with diluted UV resin

Raw Materials				Thickness(μm)	Transmittance	Haze	Deformation (Curl after 110 °C)
Soda Glass				700	89.02	0.42	O
Glass Fiber				30	71.13	88.01	O
GFRF Samples	UV Resin	HEMA	Layers				
821	80	20	1	113	86.75	8.16	X
822	80	20	2	113	88.02	5.23	X
823	80	20	3	220	87.21	8.65	△
731	70	30	1	100	88.49	11.83	X
732	70	30	2	130	88.50	8.57	X
733	70	30	3	160	87.73	11.17	O
551	50	50	1	90	86.81	14.95	X
552	50	50	2	163	82.79	31.66	X
553	50	50	3	180	83.33	39.17	O

close refractive index value (nd = 1.50) to that of glass (nd = 1.52). The GFRF composite film was not flexible enough for the fabrication of flexible OLED device. This could be attributed to the thickness of the film and to the high crosslink density in the UV matrix.

In order to solve the problems, the UV resin (PM-472) was diluted with the monofunctional UV monomer (HEMA) and the GFRF composite films were made with up to 3 layers of glass fabric. The data in Table 3 exhibited that GFRF 733 sample made with 3 layers of glass fabric and UV resin diluted with 30 weight% of HEMA monomer had optimum thickness for mechanical strength, high transmittance, low haze and low deformation (degree of curling after 110 °C heating). The GFRF 823 sample had good optical property that exhibited high degree of curl due to high crosslinking density after UV curing with insufficient monofunctional monomer. The comparison of the mechanical property of GFRF (821 ∼733) samples are shown in Fig. 1. The GFRF 733 sample exhibited both high toughness and smooth deformation (flexibility).

3.2. Fabrication of Flexible OLEDs and Performance

The typical luminance and current efficiency curves of the flexible OLEDs made on GFRF (733) substrate are shown in Figure 2. As shown in Figure 2, the OLED device exhibited high threshold voltage and low current efficiency. The poor performance of the initial stage OLED devices seemed to be originated from the leaky interface between the OCA gasket and GFRF substrate on which gas barrier layer was not formed. Therefore modification of flexible OLEDs was conducted by depositing AlNx gas barrier layer on the GFRF film and also surface treatment of GFRF encapsulating substrate.

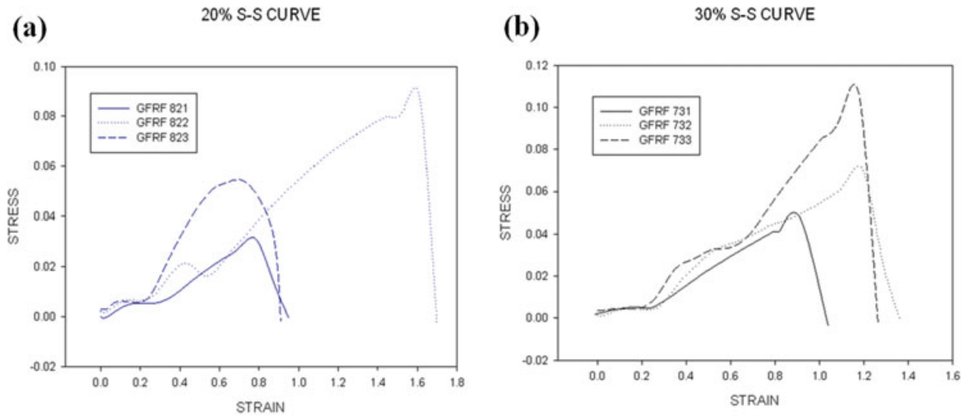

Figure 1. Stress-strain curves of GFRF composite films.

The surface treatment of the GFRF film was conducted with the UV/ozone cleaner the rectangular edge on which OCA gasket was inserted. The changes of the water contact angle on various substrates are shown in Figure 3. The surface treated GFRF film showed lower contact angle than the untreated GFRF sample, close to that of poly(ethylene naphthalate), PEN, film. The combination of PEN film with OCA (3M) gasket was found to give encapsulation with low gas permeation in our previous work [11]. The easy separation of OCA gasket on untreated GFRF substrate was also shown in Figure 4. The structure of the improved flexible OLEDs on GFRF film is shown in Figure 5 with optimized thickness of the gas barrier layer and UV/ozone treatment. The typical eletro-optical property of the improved OLED device in shown in Figure 6 which had Vth of 6 volt, high luminance of 30,000 cd/m^2 and current efficiency of 10.5 cd/A. These data also support that prevention of air permeation into the thin organic layers of flexible OLED is important process for the high performance of flexible OLEDs. It also noted that the flexible OLEDs made on GFRF composite film could withstand high impact forces compared to the flexible OLED made on neat transparent films.

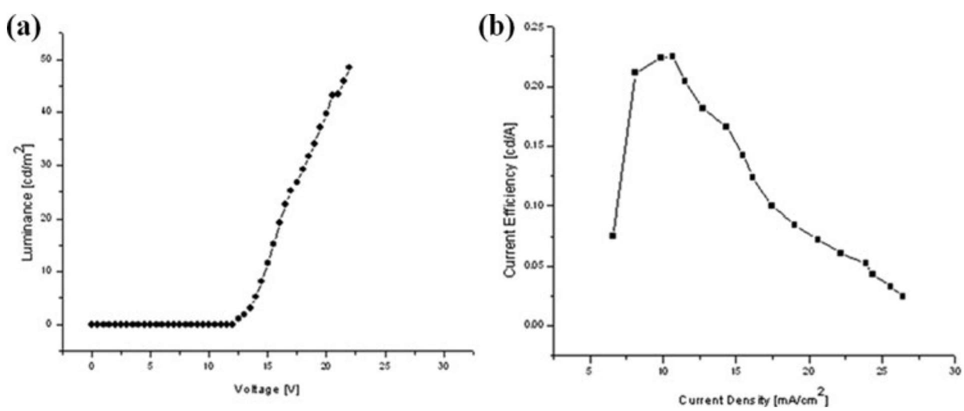

Figure 2. Luminance (a) and current efficiency (b) curves of flexible OLEDs made with untreated GFRF films.

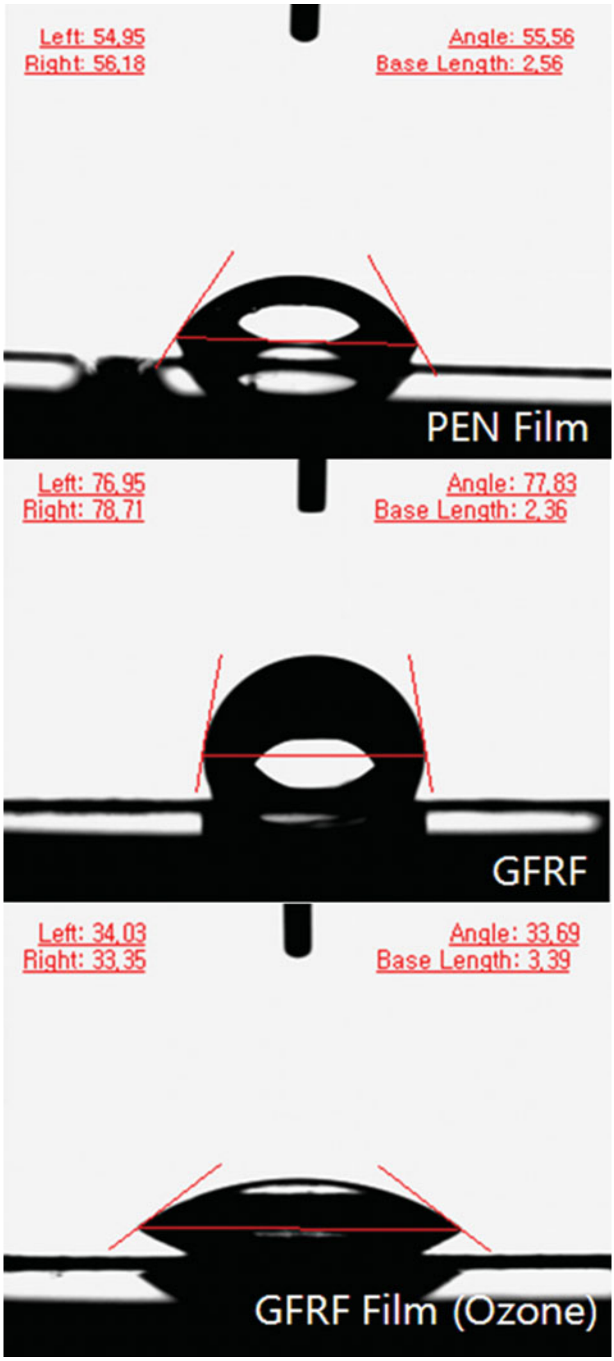

Figure 3. Contact angles of flexible substrates.

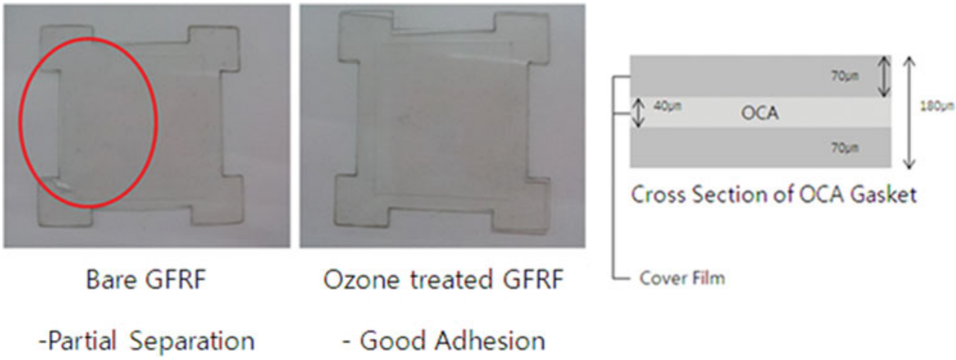

Figure 4. Structure of OCA gasket and GFRF interface.

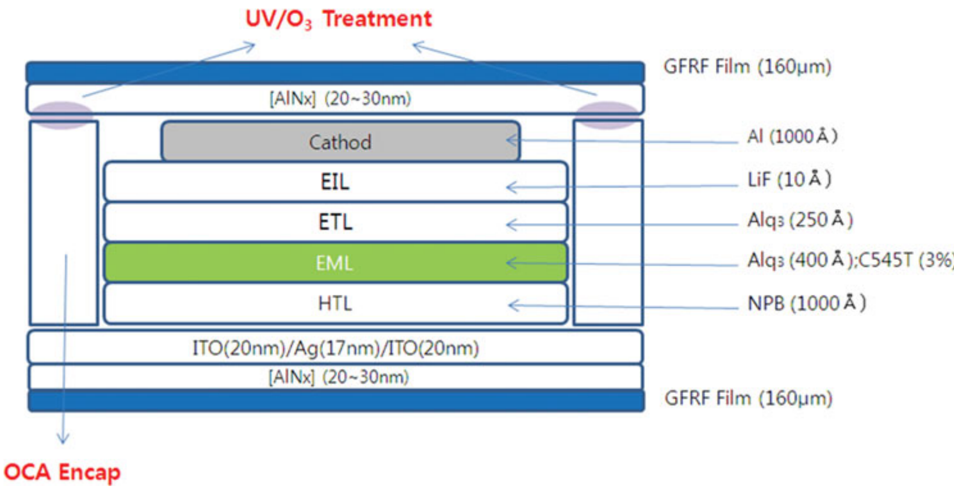

Figure 5. Structure of flexible OLED made with GFRF film with AlNx gas barrier layer and surface treated GFRF film encapsulation.

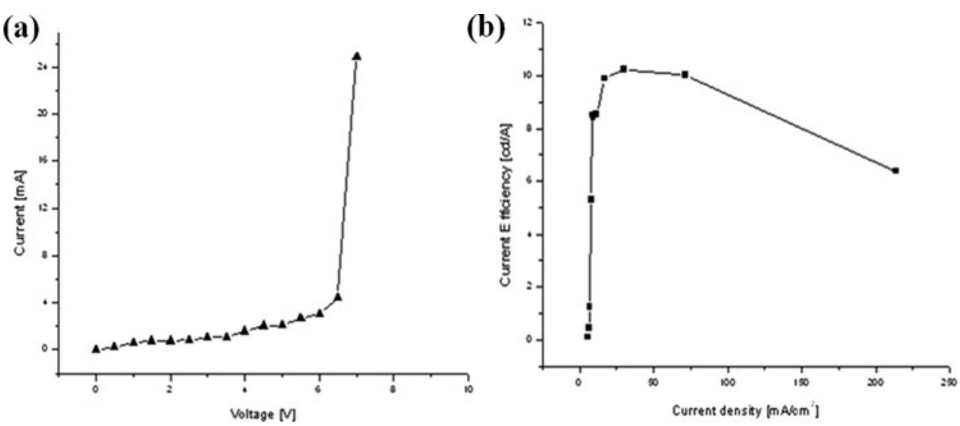

Figure 6. Luminance (a) and current efficiency (b) curves of flexible OLEDs made with surface treated GFRF films.

4. Conclusion

Flexible OLEDs have been studied actively for their potential application to both large size OLED display and decorative lighting. The efficiency and life time of flexible OLED are still major problem to overcome compared to the OLED devices based on glass substrate. The short life time of flexible OLEDs are attributed to the increased penetration of oxygen and water vapor to the thin organic layer of OLED device through the flexible polymer film substrate.

The OLEDs made on GFRF flexible substrate showed Vth of 6 volt, high luminance of 30,000 cd/m^2 and current efficiency of 10.5 cd/A, comparable to OLEDs on rigid glass substrate. It was found that the prevention of air permeation into the thin organic layers of flexible OLED is important process for the high performance of flexible OLEDs.

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