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Electro-optic characteristics of surface-stabilized ferroelectric liquid crystal devices with the stripe-shaped domain structure

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The stripe-shaped domain (SSD) structure has been obtained in the initial ferroelectric liquid crystal (FLC) alignment after the doping of a naphthalocyanine compound into rubbed polyimide films. Pre-tilt angles on the aligning films have been measured. The memory capability of aligned SSFLC cells has been enhanced nearly to completion, and contrast ratios reached 86:1 with the appearance of the SSD structure. Thus fabricated, 64×64 electrically controlled FLC spatial light modulator has better electro-optic characteristics and stability than a non-doped device.

The surface-stabilized ferroelectric liquid crystal (SSFLC) structure has been widely investigated because it shows a quicker response time, and higher contrast ratio and memory capability than nematic liquid crystals (NLCs) [1]. A homogeneous FLC alignment is usually required for a high optical contrast and good bistability. In the case of a sandwiched SSFLC cell, FLCs are sensitive to the aligning surface, and the aligning layers play a major role in realizing the ideal smectic configuration [2–4], which must be pre-treated before assembling; it is much more difficult to obtain a desired FLC alignment. That is one of the difficulties that impedes commercialization of SSFLC devices.

There are two more serious obstacles that hinder the commercialization of SSLFC devices. One is the appearance of zig-zag defects [5, 6], which can impair the electro-optic (EO) quality of the devices. The other is the degeneracy of the SmC* alignment as a result of ion migration [7–9], which exists during and after the electrically controlled switching process. It is detrimental to memory capability and can cause an instability of the SmC* layer configuration if the aligning layers are insulating or too thick.

Various methods have been used for the elimination of zig-zag defects in SSFLC devices. In near-surface alignment, special polyimide (PI) films [10] and glancing-angle evaporated SiO films [11], which provide a high pre-tilt angle to FLC molecules, can ensure a unidirectionally bent SmC* layer and avoid the cusping of neighbouring layers with contrary senses which leads to zig-zag defect line. The use of a.c. stabilization has also proved effective in removing zig-zag defects under the application of a strong electric field [12, 13]. An alternative way to overcome this problem is the use of different FLC materials. FLC mixtures containing materials derived from naphthalene rings can produce bookshelf-type structure when cooled from SmA phase to SmC* phase and defect-free alignment can be obtained [14].

Ultra-thin and conducting LB films or charge-transfer complex doped cells [15–17], which are doped either into the aligning layer or the FLC materials directly, are also effective ways to overcome the problem of ion-degradation and improve device stability.

As a special case of zig-zag defects, the stripe-shape domain (SSD) structure can usually be obtained when an outer electric field is applied to the SmA or SmC* phase during the cooling of cells [18–20]. The SSD structure can maintain a good memory capability and may be more stable for its peculiar configuration compared with the other types of alignment textures in SSFLC cells.

We have succeeded in doping a phthalocyanine compound into the aligning layers to obtain the SSD structure and improve the EO characteristics of the SSFLC cells [21], although there was a problem with the solubility and fusion characteristics between the dopant and PI precursor. In the present study we chose

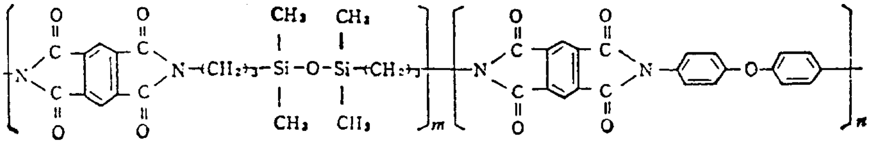


Figure 1. The polymer molecular structure of the polyimide compound.

a naphthalocyanine candidate with better solubility and meltability as the dopant to obtain a uniform SSD structure. We have investigated the corresponding EO properties and the application of this dopant to a 64 × 64 electrically controlled, matrix-addressed FLC spatial light modulator (SLM).

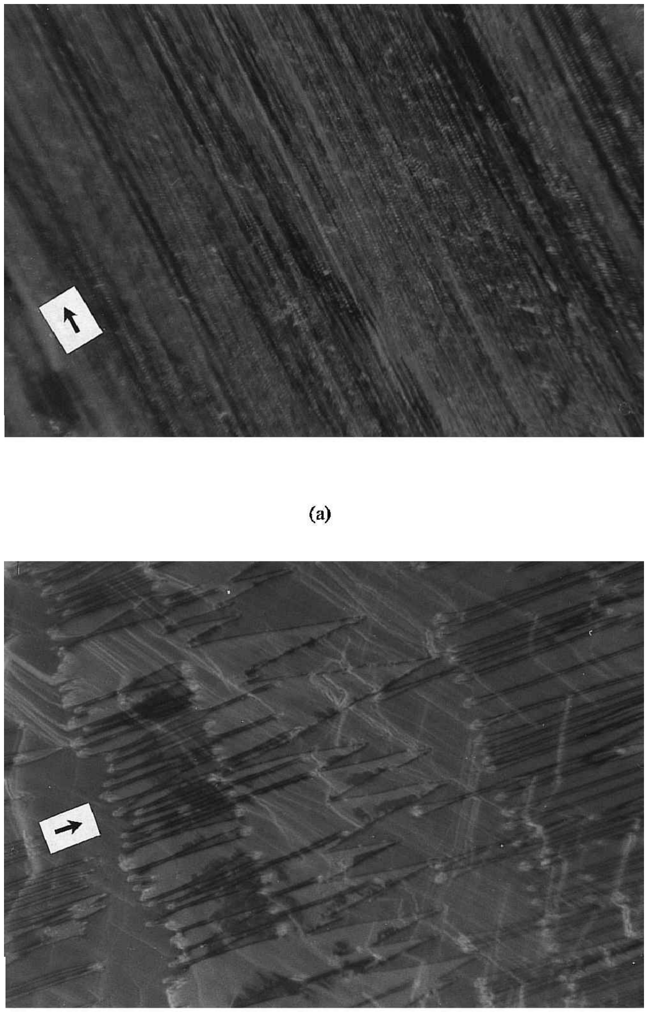
The chemically and heat stable silicon naphthalocyanine (SiNc) was doped into the special polyamic acid shown in figure 1. The amount of the doping was from 0.1 to 0.3 wt %. The solution was spun onto ITO substrates at 4000 revolutions per minute. The spun precursor layers were imdized at 200°C for 1 h. The resulting PI films were unidirectionally rubbed under a velvet-coated cylinder and a SSFLC cell/device was fabricated with the substrate rubbing directions parallel. The cell gap was controlled at 1.5 ~ 1.8 μm with photolithographed PI spacers. The FLC material CS-1024 (Chisso Co., Japan) was injected into the cell.

An antiparallel type cell was assembled for the measurement of pre-tilt angle in the nematic phase, where the crystal rotation method was used. The cell thickness was controlled at 27 μm. The NLC material ZLI-3417-006 (E. Merck, Germany) was poured into the cell gap under vacuum.

The EO properties of the SSFLC cells were measured by placing them between crossed polarizers, and a He-Ne laser at a wavelength of 632.8 nm was used as the light source. The light transmission signals were probed and recorded by a photomultiplier and a dual-trace memory oscilloscope. The contrast ratio between the bright state and the dark state was measured under the application of $\pm 10\ \mathrm{V} \times \mu\mathrm{m}^{-1}$, 10 Hz square voltage pulses. The memory ratio was measured under a 1 ms bipolar pulse with a period of 20 ms.

Figure 2 (*a*) is a typical SSD structure of a SSFLC cell observed under the polarizing microscope near the extinction position at a dopant content of 0.2 wt %. The SSD structure is long and narrow with an average width of 2 ~ 4 μm along the surface-rubbed direction, which reveals that the FLC molecules are divided into many separate domain regions and can be aligned uniaxially by the rubbing process due to the surface anchoring effect. In the non-doped, pure PI films aligned cell, an irregular zig-zag defect structure is seen, figure 2 (*b*).

Figure 3 shows the relationship between dopant content and pre-tilt angle. Although there is no linear relationship between them, it can still be certain that a relatively low pre-tilt angle is beneficial to the formation of the SSD structure, since the SSD structure can be easily obtained in our adopted doping range.



(a)

(b)

Figure 2. The SSD structure in a SiNc doped SSFLC cell (*a*), and the zig-zag defect structure in a non-doped SSFLC cell (*b*), observed under the polarizing microscope. The arrow indicates the rubbing direction.

Figure 4 shows the memory capability and contrast ratio of the SSFLC cells at various dopant contents. It can be seen that the memory capability and contrast ratio of the SiNc doped cells have been enhanced and improved significantly compared with those of the non-doped cells. It is noticeable that the cell doped at 0.2 wt % has the best memory capability of 97%, and

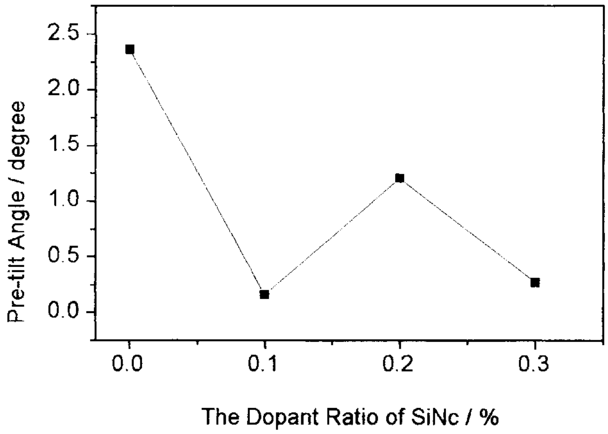


Figure 3. The relationship between the pre-tilt angle of the NLC and the dopant content of SiNc.

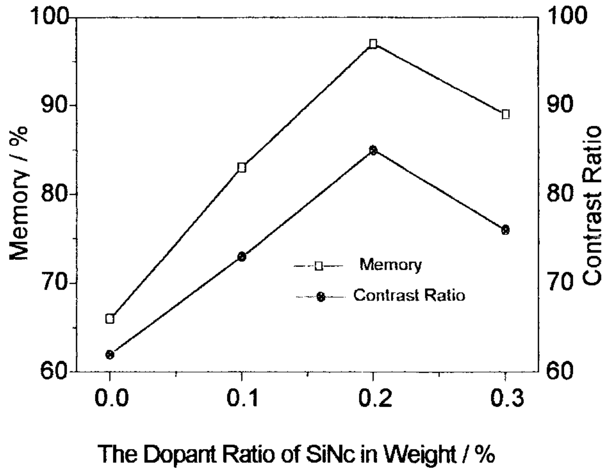


Figure 4. The memory capability and contrast ratio of SSFLC cells at different dopant contents.

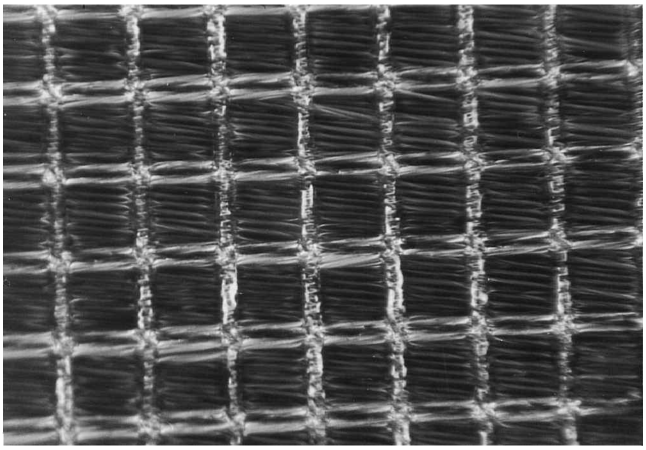


Figure 5. The SSD structure in a 64 × 64 FLC SLM at a dopant content of 0.2 wt %.

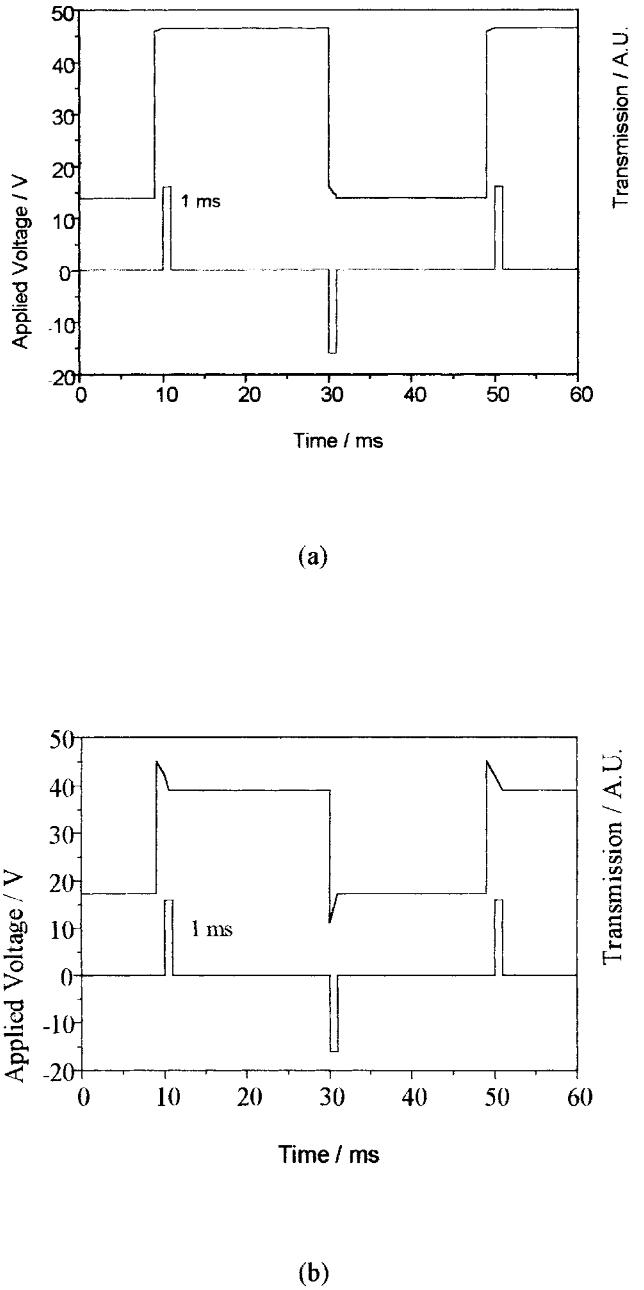


Figure 6. Optical response of (*a*) SiNc doped and (*b*) undoped rubbing aligned films, 64 × 64 FLC SLMs; dopant content is 0.2 wt %. The applied voltage is $\pm 10\ \mathrm{V\,\mu m^{-1}}$ under a 1 ms bipolar pulse with a period of 20 ms.

the highest contrast ratio of 86:1. This may be because corresponding aligning surfaces are suitable for formation of the SSD structure and provide an appropriate anchoring strength for the assurance of excellent EO characteristics [22].

Figure 5 shows a similar SSD structure in 64 × 64 FLC SLM to that shown in figure 1, at the dopant content of 0.2 wt %. The area of each pixel is

80 μm × 80 μm, so an average width of the SSD is about 5 μm. A thinner width is beneficial in obtaining a high information content in a transmissive type SLM.

Figures 6 (*a*) and 6 (*b*) show the optical response of the doped and undoped 64 × 64 FLC SLM, respectively, under bipolar pulses. The doped SLM has an almost complete memory capability, while that of the non-doped device is only 60%.

It is important to note that SSFLC cells and FLC SLMs aligned with the SiNc doped films can retain the SSD texture without degradation and show stable EO properties after more than 6 months storage or operation; non-doped devices show degeneracy of the SmC* structure which can not be restored even under a.c. stabilization. This demonstrates that SiNc doped devices have a better stability, which is valuable from the application point of view.

In conclusion, we have realized the formation of SSD structure in the initial FLC alignment by doping SiNc into the aligning layers. The resulting cells have an enhanced memory capability and improved contrast ratio compared with non-doped cells. The same applies to a fabricated FLC SLM, which shows excellent EO characteristics and improved stability. The SiNc doping process both guarantees the formation of the SSD structure and provides improved EO properties and stability of the SSFLC devices.

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