# A low $T_g$ substrate for film-like liquid crystal display

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## Abstract

*A UV-cured adhesive with a low $T_g$ below the room temperature was used as a substrate for manufacturing a film-like liquid crystal display. This film-like LCD shows a fully flexibility due to the low $T_g$ property, and the manufacture processes are roll-to-roll compatible due to the coating processes.*

## 1. Introduction

Flexible displays have attracted much interest and found many applications in recent years. Generally speaking, flexibility could be classified into four grades, elastic, curved, bending and folding [1]. Replacing a heavy fragile glass-substrate with a light rugged plastic-substrate is a conventional way to fabricate a flexible display. In order to adopt the current glass-line technology with high temperature process, such as alignment layer baking and TFT manufacture, several types of high $T_g$ (glass transition temperature) plastic substrates have been developed [2,3]. A plastic substrate operated in the glass state must be made as thin as possible in order to serve as a flexible substrate. However, even the thickness of a plastic substrate is as thin as ~ 100 μm or less, it is still not enough to fulfill the requirement of folding.

In this work, we have developed a film-like liquid crystal display (FLLCD), where the film-like substrate is operated in the rubber state. The property of rubber state makes the display not only flexible but also foldable. The substrate was made of UV-curable adhesive with a $T_g$ below room temperature. This flexible film-like substrate was fabricated by coating a layer of adhesive directly on a temporary supporting glass plate, which can avoid the bubble problem during attachment between plastic and glass substrates. Thermal properties of this film-like substrate were measured in this work due to their importance for manufacture process. By using this film-like substrate and a polymer-added liquid crystal (PALC), an ultra flexible film-like LCD (FLLCD) has been fabricated. This technology is roll-to-roll compatible due to the coating process [4,5].

## 2. Manufacture process of FLLCD

The detailed sequences of fabricating a FLLCD display have been published [4,5]. The processes were modified a little in our recent works. A mixture of UV-curable adhesive (NOA 65, Norland Products Inc.) and additive was coated and cured on the glass plate to serve as a flexible substrate. The additive rather than the release layer used in our early work was applied in this work for removing the film from the glass substrate more easily. In order to have a better cell-gap control in the lamination process, the photospacers were also adopted in our recent works. Two forms of PALC, polymer-encapsulated liquid crystal (PELC) and photo-induced phase separation liquid crystal (PIPSLC), have been applied on the film-like substrate to fabricate a FLLCD as shown in Fig. 1 and Fig. 2, respectively.

**Figure 1** A 4.1 inch film-like PELCD. (a) photograph (b) off state and (c) on state.


(a) (b) (c)

**Figure 2** A 4.1 inch film-like LCD operated in the TN mode. (a) photograph (b) on state and (c) off state.

## 3. Thermal properties of film-like substrate

The coefficient of thermal expansion (CTE), $T_g$ and decomposition temperature ($T_d$) of the UV-cured film-like substrate were measured by thermomechanical analyzer (TMA), differential scanning calorimeter (DSC) and thermal gravity analyzer (TGA), respectively. The measured results are shown in Fig. 3. Properties of NOA65 film and other conventional plastic substrates are summarized in Table 1. Although the coefficient of linear thermal expansion of our film-like substrate is as high as $2.0\times10^{-4}$ /°C, 4 times higher than a polyethersulfone (PES) substrate, it is applicable for displays operated in the passive driving mode. The film-like substrate has a very low $T_g$ of ~ – 9.5 ℃ and a sufficiently high decomposition temperature $T_d$ of ~300 ℃. The property of low $T_g$ makes the FLLCD not only flexible but also foldable compared with a PES substrate ($T_g$: ~210 ℃). The $T_d$ of ~300 ℃ is high enough in the manufacturing processes, such as PI baking.

## 4. Electro-optical properties of film-like display

A typical curve of contrast ratio (CR) versus driving voltage for a TN mode FLLCD is shown in Fig. 4. A CR as high as ~ ~100 is reached by a 40 V driving voltage. Electro-optical properties were also measured for TN-FLLCD bent to different radius of curvature as shown in Fig. 5. No significant change is observed.

| Film | Light transmittance (0.1 mm thickness) | Tg °C | CTE ($10^{-6}$°C$^{-1}$) |
|---|---|---|---|
| NOA 65 | 90 | -9.5 | 200 |
| PES | 89 | 223 | 55 |
| FST-XA067 | 89 | 250 | 14 |
| PC | 90 | 145 | 70 |
| COP | 90 | 165 | 60 |

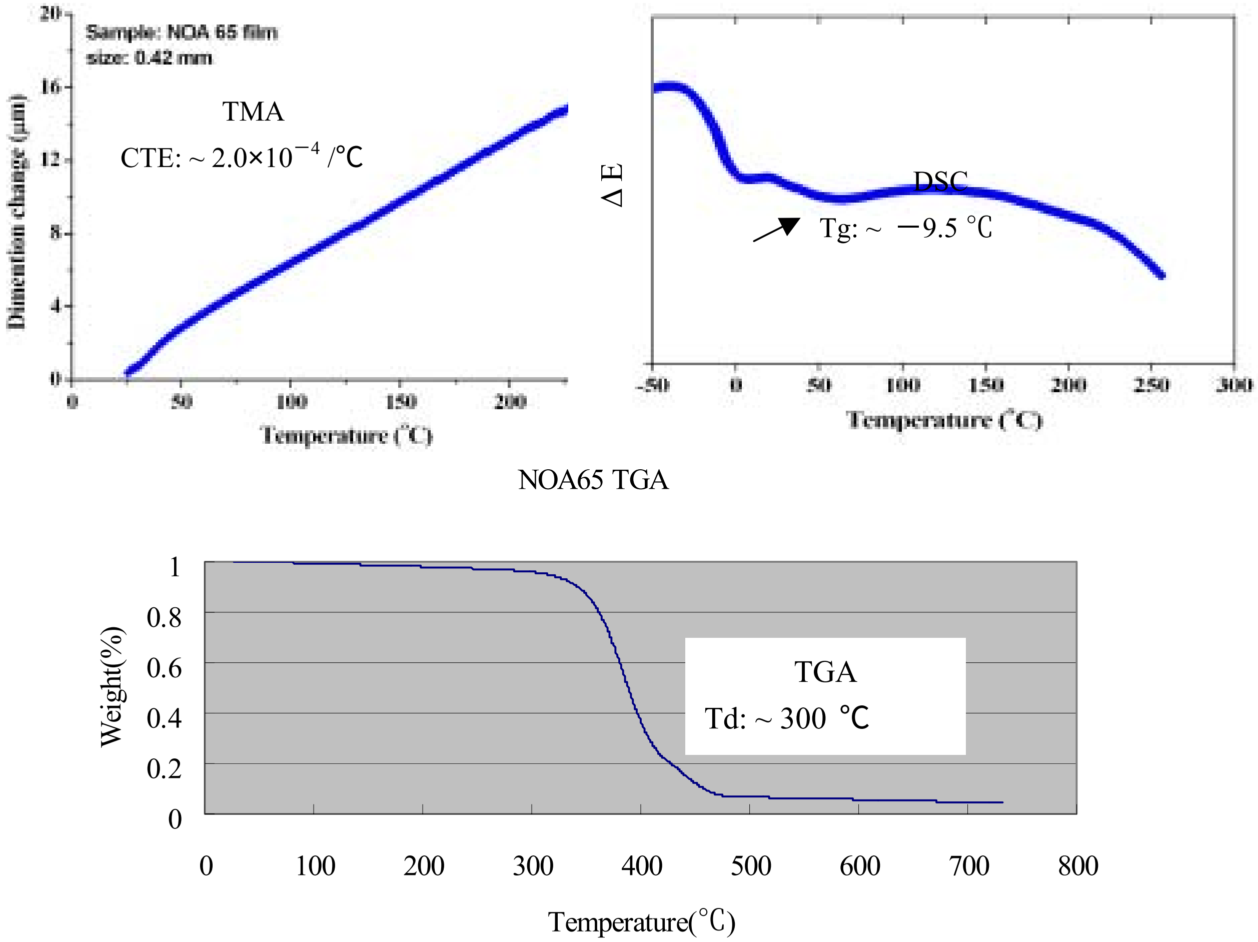


**Figure 3** Thermal properties of UV-cured adhesive film.

**Table 1** Properties of UV-cured adhesive film and conventional plastic films [3].

## 5. Conclusion

The combination of coating substrate and coating PALC developed in this work could reach the goal of mass-production with low cost due to the roll-to-roll compatible coating technique. The unique feature of low $T_g$ film-like substrate also open a window for realizing a foldable display.

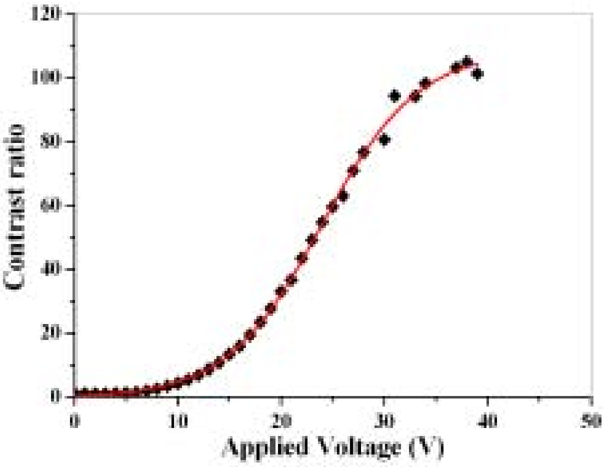


**Figure 4** Contrast as function of voltage for a TN mode PIPS-FLLCD.

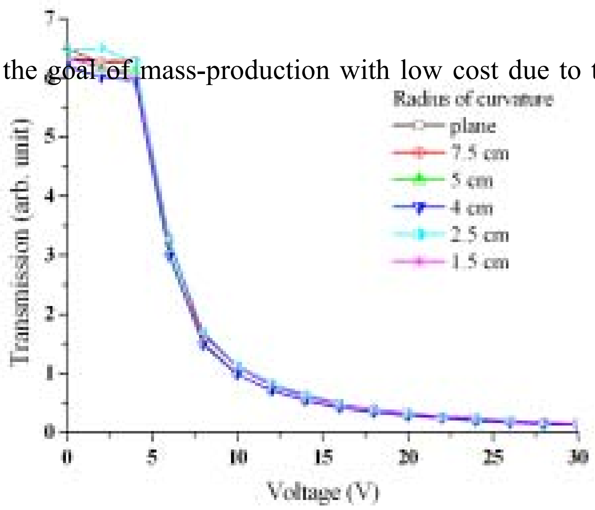


**Figure 5** Transmission-Voltage curve of a TN mode FLLCD bent in different radius of curvature.

## 6. References


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