# 16-2: Development of *Binem®* Displays on Flexible Plastic Substrates

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## Abstract
*We have successfully fabricated Binem® displays on thin flexible plastic substrates. The fabrication is based on the standard Binem® process for glass which has been adapted to plastic with new materials and technologies. The first application is targeted to an embedded display for smart card products.*

## 1. Introduction and *Binem®* Principle
There is a high demand from smart card manufacturers for multi-components card having displays. Bistable displays which can store the image when the supplies are removed enable smart card products without a battery. The image is stored between uses and refreshed every time the card is inserted into a read/write station. Moreover, plastic displays offer other advantages such as low weight, robustness (not as brittle as glass) and the most important: flexibility and thinness.

*Binem®* displays on plastic substrates meet these requirements. *Binem®* is a *B*istable *Nem*atic LCD technology based on the switching between two stable textures. The uniform texture (no twist) and the 180°-twisted texture can be obtained by applying dedicated electronic waveforms to the display [1]. The texture obtained depends on the pulse falling edge: if it is smooth, the elastic relaxation is dominant and the uniform texture is obtained. If the pulse falling edge is sharp, the LC backflow becomes the dominating factor resulting in the twisted texture. Both states are stable over a very long period of time; switching is obtained by zenithal anchoring breaking on the weak anchoring layer and by applying a vertical electrical field (Figure 1) [2]. *Binem®* displays can be used in both transmissive and reflective modes. The T state shows a very flat optical response over the visible spectrum so this state is used as the white state in reflective mode. It is the opposite case in transmissive mode.

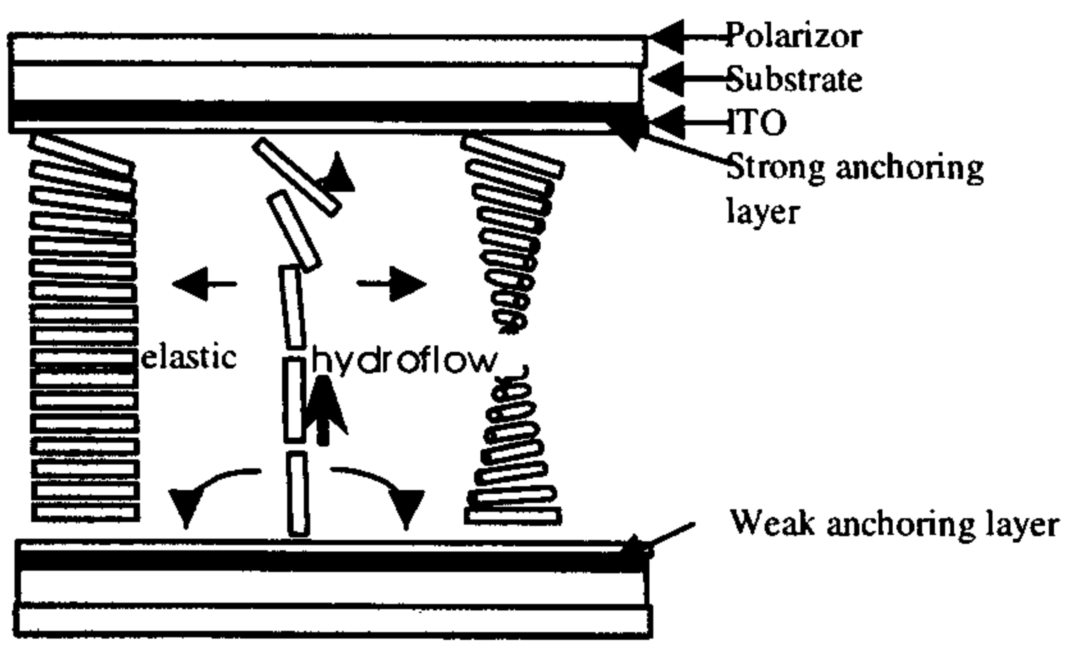


**Figure 1:** *Binem®* Principle

In this paper, we describe the implementation of the *Binem®* technology on flexible plastic substrates.

We are developing two types of displays on flexible substrates for smart card applications in the framework of two European projects called Carbine and Format. The display developed in the Carbine project is alphanumerical, the Format one is a 16x80 dot matrix.

## 2. Development Required for Smart Card Applications
Displays to be embedded into smart cards must meet many requirements, the main ones being thickness and interconnect. Smart cards themselves must have a total maximum thickness of around 800µm in order to obtain a reliable product. The total display thickness should therefore not exceed 500µm. Another constrain is that the interconnection between the rows and columns must be made inside the display because there can be only one bond between the display and the smart card electronics.

### 2.1 Thickness Constraint
We had to find new materials and process to fabricate *Binem®* displays for smart card applications. The most critical specification is the total panel thickness (see figure 2). The typical thickness of a glass LCD is about 1.8mm (2x0.7mm substrates + 2x0.2mm polarizers). To be embedded into a smart card, the display must be thinner than 500µm for commercial products.

#### *2.1.1 Substrate and conductive layer*
We have focused on 100µm Poly Ether Sulfone (PES) substrates that are non-birefringent and commercially available with a gas barrier and hard coat. These layers protect the display from moisture and mechanical scratches.

**Table 1:** PES main properties

| Main PES properties | |
|---|---|
| Tg | 223°C |
| % transmission | 90% |
| Retardation | <10nm |
| CTE | 54ppm/°C |
| $H_2O$ absorption | 1.4% |

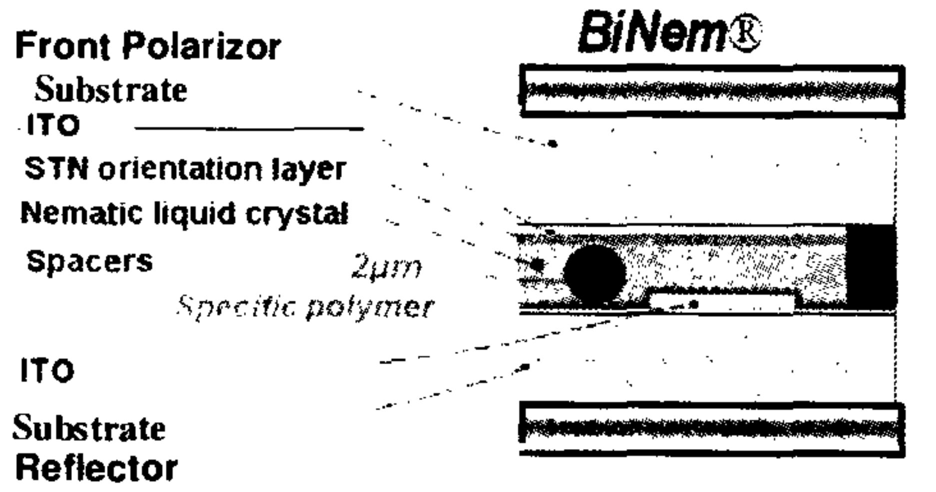


**Figure 2:** *Binem*® LCD structure in reflective mode (external reflector)

The thin PES substrates are coated with a thick Indium Tin Oxide (ITO) layer (100nm) that is then tempered to lower the resistivity. The result is a 100µm PES film coated with a 30 ohms/sq ITO layer.

### *2.1.2 Optical components*

Due to the thickness specifications, we use very thin optical components such as Thin Crystal Film™ (TCF™) polarizers from Optiva Corp.[3]. The polarizer and reflector films are respectively 80µm and 90µm thick. The total thickness of the plastic *Binem*® display is then 370µm. Moreover, as the thickness of the display is reduced, its flexibility is increased (thicker optical components make the display less flexible). The TCF components lead to slight reduction of optical contrast, but it is still in compliance with the end-user specification (Figure 3).

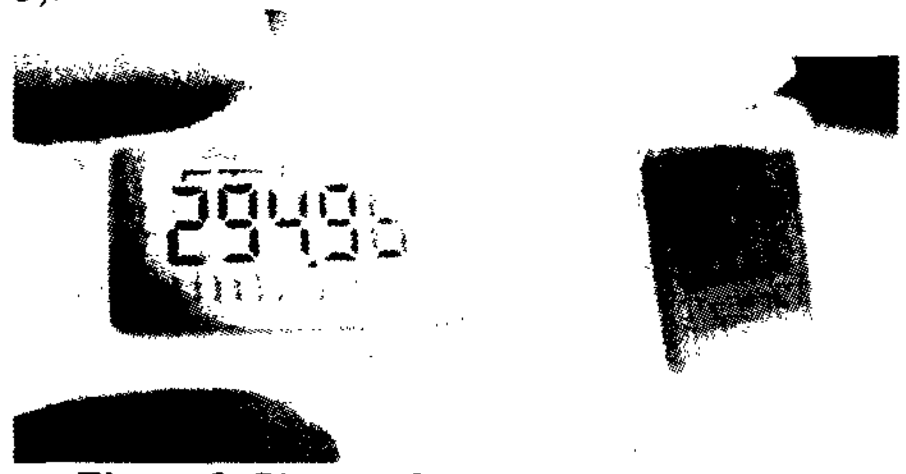

**Figure 3:** Picture of an alpha numerical *Binem*® display in reflective mode

The contrast ratio measured under diffuse illumination [4] on a *Binem*® plastic display is 3:1 in the centre (Figure 4) with a brightness of 25%.

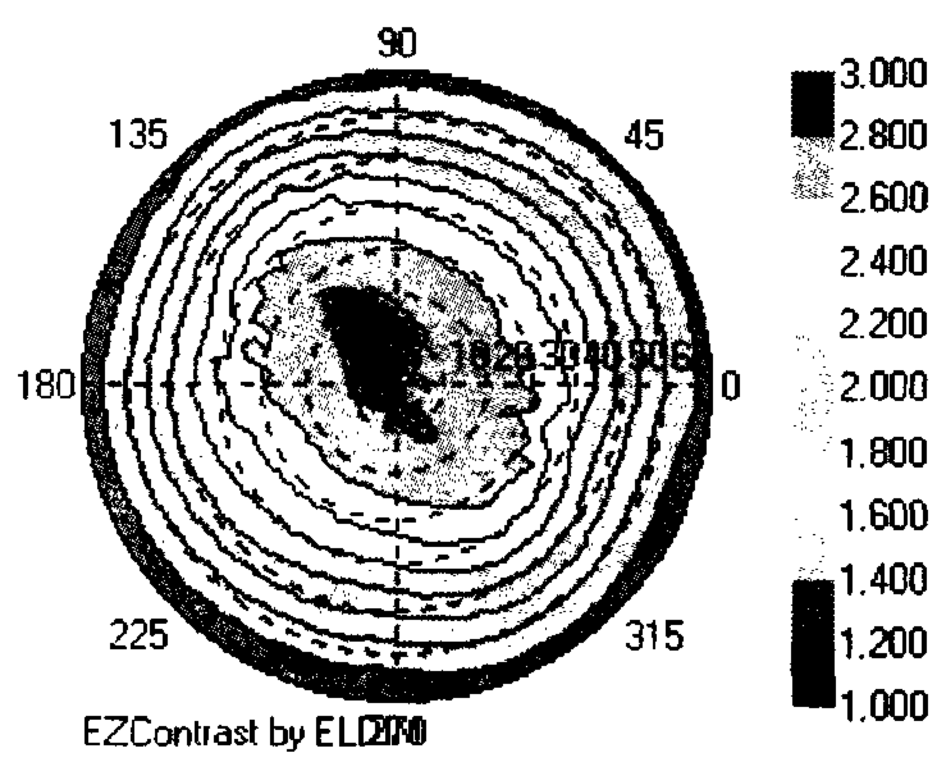


**Figure 4:** Iso contrast curves measured with an Eldim apparatus in diffuse light on a reflective *Binem*® PES LCD (TCF polarizors, no Anti-Reflection coating)

## 2.2 Via Technology for *Binem*® Plastic Displays

Due to the embedding of the displays inside smart cards, vias had to be introduced inside the display in order to interconnect rows and columns to the same substrate (Figure 5). An isotropic conducting adhesive is needed in order to make electrical contact through the thickness of the LC layer without causing short circuits in the plane of the layer. Since no materials with particles smaller than 5µm are commercially available we had to develop our own mixture of smaller conductive particles and adhesive. The most critical issue in the mixture formulation process is to obtain well dispersed particles without clustering and to ensure a uniform cell gap in the active area. We had to find the right balance between particle diameter, particle dispersion and concentration.

We obtain best results with conductive particles that are slightly larger than the ~2µm spacers. This does not cause an over-thickness in the active area of the display because of the flexibility of the plastic substrates (see Figure 5).

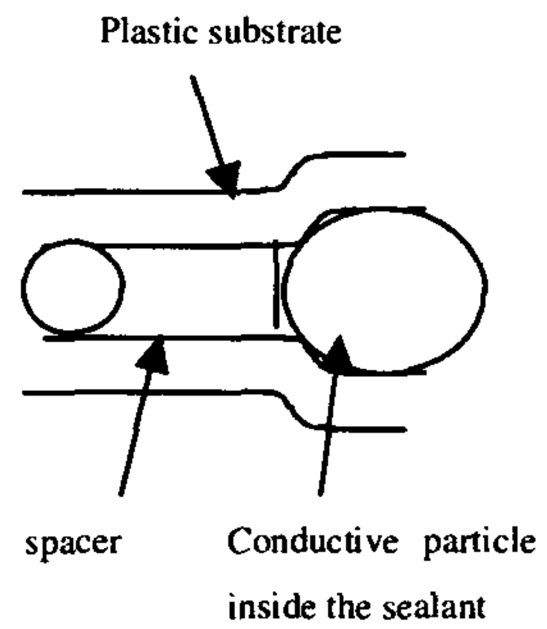


**Figure 5:** Scheme showing the distortion of the plastic substrate on the edge of the cell due to the use of conductive particles large than 2µm

The mixture of sealant and conductive particles is continuously dispensed around the periphery of one substrate to make the electrical contact as well as to seal the display. We were successful in developing a via process allowing no short circuits between adjacent rows. The cell is flexible as the selected adhesive has high elasticity properties.

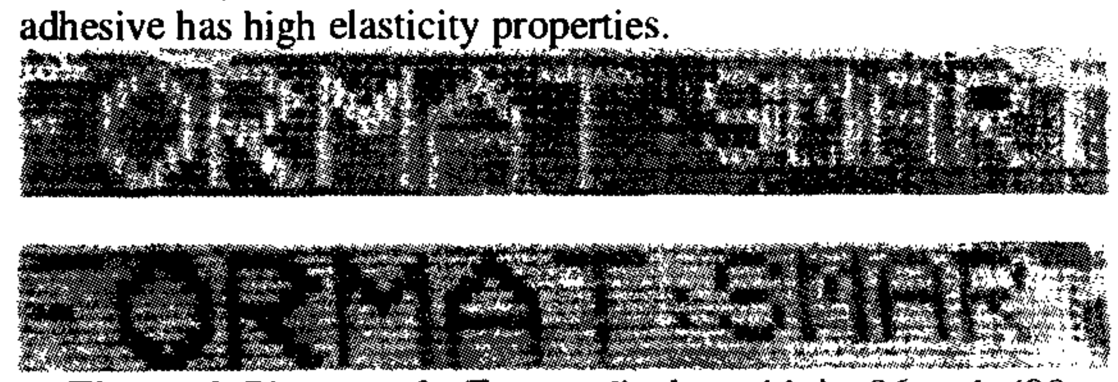

**Figure 6:** Pictures of a Format display with its 96 pads (80 columns and 16 rows) coming out on the same substrate

## 3. *Binem*® Plastic Displays Specific Developments

## 3.1 Covering the Non Addressed Areas of an Alpha Numerical Display

For *BiNem*® LCDs, both twisted and uniform states are stable. Since the areas outside the digits are not electrically addressed in alphanumeric displays, we cannot control the "texture" in these areas by applying an electric field. The areas can be either in the twisted or uniform state after applying a mechanical stress (see Figures 3) To improve the appearance of the Carbine LCDs, we therefore introduced a screen-printed mask between the top substrate and the front polarizer (Figure 7). Figure 8 show a "written" Carbine displays with a shadow mask.

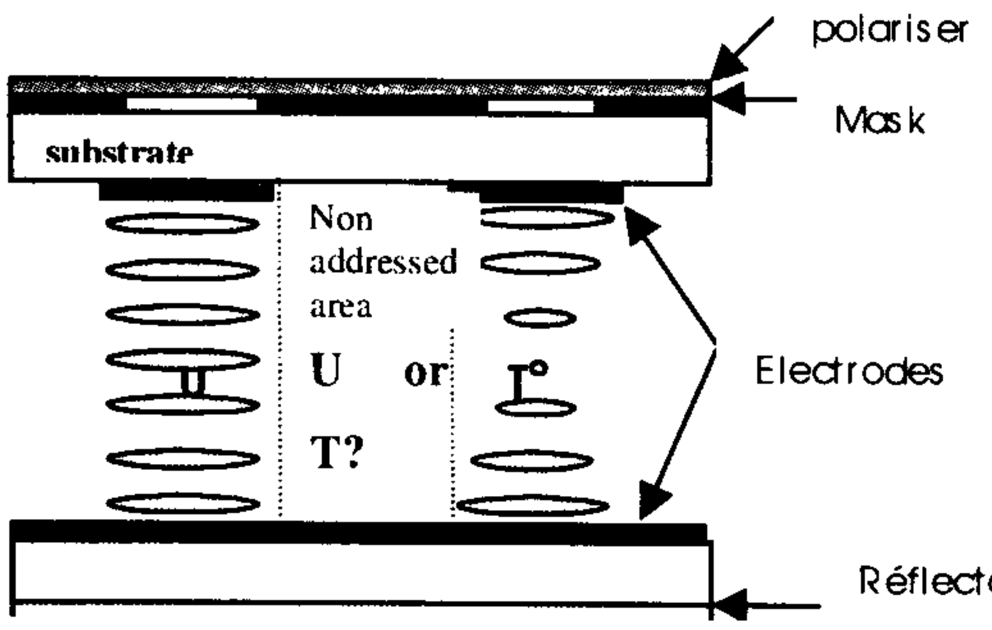


**Figure 7:** Structure of a display with a mask covering the electrically non-addressed area which can be either in U or T state

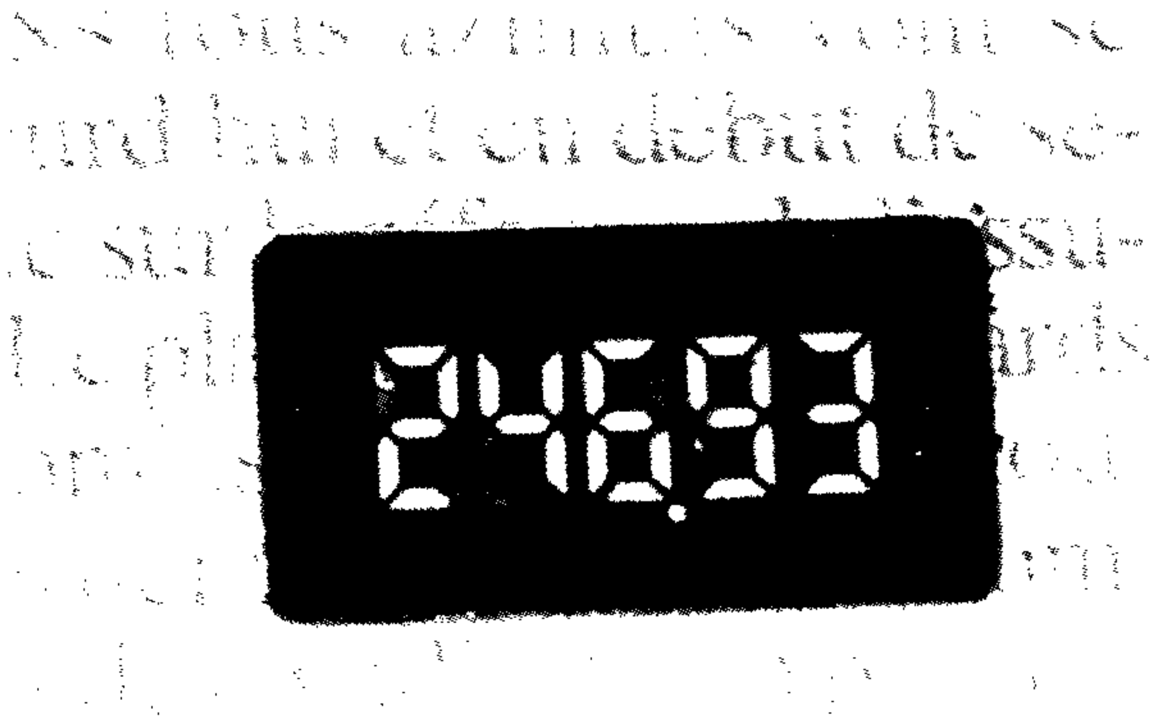

**Figure 8:** Picture of a "written" *BiNem*® Carbine display on a news paper. This display has a printed black mask covering the non addressed areas. No power is applied to the cell

This printed mask allows some flexibility on the design of the electrodes: they were enlarged in order to facilitate the alignment between the mask and the display design. This mask is screen-printed on the top of the up substrate after patterning the ITO. The alignment between both designs is made optically with an accuracy better than 50µm. The mask could be printed before ITO patterning or even printed on the polariser depending on the available alignment tools.

## 3.2 Design and Fabrication of a Dedicated Chip

In both Carbine and Format projects, the displays are addressed in multiplexing modes. Nemoptic and the Interuniversity MicroElectronics Center (IMEC) are collaborating within the framework of the Carbine project. IMEC is in charge of the driver/controller development. They have designed and developed a 292µm thick controller driver chip that is able to deliver the waveforms needed to drive a *BiNem*® display. IMEC has also developed a technology to transfer the chip onto the PES substrates.

# 4. Process Development for Plastic Displays

## 4.1 Structured Spacers Technology

In glass LCD manufacturing process, spacers consist of SiO2 or plastic beads with the specified diameter. For plastic LCDs, the right cell gap can be obtained with this kind of spacers, but using beads have some drawbacks. Indeed, we have observed experimentally that the spacers could move about inside the plastic cells either with the liquid crystal flow during filling or during external mechanical stress such as bending of the cell (Figure 9). In this later case, a reduced cell gap can be observed in areas where the spacer density is too low causing the U state to look grey instead of white in transmission and the T state to become unstable. Some other areas show clusters of beads.

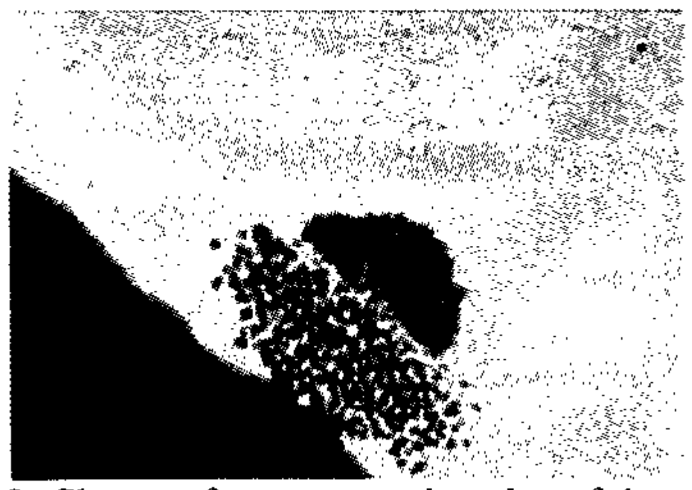

**Figure 9:** Cluster of spacers on the edge of the cell after mechanical stress (rubbing)

To improve the mechanical properties, we have integrated structured spacers (Figure 10) resulting from a photo-sensitive material process in the *Binem*® display. This work was done in collaboration with the Lehrstuhl für Bildschirmtechnik (LfB) of Stuttgart.

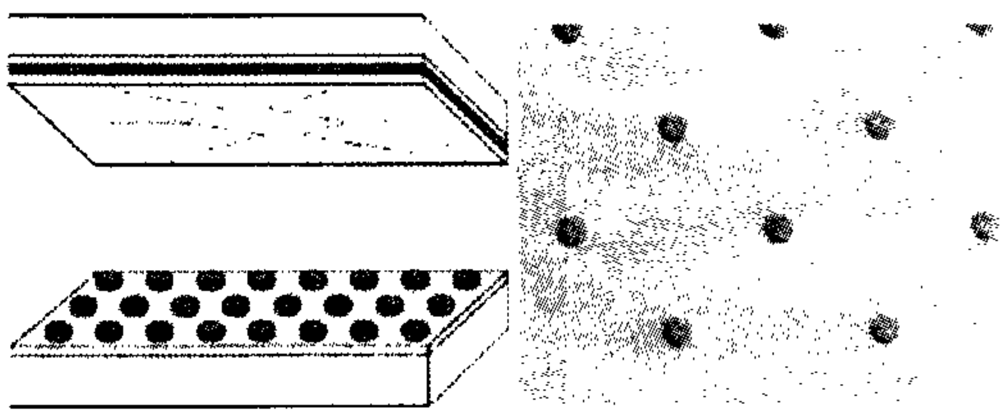

**Figure 10**: Principle scheme of the structured spacers in a display (left) and SEM picture of structured spacers on a glass substrate

These spacers offer better mechanical resistance against external pressure and shearing forces than conventional bead spacers. Indeed, they show a very strong adhesion to the substrate preventing any motion. Moreover, as they have a columnar shape, they have a large contact area with the surface (Figure 11) that guaranties a uniform cell gap.

**Figure 11:** 3D AFM picture of a spacer on PES substrate. The spacer has a 16µm diameter and a 2µm height

The introduction of such large diameter spacers into the cell creates limited perturbation of the liquid crystal texture around each spacer, but this phenomenon does not significantly degrade the contrast ratio. As a matter of fact, we have measured for a *Binem®* PES cell with TCF Optiva polarizor and structured spacers a contrast ratio of 2.6:1 instead of 3:1 measured with standard spacers. The eye can scarcely notice the difference.

## 4.2 Cutting of the PES Substrates

For glass LCDs, the cutting and breaking of the substrates is carried out at the finish of the front-end process. For PES displays, cutting steps have to be integrated within the front-end process flow.

The precision required for the cutting process is rather high. Moreover, this step is very sensitive as the ITO films are brittle. We have designed and developed a dedicated lab cutting tool for this process. It is composed of a punching machine, removable cutting dies and a camera with high magnification for alignment. The PES substrates are cut before assembly. After assembly, the tolerance on the alignment of the cells is within the end user's specifications of +/-200μm.

Based on our experience and our partner's experience, the optimum solution is to manufacture the display by batch using small mother substrates of 2 cells. The upper and lower substrates are cut during the front-end process, whereas the final cut process is carried out after filling.

Another advantage of using plastic substrates is that the displays could have almost any shape from a square (with a radius of the angle of 0.5mm) to a circle.

## 4.3 Process Constrains for Plastic Substrates

Compared with glass displays some process constraints must be taken into consideration for plastic displays. In this section, we give a few examples of these constraints such as temperature, sensitivity to solvents and fixturing of the substrates during several process steps.

PES cannot be heated above 170°C for long periods of time without distorting, so all processes have to be adjusted to avoid this condition. The strong anchoring polymer has been chosen in order to have a curing temperature below 170°C while maintaining the required anchoring properties and pretilt angle. The process of the weak anchoring polymer has also been adapted to plastic substrates.

Another difficulty is the fixturing of the plastic substrates during process steps such as coating, rubbing, etc.. Indeed, plastic substrates are easily distorted by conventional vacuum hold-down fixtures as evidenced by the visibility of phantom hole patterns in the finished display. To coat the alignment polymer we use a dedicated fixture consisting of a glass plate coated with a weak adhesive layer. The plastic substrate is laid on the fixture and coated just like a glass substrate and then it is peeled off for further processing. For rubbing, we have designed a dedicated vacuum holder where the suction is applied outside of the active area.

## 5. Conclusion

We have developed and fabricated *Binem®* LCDs on PES substrates. The displays show the performances of the *Binem®* technology (true bistability with low power consumption, high contrast ratio and wide viewing angle). Furthermore, the total display thickness is below 400μm leading to flexibility, light weight and high robustness. Plastic substrates have another advantage in that they can have almost any shape. These properties open doors to other applications such as electronic tag, ID cards, transportation cards or advanced reading devices.

## 6. Acknowledgements

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