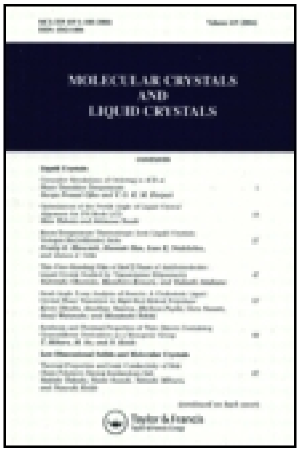

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Erasable Optical Storage in Bistable Liquid Crystal Cells

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Version of record first published: 04 Oct 2006.

To cite this article: Markus Kreuzer , Theo Tschudi & Rudolf Eidenschink (1992): Erasable Optical Storage in Bistable Liquid Crystal Cells, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 223:1, 219-227

To link to this article: http://dx.doi.org/10.1080/15421409208048253

Mol. Cryst. Liq. Cryst. 1992, Vol. 223, pp. 219–227
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Printed in the United States of America

ERASABLE OPTICAL STORAGE IN BISTABLE LIQUID CRYSTAL CELLS

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(Received November 22, 1991)

Abstract In this paper, we present a new kind of bistable liquid crystal display (Filled Nematic) using static light scattering, and its application as a high resolution laser–addressed display. The new material consists of small inorganic particles dispersed in a nematic liquid crystal. In dispersion the particles form internal interfaces with a large specific surface making it possible to stabilize different director configurations. We report the key parameters for reversible optical data storage in this medium and give a first explanation of the physical mechanism of the laser–writing process.

INTRODUCTION

Over recent decades, liquid crystal displays (LCDs) have found many applications. Recently, polymer dispersed liquid crystals (PDLCs) have revived interest in displays based on light scattering. PDLC films form micron sized, randomly aligned droplets of (nematic) liquid crystals in a polymer matrix. In this case, the film normally scatters light, but, if the ordinary refractive index of the liquid crystal is matched to that of the polymer, the film can be switched to a transparent state by applying a steady electric field. Since these displays do not require polarizers and are insensitive to small variations of cell thickness, they offer good potential for large scale displays and have many other interesting applications[1,2]. A new approach are bistable switchable polymer gel dipersions[3].

Recently, scattering type displays based on Filled Nematics have been discovered[4] and shown to have some additional potential advantages. For instance, their contrast is independent of viewing angle, and there is no need for index matching. Moreover, they are bistable, and this allows several different kinds of addressing modes, one of which is laser addressing. The two stable modes are: static light scattering (SS) due to a large amount of randomly aligned nematic domains and a homeotropically aligned, transparent state (TS).

Material

Filled Nematics consist of small solid particles of pyrogenic silica dispersed in a nematic liquid crystal[4].

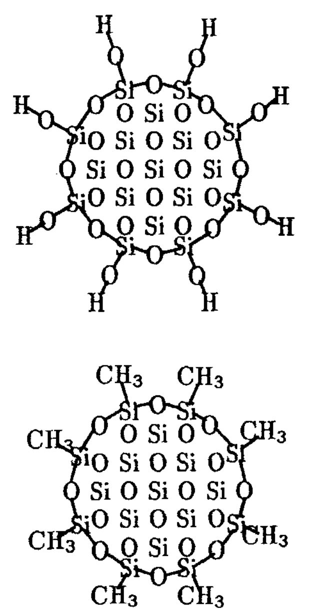

FIG. 1 Primary particles

Figure 1 shows two types of particles which may be used in these displays. Typically, the diameter of the particles is chosen in the range 7 nm to 40 nm. Inside the dispersion the particles form agglomerates and aggregates with a large specific surface[5] (typ. 50 – 380 m^2/g). The relatively closely packed particles are surrounded by the nematic phase. Investigations, using scanning electron microscopy (SEM), have shown that densely packed pyrogenic silica has free spaces with diameters in the range of about fifty to some hundred nanometers. Due to the low bulk density of the dispersed pyrogenic silica, we can achieve stable dispersions with high volume ratio for the nematic phase (typically 97 – 99 Vol%).

The material is placed between untreated glassplates with transparent ITO electrodes in a conventional display configuration. In our experiments, we have used cell thicknesses between 2.5 μm and 18 μm.

After preparation, the small nematic domains are naturally aligned in a random fashion. Due to the large optical anisotropy ($\Delta n \approx 0.1-0.2$) of the liquid crystal material, this results in strong scattering of visible light (Fig. 2). By applying a low frequency electrical field to the display (positive dielectric anisotropy) it can be switched to a homeotropically aligned, transparent state.

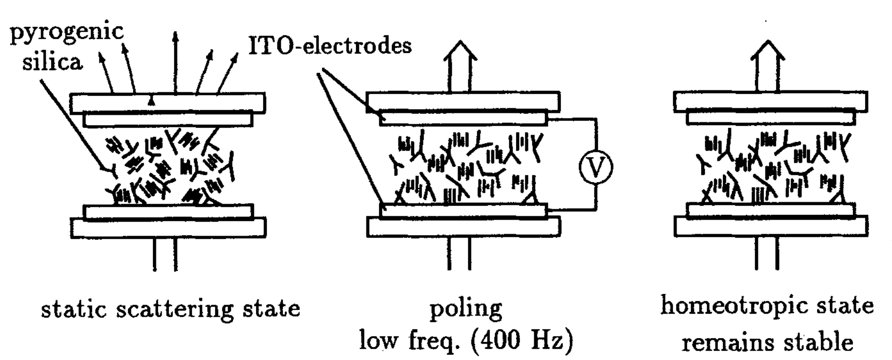

FIG. 2 Schematic diagram of scattering state and poling process

In contrast to PDLC's, there is no phase separation process and, therefore, matching between the refractive indices of liquid crystal and dispersed material is not required. Due to the high volume fraction of the nematic phase the dispersed material has virtually no influence on the optical properties of the display. There is, therefore, no dependence of the transmission on viewing angle. Because of this, there are no specific requirements for the liquid crystal and the particles can be dispersed in any conventional nematic.

The interesting property of this new type of display is that, on removal of the electric field, the liquid crystal remains in the transparent homeotropic state. Figure 3 shows scattering behaviour on poling and removal of the electric field, as a function of applied voltage.

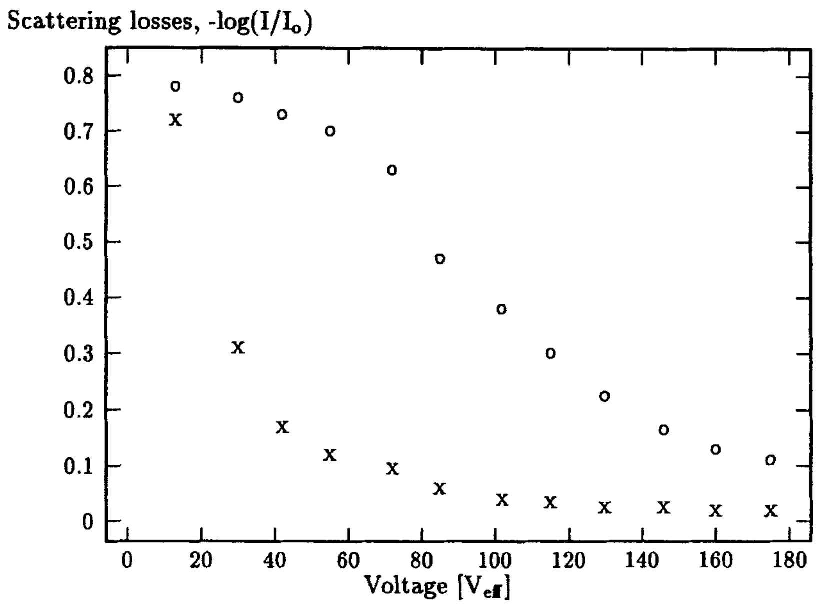

FIGURE 3 Scattering losses as a function of applied voltage (400 Hz) measured in a 14 μm cell. ZLI 1132 filled with 2.8 % of Aerosil R812. The 'x'-points denote the losses with voltage on; from this state the losses reach the 'o'-points (at same voltage in the plot) if the voltage is completely switched off. Losses are measured with a light beam having an aperture of 4° in front of and behind the cell [from Lit. 2].

Display

In the previous section we have shown how it is possible to switch from the scattering state to the transparent state. In a bistable device, it is also necessary to be able to switch back to the scattering state.

Like most LC-displays, Filled Nematics are sensitive to mechanical distortion (pressure, etc.). Directed ultrasound can therefore be used to locally switch back to the scattering state. Electrical addressing can be achieved by using a two-frequency addressing scheme[4]. A nematic material which changes its sign of dielectric anisotropy at a certain frequency of the applied electric field is chosen. For $\Delta\varepsilon < 0$ the liquid crystal tries to align itself perpendicular to the electric field. Since the boundary conditions at the interfaces between the LC and the pyrogenic silica are not uniform, each nematic domain will probably then find its own preferred planar direction giving random orientation from domain to domain and an expected strongly scattering state. In experiments reported previously[4], the nematic phase of ZLI 2461 was used having the following dielectric properties at room temperature[6]:

$$\Delta\varepsilon \approx +2 \quad \text{at 400 Hz}$$
$$\Delta\varepsilon \approx -1.9 \quad \text{at 20 kHz}$$

As expected, application of 400 Hz and 20 kHz voltages gave switching to the transparent and scattering states, respectively. Typical switching times were:

at 400 Hz: SS – TS : 8 ms (3 ms delay, 5 ms rise time)
at 20 kHz TS – SS : 18 ms (3 ms delay, 15 ms rise time)

The assumption of (almost) homeotropic and random planar orientations were confirmed by dielectric measurements of the SS and TS – states which agreed approximately with the frequency-dependent values given for ZLI 2461.

LASER ADDRESSED OPTICAL STORAGE

As mentioned above, bistable displays have the potential for laser-addressing.

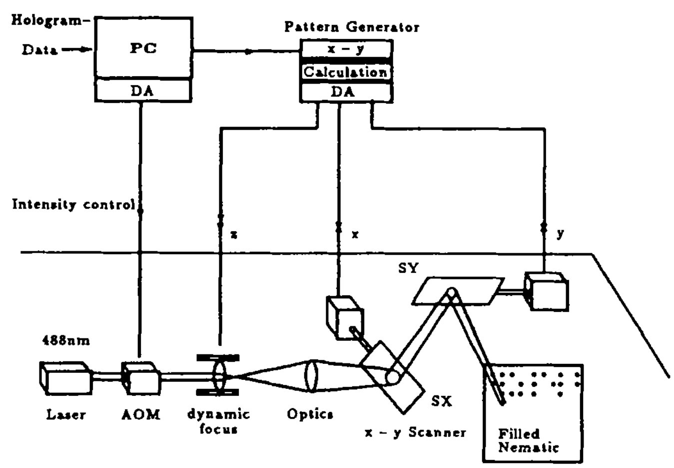

FIGURE 4 Schematic setup of the pattern generator: AOM (acousto optic modulator)

Figure 4 shows a pattern generator for computer generated holograms which we have used to demonstrate high resolution optical storage in Filled Nematics. This setup enables us to write binary holograms and also grey scale pictures with continous intensity modulation through the application of an acousto-optic-modulator.

Illumination of the homeotropically aligned Filled Nematic with a focussed laser beam locally switches the display back to a strongly scattering state. Since the laser-writing process is thermal in nature, we used dye–doped liquid crystals (P 105 in ZLI 1132 from Merck, $\lambda_{max} = 456\,\text{nm}$) in most of our experiments to enhance this effect. Figure 5 shows a part of a binary hologram written in a

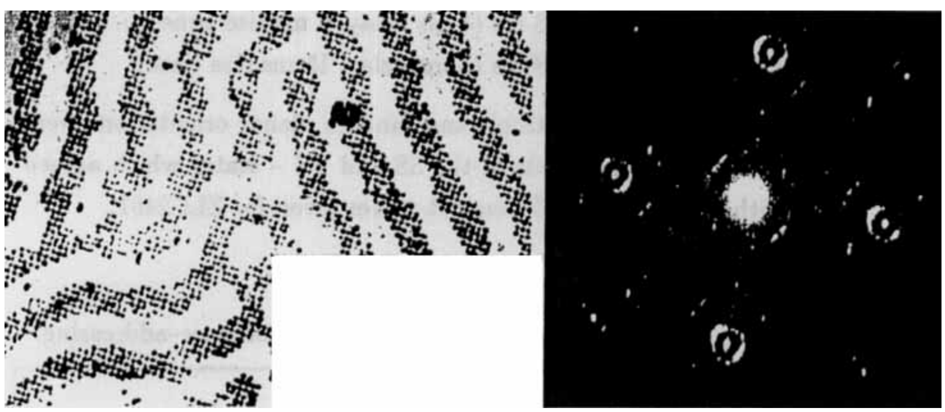

FIGURE 5 Left: part of a written binary hologram. (R812/R709 + ZLI 1132, dye–doped P 105 from Merck), $\lambda = 488\,\text{nm}$, Pixel size: 3.5μm, Exposure time : = 0.6 ms/pixel, Energy :$\approx$ 1μJ/pixel; Right: optical reconstruction

Filled Nematic and calculated to create a ring focus system.

We investigated the characteristics of the laser–writing process using an Argon–laser (at λ = 514nm, focussed onto the Filled Nematic, spot diameter a = 40μm). The illumination was controlled by an acusto-optic modulator (AOM) which enabled us to create pulse widths as short as 250 ns. Pulse energies were typically in the range 0.1 to 10 μJ. To determine the sensitivity of the Filled Nematics, we measured the diameter of the written spots as a function of the pulse energy. A simple model, assuming an energy density threshold ρ_{th} and a gaussian input beam, yields the following relation between spot diameter D_{spot} and pulse energy E_p:

$$\ln E_p = \ln(\rho_{th} \cdot \frac{\pi a^2}{8}) + \frac{2D_{spot}^2}{a^2} \tag{1}$$

where $a = 1/e^2$–diameter of the input beam.

The evaluation of experiments with pulse durations from 250 ns to 2 μs (written spot diameters were in the range between 3.5μm and 25μm with $a = 40\mu$m) gave an energy density threshold $\rho_{th} \approx 1\,\mathrm{nJ}/\mu\mathrm{m}^2$. This sensitivity is comparable to other materials for optical data storage, for instance liquid crystal/dye copolymers[7] (LCDP). The spatial resolution was found to be better than 2 μm.

We found also that not only the diameter of the spot, but also the contrast ratio depends on the pulse energy. Initially, on increasing the pulse energy the spot diameter tends asymptotically to the beam diameter. Once the beam diameter has been reached, further increasing the pulse energy causes an increase of contrast, while the spot diameter remains constant. Real grey–scale pictures may therefore be written in Filled Nematics.

FIGURE 6 Left: grey scale picture in a Filled Nematic cell. Illumination under 60° from behind. Right: enlarged picture consisting of 512 × 512 pixels of 15 μm diameter.

Figure 6 shows a 16 grey–scale picture. The contrast of a saturated spot is better than 1:50. The laser–written information can be erased by external electric fields as described above.

Mechanisms

As mentioned above, the laser writing process is a thermal effect. However, experiments have shown that it cannot be a simple process of heating by laser above the clearing point and cooling down to a randomly aligned scattering state. For example, continously monitoring the transmission of the cell during laser illumination has shown that the writing process occurs before a transition into the isotropic state. To distinguish between these two processes we have illuminated the written spot for a second time. In this case no writing process appeared and the transition to the isotropic state at higher intensities could be identified seperately. In the experiments presented here we can neglect any effect of optically induced reorientation. Rough estimation of the forces occuring inside the layer lead us to believe that a shock mechanism (e.g. fast volume expansion due to the thermal shock) probably causes a deformation of the internal interfaces, making the material revert locally to a scattering state. To understand the mechanisms in detail we need to know more about the boundary conditions at the internal interfaces.

CONCLUSION

We have described a high resolution laser-addressed liquid crystal display using Filled Nematics. The exposure times, sensitivity and resolution found in our experiments lead us to believe that Filled Nematics have considerable potential for applications like projection displays or optical data storage. If it is possible to switch from the homeotropic state to a distinct planar orientation by optically induced reorientation using linearly polarized laser beams, then Filled Nematics could have some very interesting applications in computer generated holography. Considerable further work on these materials appears to be worthwhile.

ACKNOWLEDGEMENT

We wish to thank J.-M. Asfour and J. Hoßfeld for their help with the pattern generator and for calculating the holograms. We gratefully acknowledge helpful discussions with W.H. de Jeu.

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