

Flexible Display Device with Organic Composite Film

Yang-Kyu Choi^{1*}, Oktay Yarimaga¹, Tae Won Kim², Yun Kyung Jung², Hyun Gyu Park²

¹Division of Electrical Eng. Dept., School of Electrical Engineering and Computer Science, Korea Advanced Inst. of Science and Technology (KAIST), Daejeon, Korea

^{1*}TEL: 82-42-869-3477, e-mail: ykchoi@ee.kaist.ac.kr.

²Chemical and Biomolecular Eng. Dept., Biochip & Biodevice Lab., KAIST

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Abstract

This study presents the fabrication process and display characteristics of a flexible organic polymer display device that consists of a thin substrate of Polyether Sulfone, a multilayer serpentine-type microheater array that is fabricated on the substrate, and a UV-sensitive polydiacetylene (PDA)-polyvinyl alcohol (PVA) composite film. A retention time of one second is achieved with cell sizes of 500 μ m and 700 μ m with cell-to-cell distances of 100 μ m and 200 μ m, respectively.

1. Introduction

The first decade of the 21st century has witnessed the emerging display concept known as the flexible display, such that thousands of research groups have concentrated on flexibility to bring a new product to the market using different display technologies. The substrates and materials as well as the fabrication methods of these technologies were modified to adapt to the flexible products [1, 2, and 3]. Chromic display devices have been one of the candidates of the flexible era due to their wide variety and their low-cost fabrication process. In particular, electrochromic materials have attracted much attention, and some of these materials have been reported to have good stability and contrast as display components. However, the difficulty of device integration and the slow response time are two main drawbacks of these materials, and investigation into these issues continues [4, 5]. In a previous work by the authors, a very different type of display type was introduced [6]. It was completely different from previous technologies in that thermochromism formed the basis of the pixel actuation mechanism.

Thermochromism is the ability of a material to change color by thermal stress. In order to include a thermochromic material in a display structure, this material should have some special characteristics. First, the critical temperature should be in a range that

the color change should not occur easily at room temperature, and this critical temperature should not be very high such that it damages the materials included in the device structure. Furthermore, the color change should be realizable and effective to form the images.

In the current study, these earlier investigations are extended to a flexible design that utilizes a flexible, thermally and chemically stable substrate known as Polyether Sulfone (PES). A UV-sensitive thermochromic polymer, Polydiacetylene (PDA), was employed as the active material in the device. PCDA-EDEA, an amine-terminated monomer of PDA liposome (Fig. 1), was mixed with polyvinyl alcohol (PVA) to form a solid film on the device. Polymerization of this composite by UV-light irradiation at 254nm caused a color change of the organic film from opaque to blue. Multilayer metals of a serpentine-type microheater array on a PES substrate functioned as actuators that increased the temperature of the intended pixels separately and changed the color of the activated pixels from blue to red.

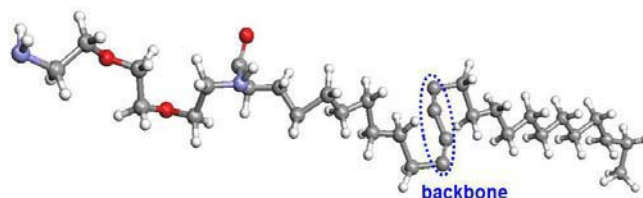


Fig. 1. PCDA-EDEA (ArgusLab)

The PDA-PVA composite provides sufficient contrast and retention time characteristics to be utilized in display applications. The three different colors of blue, red and yellow as well as the transition tones can be obtained by tuning the underlying microheaters.

2. Materials and Fabrication of the Device

The UV-sensitive diacetylene monomer PCDA-EDEA was obtained by reacting PCDA-NHS with an excess amount of EDEA in methylene chloride, as described in the literature [7]. The preparation of the composite polymer solution was done by mixing a diacetylene vesicle solution with an aqueous 10% PVA (Aldrich, $M_w=89,000-98,000$) solution at a volume ratio of 1:1 [8].

Fig. 2 shows the main components of the flexible display. The device is composed of a flexible polymer substrate, a serpentine-type microheater array, PDA-PVA film, and a polydimethylsiloxane (PDMS) coating on the top.

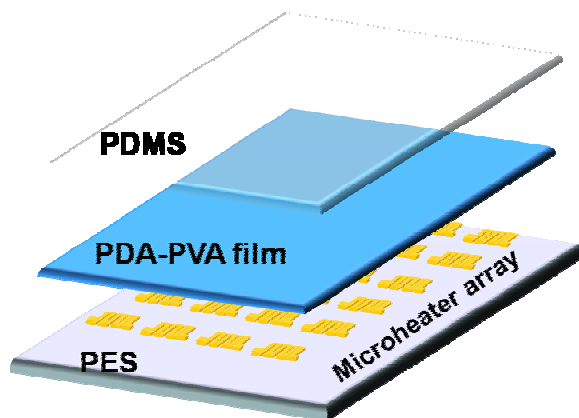


Fig. 2. Device structure of the flexible display

First, a 200 μm thick 4-inch PES film was bonded on a Si wafer before the fabrication process. Ti-Au-Ti-Au (10-50-10-200nm) multilayer microheaters were fabricated on the substrate by thermal evaporation and wet etching. The sizes of the microheaters were designed to be 700x700 μm^2 and 500x500 μm^2 with a microheater-to-microheater distance of 100 μm and 200 μm , respectively. The top Au-Ti (200-10nm) layers of the microheater regions were wet-etched in order to localize the generated heat on the specified area rather than on the connection wires. PDA-PVA film was reported to have poor adhesion on a glass substrate [6]. Although the substrate in the current case was PES, an oxygen plasma treatment was necessary to guarantee the long-term stability of the composite polymer layer on the substrate. The plasma treatment was applied for 30 seconds with a plasma power of 100 Watts and a gas flow rate of 50sccm. The diacetylene vesicle-PVA solution was dispensed onto a 1cm x 2.4cm chip, and it was kept at room

temperature for 18 hours for curing. A 40- μm thin solid film formed on the substrate after the curing process. Fig. 3 demonstrates the PES substrate with microheaters before and after the organic film coating. In order to avoid contamination, the chip surface was covered with a PDMS layer (Dow Corning Sylgard 184 10:1).

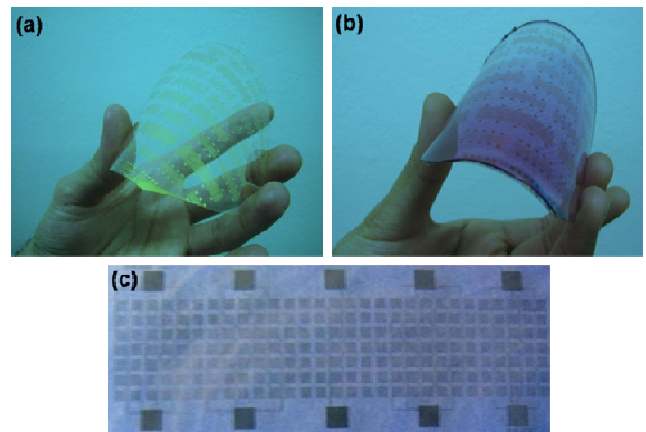


Fig. 3. (a) Microheater array on a PES substrate before PDA-PVA film coating, (b) after film coating and irradiation with UV-light of 254nm, (c) close-up view of the display region

3. Results and Discussion

A self-patterning technique with an embedded photomask was previously suggested [9]. This time, instead of generating pixel patterns on the PDA-PVA layer, the film was polymerized by UV-light irradiation of 254nm from the front side without the use of a mask (710 $\mu\text{W}/\text{cm}^2$, VL-6C Vilber Lourmat UV Darkroom). The use of front side polymerization becomes clear when Fig. 4 is considered. In the figure, the transmittance spectra of different materials are given. Back-side UV-light irradiation through an embedded mask for pattern generation can be achieved with a Pyrex substrate due to the suitable transmittance of Pyrex glass at 254nm (12.1%). However, the same method cannot work with a PES substrate, which has transmittance of 0% at the wavelength of interest. Therefore, polymerization was performed from the front side without an external mask. After five minutes of polymerization, the entire surface of the opaque organic layer changed to a blue color (Fig. 3).

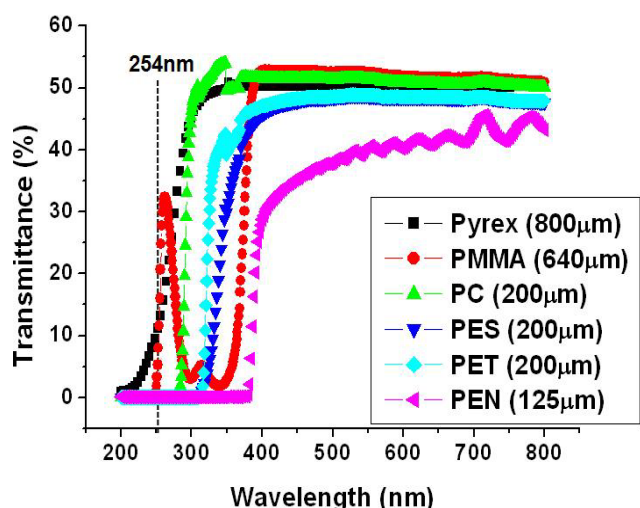


Fig. 4. UV-vis transmittance spectra for different polymers

Fig. 5 shows the temperature vs. absorption wavelength of the PDA-PVA film. The colored squares in the graph represent actual CCD camera images of the film at the corresponding temperatures. A composite polymer film before the polymerization of diacetylene vesicle is colorless though it becomes blue with an absorption peak of 640nm when the polymerization is triggered by UV light irradiation. A thermo-chromatic property of the PDA-PVA composite was observed while the film was heated from approximately 55°C to 190°C. Primarily three phases of film color existed within this temperature range. A blue-to-red transition started at 55°C and ended when the film was fully red at 75°C. There was no significant color shift from 75°C to 140°C. The third color, yellow, appeared at elevated temperatures up to 180°C. A further increase in the temperature resulted in the degradation of the polymer as well as damage to the composite film.

Blue-to-red thermo-chromatic transitions of PDA are known to be due to the rotation of the C-C bond of the polymer backbone. The degree of rotation disturbs the planarity of the structure and causes a color shift from blue to red [10, 11]. Although not verified precisely, it is surmised that the red-to-yellow shift also occurs for the same reason: a further rotation of the C-C bond at the high-temperature region.

Thermal activation of the pixels was achieved with a power supply of 4V. Fig. 6 shows CCD camera images of the letters K and S, at a size of 700x700µm² letters during a turn-on state (half of the response

time) which requires approximately 500ms.

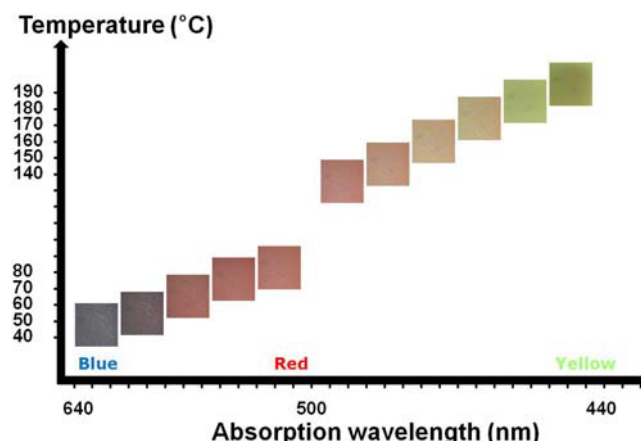


Fig. 5. PDA-PVA film absorption wavelength vs. temperature

The turn-on time of a similar structure with a Pyrex substrate was reported to be approximately 250ms. These results suggest that the response time strongly depends on the substrate material. The thermal conductivity of the PES substrate is in the region of 0.15Wm⁻¹K⁻¹. This represents nearly one-eighth of the thermal conductivity of Pyrex (1.1 Wm⁻¹K⁻¹).

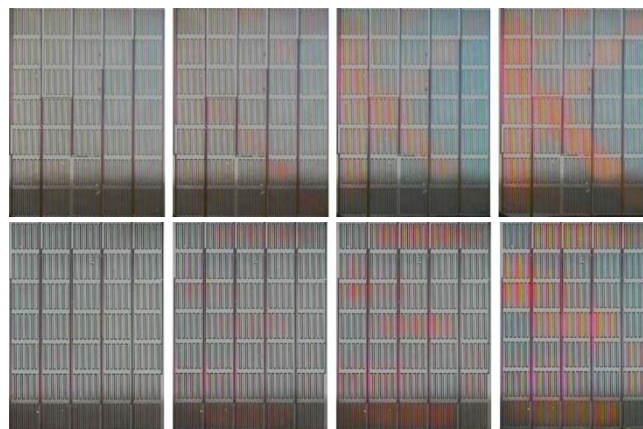


Fig. 6. Activation of the letters K and S with a pixel size of 700x700µm²

Fig. 7 compares the cross-talk effect of the cells with respect to the cell-to-cell distance. The temperature of the active cells is approximately 75°C. It is clear from the figure that separation of 200µm between the cells provides sufficient thermal isolation at that temperature (Fig. 7b).

When this distance is reduced to 100µm, the

inactive regions are affected by thermal conduction until the full activation is achieved (Fig. 7a).

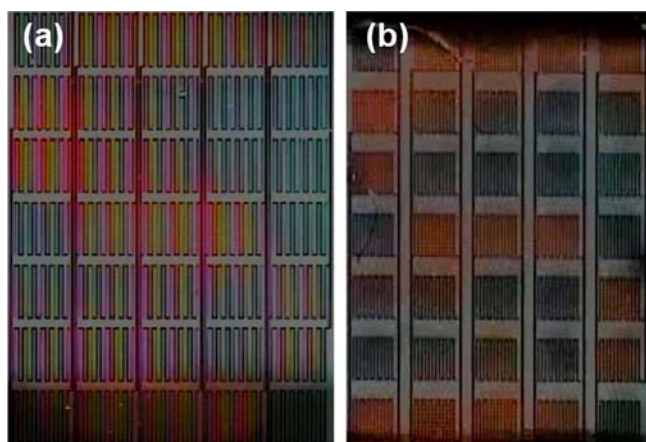


Fig. 7. Comparison of the cross-talk effect with respect to cell to cell distance: (a) 700µm pixel size with cell separation of 100µm, (b) 500µm pixel size with cell separation of 200µm

4. Conclusions

A PDA-PVA composite polymer was shown to provide sufficient contrast and retention time characteristics for use in flexible displays. PES is one of the best choices for this fabrication process because it has very good chemical, mechanical, and thermal stability. A retention time of 1 second, which was measured for the PES substrate, is superior to the retention time of reported electrochromic displays. Other problems such as the cross-talk effect and a low resolution can be overcome through a careful design of the pixel size and the cell-to-cell distance. The thermochromic displays appear to be feasible for next-generation flexible applications. In a future work by the authors, the system will be improved further by reducing the pixel pitch and using new flexible substrates.

Acknowledgements

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