True Wearable Textile OLEDs Based on Real Fabric Platform

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ABSTRACT

Wearable displays can potentially offer countless functions while worn on the human body. To realize such displays however requires a combination of various technologies that can function on various curved surfaces reliably and durably, while subjected to bending, wrinkling and stretching. In this study, true wearable large-area textile OLEDs were developed which are highly flexible and environmentally reliable.

1 Introduction

Electronics are currently being developed in human-friendly wearable forms, to permit hyper-interconnection between user and electronics, and highly portable free-form devices are key to these technologies.[1]–[8] An important milestone in smart wearable devices is the integration of functional devices into our daily clothes.

Many studies have reported efforts to realize a cloth-like display. One of the first was an AC electroluminescent (EL) display on textile planarized by repetitive inkjet printing was reported, and the EL devices showed a 40 cd m^{-2} at 440 V.[9] Then, a screen-printed watch display using EL devices was reported.[10] Several other textile display studies have been conducted,[11]–[13] but technical challenges including low luminance and high operating voltage, lack of practicality due to the use of plastic-like fabric, lack of skills in large-area fabrication and insufficient environmental stability still remain before truly wearable displays can be realized.

In this paper, an approach to surmount these challenges is suggested, and true wearable large-area textile OLEDs based on a fabric already in daily use, polyester, is reported. The proposed wearable OLEDs were fabricated to be highly deformable and chemically stable by utilizing the novel fabrication skill of the textile platform and a multi-functional encapsulation system.

The RGB OLEDs were directly built on a commonly available fabric using a combination of a planarization layer and strain buffer. The strain buffer layer has a notable role, decreasing the strain transferred from the textile to the planarization layer.[4] The resulting textile OLEDs exhibit mechanical flexibility during folding or wrinkling deformation.

2 Experiment

Fabrication of the textile platform

The sacrificial layer, the planarization layer, and the strain buffer were coated on a glass substrate, and the polyester textile was laminated. After natural curing of the strain buffer, the sacrificial layer was removed by deionized water. Then, the textile substrate with functional thin films was naturally dried.

Fabrication of the encapsulation system

The encapsulation film was formed as a bilayer structure consisting of a pair of inorganic and organic layers via atomic layer deposition (ALD) and a spin-coating system. As the inorganic layer, Al_2O_3 and TiO_2 materials were used and I-OPTO TB polymer material was used as the organic layer.

3 Results and Discussion

3.1 Large-area textile OLEDs

To obtain large-area textile OLEDs, the surface of the textile substrate on which the OLED devices will be grown should be mechanically robust, smooth, and uniform. Therefore, a technology was introduced to replicate the surface of a glass substrate on a textile substrate. The surface-replicating process followed a previously reported method.[4] Functional thin films such as a planarization layer and a stress buffer layer were formed on a fabric substrate, and an OLED device was fabricated thereon. The planarization layer stably formed a nanoscale OLED device, and the stress buffer layer decreased the stress of all the constituent layers. Fig. 1 shows the large-area RGB textile OLEDs fabricated with this method. The RGB OLEDs maintained their emitting state without cracking or delaminating even when folded or wrinkled like daily clothes.

To verify the feasibility of the large-area textile OLEDs, the electroluminescent characteristics were systemically investigated and compared to glass OLEDs. Fig. 2 shows the JVL properties of the large-area textile OLEDs, which are comparable to those of glass OLEDs.

In addition, the luminance uniformity of large-area textile OLEDs was evaluated as shown in Fig. 3. The emission area of the large-area OLED was about 6400 mm^{-2}. 9 points were measured: top-left, top-mid, top - right, mid-left, mid-mid, mid-right, down-left, down-mid, down-right.

For wearable platforms, high deformability that does not limit human movement is a most important specification, so a cantilever test was conducted to determine whether the constituent layers of the OLEDs affected the flexibility of the textile substrate.[14] As shown in Fig. 4, the bare fabric, fabric substrate, and textile OLEDs had almost the same cantilever lengths, indicating that the planarization layer, strain buffer, and constituent layers of the OLEDs did not hamper the wearability of the fabric.

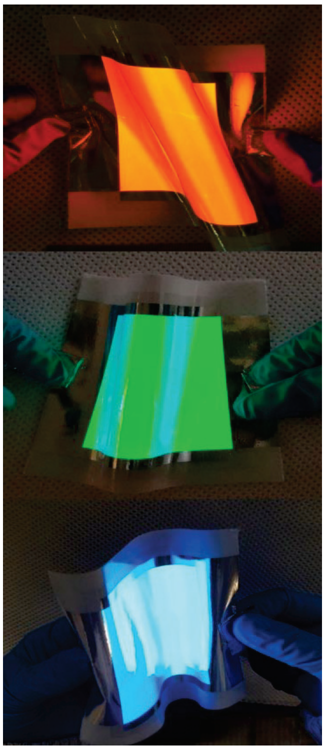

Fig. 1 Photographs of truly wearable large-area RGB OLEDs

3.2 Low temperature encapsulation system

There are various types of textiles used in daily life, such as silk, cotton, linen, wool, leather, as well as polyester. Among these common fabrics, some are extremely sensitive to heat, such as silk and linen types, so they need to be handled carefully even when washing or ironing. Therefore, to produce a truly wearable display that is not restricted by the type of fabric, an encapsulation process, which is an essential OLED post-process, should be performed at near room-temperature to avoid deterioration of the textile substrate.

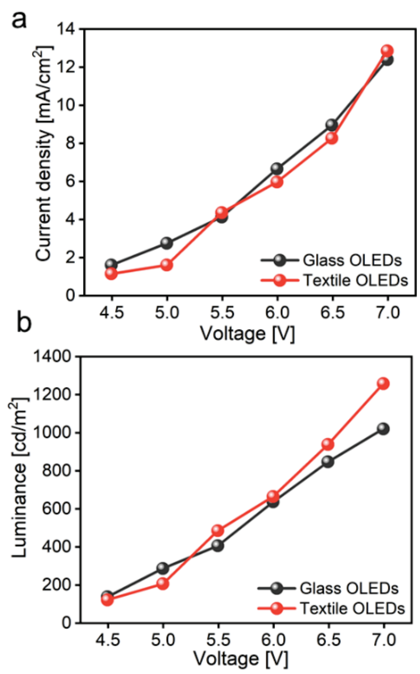

Fig. 2 a) Current density-voltage (J-V) curve and b) Luminance-voltage (L-V) curve of the large-area textile OLEDs

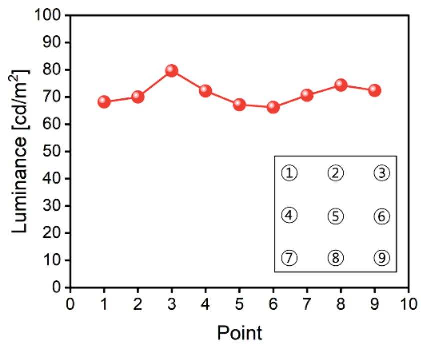

Fig. 3 Luminance uniformity of the large-area textile OLEDs

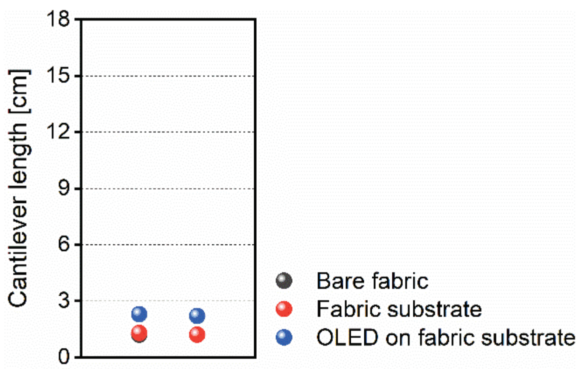

Fig. 4 Cantilever lengths of bare fabric, fabric substrate and the OLED on fabric substrate obtained from the cantilever tests.

It was revealed that TiO_2 deposited at near room-temperature via ALD shows exceptionally outstanding moisture impermeability [6] and a 1.5dyad multibarrier encapsulation was fabricated using a combination of an inorganic thin film nano-laminated with TiO_2 and Al_2O_3 and an I OPTO TB polymer film. Despite the near room-temperature process of 40℃, the encapsulation exhibited a WVTR of 3.95×10^{-5} g $m^{-2}day^{-1}$. The results of the Ca-test are shown in Fig. 5.

Because the inorganic layer has extremely high brittleness, encapsulation is the limiting factor to the flexibility of the entire structure of textile OLEDs. Therefore, improving the flexibility of the encapsulation layer is considered to be an important key technology in the field of flexible OLEDs.[6], [15]–[18], [5] To improve the flexibility of the encapsulation layer, a multilayer was formed with a 1.5 dyad stack using I OPTO TB polymer, which possesses high mechanical deformability, and this was applied to the textile OLED in this study.

To evaluate the foldability of the encapsulated textile OLEDs, their optoelectrical characteristics were measured before and after applying 1,000 / 3,000 / 5,000 / 10,000 times bending deformations to the encapsulated textile OLEDs, with a radius of curvature of 1.5 mm. The results are shown in Fig. 6.

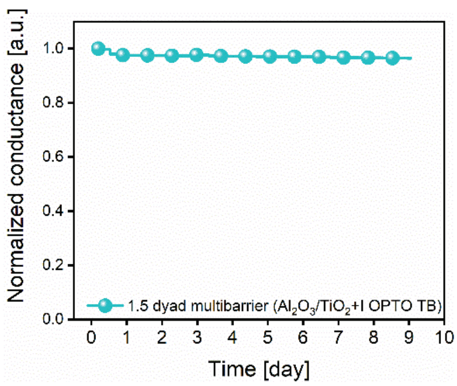

Fig. 5 Normalized conductance of Ca film protected by 1.5 dyad barrier

4 Conclusions

In summary, the technologies developed to fabricate a deformable textile display were demonstrated. Large-area RGB textile OLEDs were realized and various optoelectronic properties such as J-V-L and luminance uniformity were evaluated. In addition, the flexibility of the textile OLEDs was also confirmed by cantilever test and bending test, and the results verified the compatibility of the textile OLEDs as a wearable platform on the human body. Lastly, a near room-temperature encapsulation process was utilized to enhance the reliability of the textile OLEDs, protecting them from moisture molecules, without deteriorating the thermally sensitive textile substrate and organic materials.

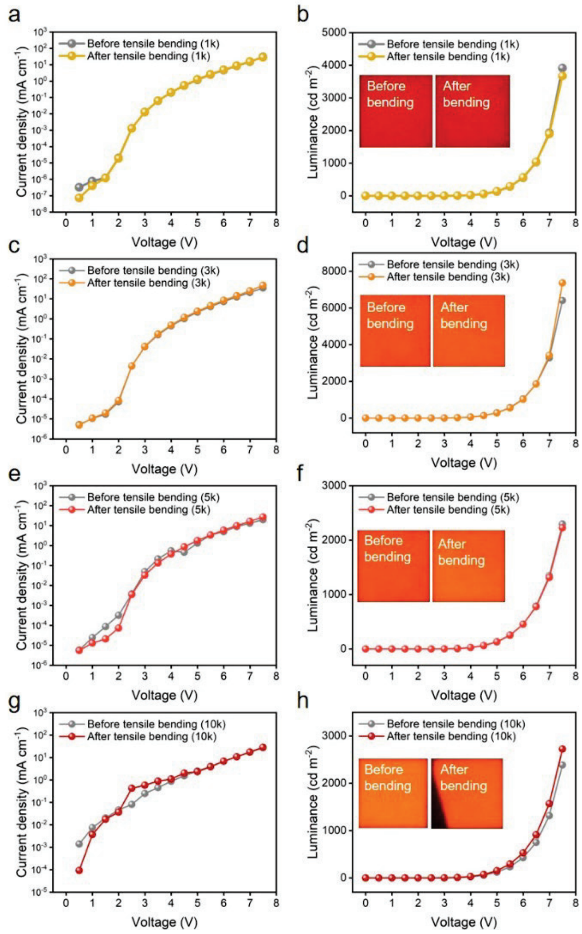

Fig. 6 Optoelectrical characteristics of the textile OLEDs after 1.5 mm bending a-b) 1,000 times, c-d) 3,000 times, e-f) 5,000 times and g-h) 10,000 times.

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