10.4: Mechanically Stabilized Bistable FLC Cells on Plastic Substrates

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Abstract
The electro-optical properties of a fully flexible photo-aligned FLC cell are investigated. Two different methods, sticky spacers together with a photo-sensitive monomer and polymer spacers in a regular pattern formed by photo-lithography, are proposed to stabilize the structure in order to increase the bending tolerance of the FLC material during deformation of the cell.

1. Introduction
Today there is an increasing demand for flexible liquid crystal displays (LCD) in many applications such as mobile phones, smart cards and integrated displays [1]. Compared to traditional glass LCD's, flexible displays manufactured with plastic substrates have the advantage of being thin, lightweight and more mechanically robust. It also offers a clear advantage in design, since it allows integration into devices of non-rectangular and curved nature. If the aimed application is smart cards, the display should withstand frequent bending. For smartcards it is also desirable if the device is bistable since it will result in lower power consumption as well as high resolution displays on a passive matrix. Several bistable technologies have been demonstrated, but the ferroelectric liquid crystal (FLC) display is to this date the only truly bistable liquid crystal technology allowing switching at low voltages [2-4]. Of key importance to the use of any liquid crystal material in an electro-optical device is the issue of alignment. Since the majority of important applications are based on the interaction between polarized light and the optical anisotropy of the liquid crystal material, a well aligned initial state is desirable. While this is relatively easy for monostable devices based on the nematic phase, it is somewhat more difficult to construct devices containing smectic liquid crystals which are well aligned. FLC displays are extremely sensitive to dust particles that induce nucleation centers for disclinations. The competing issues of alignment of the molecular axis and alignment of the smectic layers further complicate the FLC alignment. If these issues are not resolved through the formation of a well defined structure it is common for defects to form, which can significantly influence the electro-optical properties of the device. Due to its non-contact nature, the photo-alignment technology eliminates generation of dust and electrostatic charges as well as mechanical damage to the surface. This advantage over conventional rubbing of polyimide layers makes the photo-alignment technology especially attractive for the alignment of smectic liquid crystals. From another point of view, photo-alignment is also interesting because of its low process temperature and it is therefore suitable in the manufacturing of flexible LCD's with plastic substrates.

It has been shown that azo dye films can be used as materials for photo-alignment of liquid crystals [3,4]. In this study the azo dye SD-1, which chemical structure is shown in Fig.1, will be used for the alignment of FLC on plastic substrates. It is proved to be photochemically stable and having a pure reorientation of the molecular oscillator perpendicular to the polarization plane of the activating UV light, without any cis-trans isomerization process [5]. This response to polarized UV light of the azo dye film can be described by the diffusion model [6].

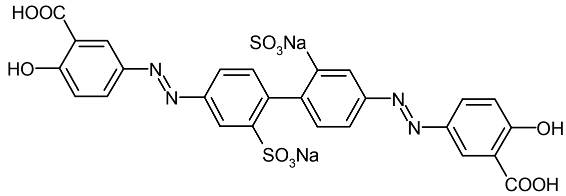

Figure 1: Chemical structure of SD-1.

Apart from the alignment problem, the FLC is also sensitive to mechanical deformation; therefore special stabilization of the LC cell is needed for the use of FLC together with flexible substrates. Polymer stabilization of FLC cells has previously been reported [7, 8]. The structure is stabilized by forming polymer net and/or polymer walls inside the LC cell by the exposure of UV-light to a photo-sensitive monomer dissolved in the liquid crystal material. However, these investigations do not involve the effect of polymer net on the bistable properties of the stabilized FLC cell.

In this study, we will for the first time use the azo dye SD-1 for the alignment of FLC on flexible substrates. Two different possibilities of stabilization of the FLC material will be presented, sticky spacers together with a photo-sensitive monomer and polymer spacers in a regular pattern formed by photo-lithography. The electro-optical properties of the stabilized cells will be investigated as a function of a bending deformation of the flexible FLC cell. We have previously studied the alignment properties of azo dye photo-alignment material on flexible substrates together with nematic LC [9]. Now we will demonstrate that the azo dye SD-1 is an excellent choice of alignment material for FLC on flexible substrates and show that the structure can be stabilized to increase the tolerance against mechanical deformation. Previously only glass substrates have been used for the application of photo-aligned FLC displays [10].

2. Photo-alignment of FLC
The schematic drawing of the cell structure is shown in Fig. 2. In order to avoid a competition in aligning action form solid surfaces of the FLC cells, asymmetry has been provided by only coating one substrate with SD-1 alignment material. The asymmetry of boundary conditions does not disturb the bistability, but minimizes the density of defects.

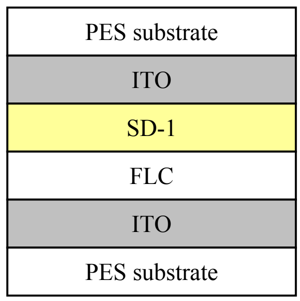

Figure 2: Schematic drawing of asymmetric FLC cell.

It has previously been shown that the alignment quality and hence the contrast ratio of the cell are dependant both on the SD-1 thickness and the exposure time [11]. In the case of a very thin layer, focal-conic domains will occur due to broken SD-1 layer. If the layer thickness on the other hand is too large, a stripe deformation along the normal to the smectic layers arises. These stripe domains are identified as ferroelectric domains in the FLC cell, which create a modulation of the apparent birefringence [12].

Since the optimal film thickness is relatively small, 3-5 nm, the choice of flexible substrate is also important since a rough substrate surface will not provide a continuous, unbroken alignment layer. Figure 3 shows an AFM image of the uncoated ITO covered 208 µm flexible PES substrate (Sumitomo). The surface roughness was measured to Rms = 0.28 nm and Ra = 0.22 nm, smooth enough to give the uniform and continuous alignment layer.

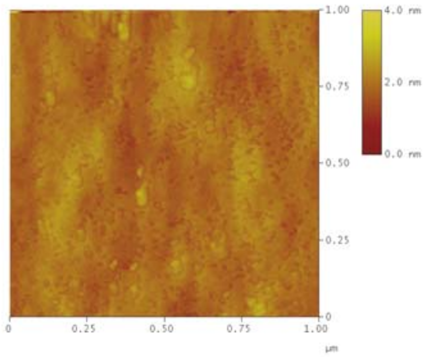

Figure 3: AFM picture of uncoated ITO covered PES substrate. The image size is 1×1 µm^2 and the height scale is 4 nm.

To achieve the optimal layer thickness of 3-5 nm, the SD-1 was dissolved in DMF to 0.4% and then spin-coated to the ultrasonically cleaned ITO covered PES substrates at 800 rpm for 5 seconds followed by 3000 rpm for 30 seconds. The film thickness was confirmed by AFM. After coating the substrate was dried on a hot-plate at 100°C for 10 minutes to evaporate the solvent before the SD-1 layer was exposed to a 2.6 mW/cm^2 linearly polarized light source at 365 nm for a total exposure dose of 9.4 J/cm^2. The other, non-coated substrate was just washed before the two substrates were assembled to form a liquid crystal cell with the cellgap 5 µm. The cellgap is controlled and maintained by sticky spacers (Sekisui). The FLC mixture FLC-497A (from P. N. Lebedev Physical Institute of Russian Academy of Sciences) was injected into the cell in its isotropic phase by capillary action. The cells were then slowly cooled to room temperature and the FLC was arranged in the "bookshelf" structure. The FLC-497A has a spontaneous polarization of 98 nC/cm^2 at T = 23°C and the following phase transitions:

$$Cr \rightarrow^{4°C} \rightarrow SmC^* \rightarrow^{57°C} \rightarrow SmA^* \rightarrow^{76°C} \rightarrow Iso$$

The helical pitch tends to infinity as compensated in the bulk due to the presence of two chiral dopants with the same signs of the spontaneous polarization but opposite handedness [12].

Excellent alignment quality was achieved and no difference from reference glass cells could be observed, see Figs. 4a and b, respectively. The active area of the cells were 12×6 mm^2. The cells showed truly bistable switching as illustrated in Fig.5.

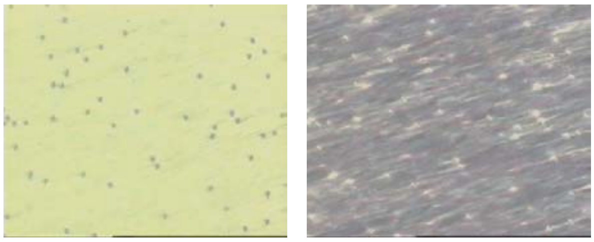

Figure 4a: Polarizing microscope images of flexible PES substrate cell. The image size is 117×142 µm^2.

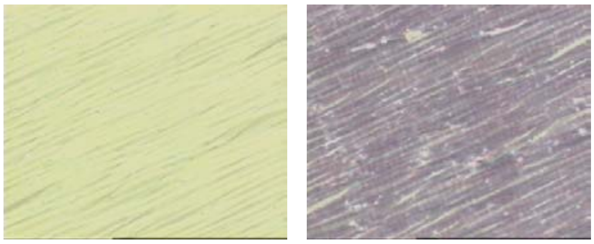

Figure 4b: Polarizing microscope images of bright and dark states of glass reference cell. The image size is 117×142 µm^2.

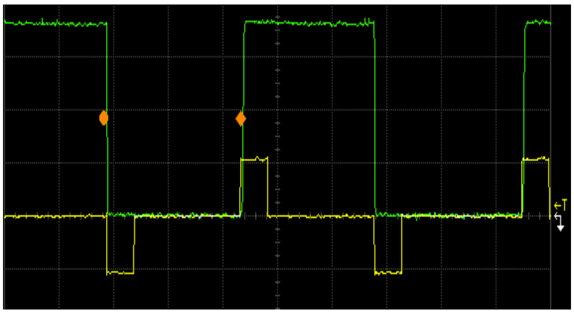

Figure 5: Bistable switching of FLC cell on flexible PES substrates.

The contrast ratio of the glass and plastic FLC cells was determined by measuring the transmittance of the two stable states when the cell was placed between crossed prism polarizers and the optical axis of one of the states was parallel to the transmission axis of one of the polarizers. The light source was a HeNe laser with λ = 632.8 nm. The light transmission in the dark state highly depends on the alignment quality since any defects will induce scattering of light, leading to reduced contrast ratio. Due to the excellent alignment shown both on glass and plastic substrates, very small amount of light leakage could be detected in the dark state, yielding a contrast ratio of the two stable states of 450:1 for both types of substrates. The switching times were measured to less than 300µs in both directions for 5 V switching pulses.

3. Mechanical stabilization

The plastic cell structure is however very sensitive to mechanical deformation. When the device is bent, forces are applied to the substrates resulting in a change of the cellgap. To increase the stability against mechanical deformation, two different methods of stabilization are proposed. In the first method sticky spacers (Sekisui) are used together with the photo-sensitive monomer ULC-011 (DaiNippon Inc). Polymer net has been reported to form by this monomer under exposure of UV-light [7]. As a result, a polymer net inside the cell will prevent flow of the FLC material during mechanical deformation. The polymer net will, together with the sticky spacers helping to maintain a uniform cellgap, increase the bending tolerance. The monomer was dissolved in the FLC-497A to various concentrations before filling and the filled cells were then exposed to polarized UV-light. It was found that the monomer concentration highly affects the bistability and for concentration larger than 10% no bistable switching could be observed. In the other stabilization method a regular structure of polymer spacers are formed by photo-lithography. The spacer width is 65 µm and the distance between them 275 µm. No polymer net is present in this structure.

The contrast ratio and switching times of the two types of stabilized cells were investigated. Light transmission of the two stable states was measured as described above and the corresponding contrast ratio is plotted in Fig.6. For both types of stabilized cells the contrast ratios were only slightly lower (340:1) compared to the non-stabilized cells. This decrease is mainly a result of scattering of light in the dark state induced by the stabilization structure of the cell. For bistable switching the relation between the pulse duration and the amplitude is presented in Fig.7. It can be seen that the electro-optical properties are not significantly affected by the stabilization methods.

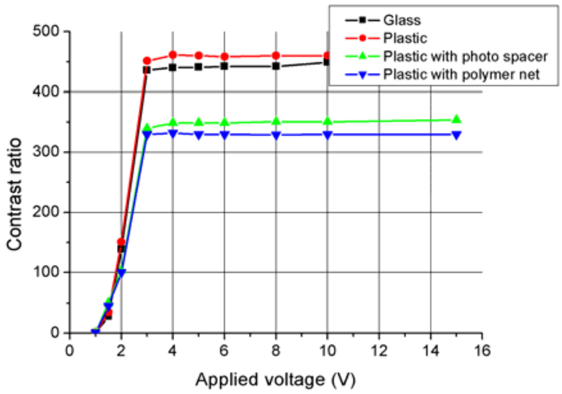

Figure 6: Contrast ratio as a function of applied voltage for the different cell configurations.

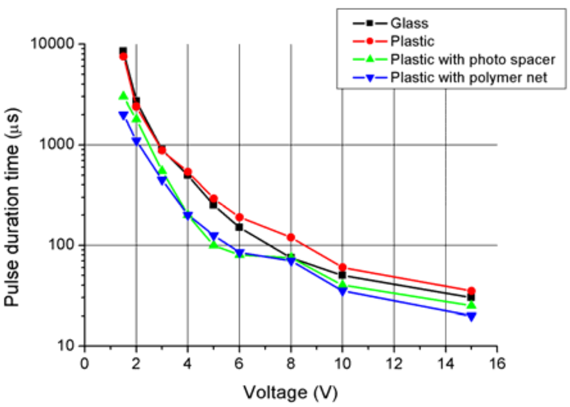

Figure 7: Relation between pulse duration and amplitude required to achieve bistable switching.

4. Mechanical deformation

Since one possible application for the FLC cells is as the display in smart cards, the cells were exposed to mechanical testing based on the ISO/IEC 10373-1:1998(E) standard, a test method for identification cards. Based on the fact that the deformation radius is smallest in the centre of the smart card, the test cells were mounted off-center on the cards in order to minimize the deformation. The requirement in this test for bending of the long side of the card is 20 mm. The stabilization quality and bending tolerance were investigated in terms of contrast ratio versus deformation of the smart card. An optical characterization of the cell in polarizing microscope in a bistable mode was also performed. Without any mechanical stabilization, the layered FLC structure was destroyed already at a deformation of 5 mm. However, it can be deduced that both proposed stabilization methods increase the tolerance to mechanical deformation as shown in Fig.8 in which the relative contrast ratio is plotted as a function of the bending deformation. The 20 mm deformation requirement for smart cards was passed by both types of cells. If the deformation was too severe, the FLC layer was partially destroyed and disorder in the FLC alignment could be observed, see Fig.9. The bright spots are disclinations resulting in degradation of the contrast ratio and also affecting the bistability operation.

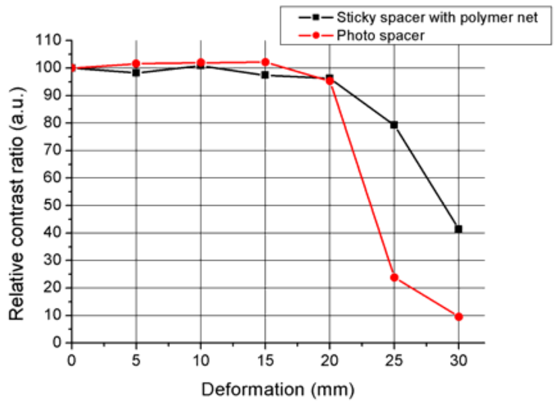

Figure 8: Contrast ratio as a function of bending deformation along the long axis of a smart card with mounted FLC cell.

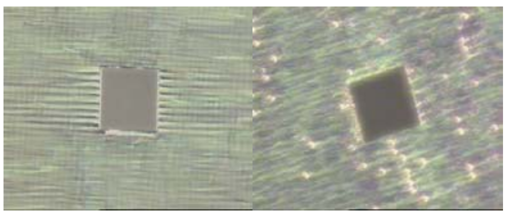

Figure 9: FLC structure before (left) and after (right) severe mechanical deformation of the cell with photo spacers.

The bending iteration tolerance was studied by repeatedly making the 20 mm deformation up to 1000 times. The cells showed no noticeable change in contrast ratio or bistable operation after the deformation cycle, see Fig.10. Hence, the FLC layer structure remains constant and the alignment is not affected by the deformation.

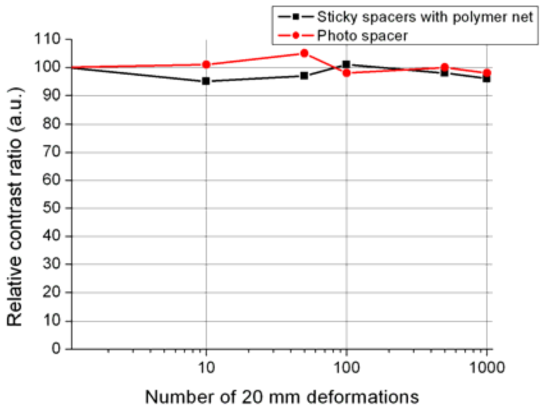

Figure 10: Contrast ratio as a function of number of 20 mm deformations along the long axis of a smart card with mounted FLC cell.

5. Conclusions

In this study we have investigated the possibility of using photo-aligned bistable FLC displays on plastic substrates and presented two different methods of mechanical stabilization of the FLC structure. The contrast ratio of the manufactured cells is extremely high due to the excellent alignment quality of the FLC material. The bending tolerance has been investigated by measuring the contrast ratio as a function of the deformation of a smart card with mounted FLC cell. It can be concluded that both proposed methods indeed improve the FLC cell bending tolerance and stability against mechanical deformation. This work will be valuable when considering this type of device for real applications, where smart card display is the most important.

6. Acknowledgements

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7. References

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