
**Liquid Crystals**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713926090

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Online publication date: 11 November 2010

**To cite this Article** Almeida, P. L. , Lavareda, G. , De Carvalho, C. Nunes , Amaral, A. , Godinho, M. H. , Cidade, M. T. and Figueirinhas, J. L.(2002) 'Flexible cellulose derivative PDLC type cells', Liquid Crystals, 29: 3, 475 — 477

**To link to this Article: DOI:** 10.1080/02678290110113487

**URL:** http://dx.doi.org/10.1080/02678290110113487

LIQUID CRYSTALS, 2002, VOL. 29, NO. 3, 475–477



# Preliminary communication
# Flexible cellulose derivative PDLC type cells

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(*Received 28 September 2001; accepted 12 October 2001*)

In this work we perform a study of ≈ 250 μm thick flexible electro-optical PDLC type cells made from a biocompatible cellulose derivative film and several conductive substrates. The deposition of an ITO layer by reactive thermal evaporation on a polymeric substrate was referred to in the literature very recently and this type of coated substrate was used in the present work. In order to consider the influence of the substrates on the electro-optical behaviour of the cells, five cells were made using different substrates (three flexible polymers and two glass for comparison). Three of the substrates were coated under the same conditions, and the other two were commercially available substrates.



Composite materials made from a nematic liquid crystal and a cellulose based polymeric matrix [1] give rise to systems relevant for electro-optical applications exhibiting electro-optical properties similar to those observed in standard PDLC systems [2–5].

The cellulose derivative based PDLC-like system (CPDLC) uses a liquid crystal distribution different from usual PDLCs, where the liquid crystal is confined to droplets. The CPDLC optical cell consists of a thin rugged polymeric film covered on both surfaces with a liquid crystal layer and placed between two conducting transparent substrates [1, 6–8]. The electro-optical properties registered in these systems may surpass those observed in classical PDLCs favouring the use of CPDLCs for window applications. In this work a new type of CPDLC optical cell based on flexible polymer substrates is studied, clarifying the role of the different types of substrate used on the electro-optical properties of these systems.

The cellulose derivative used, HPC (hydroxypropylcellulose Aldrich, $M = 100\,000$) was dried in vacuum at 50°C for about 48 h before use. Solutions of HPC in acetone were then crosslinked with 1,4-di-isocyanatobutane (BDI) (7 wt %) according to the procedure previously described [1, 7]. The nematic liquid crystal mixture used was the commercially available E7 (Merck Ltd., UK). 10 μm spacers were used to maintain the thickness of the liquid crystal layers.

The different substrates used were glass (1 mm thick), acetate (Staedtler) (87 μm thick), Rubilite (Kodak) (77 μm thick) and polyethylene terephthalate (PET) (171 μm thick). The conductive layers of indium tin oxide (ITO) were deposited under the same conditions on the glass, acetate and rubilite. Thin ITO films were deposited by RF plasma enhanced reactive thermal evaporation (PERTE) [9] of a 90% In–10% Sn alloy in the presence of oxygen, on the unheated substrates. The deposition was performed with an RF power of 45 W, and with a deposition pressure in the range $7–8 \times 10^{-4}$ mbar, for 12 min at room temperature (24°C).

Two other substrates used were commercially available; one was a glass and the other a PET film, both ITO coated by Delta Technologies Inc. The sheet resistance of the five substrates was measured using a four-point probe FPP 5000 from Veeco Instruments, Inc.

Light scattering patterns were obtained using a helium-neon laser ($\lambda = 0.6328$ μm), a goniometer and an optical bench equipped with a photomultiplier light detector. An a.c. controllable generator was used to set the voltage applied to the samples. All measurements were performed at a temperature of 24°C.

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*Liquid Crystals* ISSN 0267-8292 print/ISSN 1366-5855 online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/02678290110113487

The voltage dependence of the light transmission coefficient measured for the 5 samples analysed is shown in figure 1.

The values of $V_{on}$, the maximum and minimum transmissions, and the contrast are shown in the table. The maximum transmissions obtained for all samples are very similar and in the same range as in previous studies [6, 7].

Scattering patterns were recorded by measuring the angular dependence of the scattered light for several levels of voltage excitation. Each curve in figures 2 (*a*–*c*) corresponds to a different sample, and each figure corresponds to a different level of electrical excitation. To make the values of the differential cross section of the five different samples comparable, the measurements were not made at specific voltages, but for voltages that induced in each sample a predefined transmission coefficient. Measurements were made while applying 0 and 10 V to the sample (where the scattering is more significant) and for applied voltages that induce 75% of the maximum transmission coefficient in each sample.

Up to a scattering angle of 0.2° the pattern recorded is a mixture of scattered and transmitted light; for a



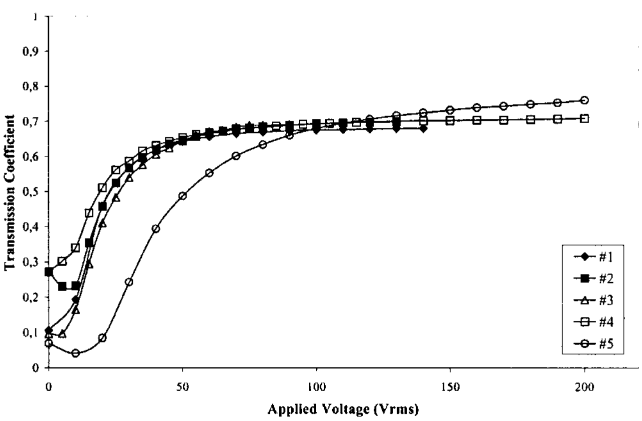


Figure 1. Voltage dependence of the transmission coefficient for the five cells (see the table).

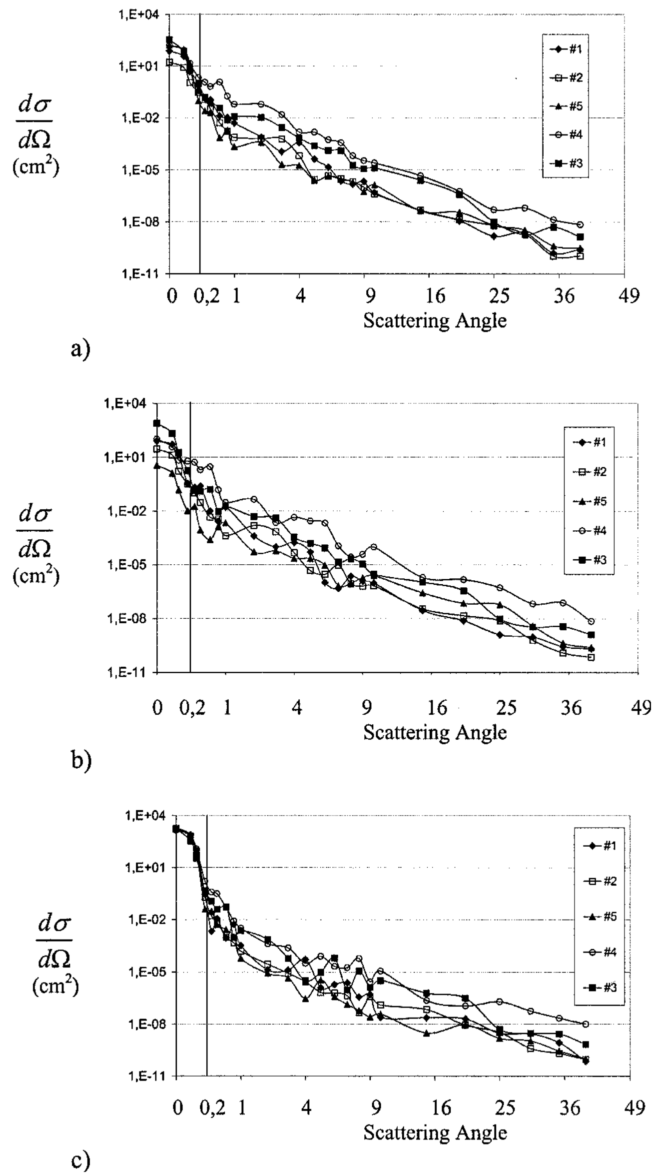


Figure 2. Angular dependence of the differential cross section for the five cells with an applied voltage of (*a*) 0 V, (*b*) 10 V, (*c*) corresponding to 75% of the maximum transmission.

Table. Designation and optical parameters measured for the five different cells.

| Designation of the sample | Substrate used in sample | $V_{on}{}^{a}/V_{rms}$ | Max. trans. | Min. trans. | Contrast[b] |
|---|---|---|---|---|---|
| 1 | Acetate | 40 | 0.680 | 0.106 | 6.42 |
| 2 | Rubilite | 45 | 0.698 | 0.230 | 3.03 |
| 3 | PET | 45 | 0.699 | 0.096 | 7.28 |
| 4 | Glass (coated in-house) | 40 | 0.700 | 0.249 | 2.81 |
| 5 | Glass (commercial) | 100 | 0.760 | 0.041 | 18.53 |

[a] $V_{on}$ is the applied voltage for the sample to reach 90% of its maximum transmission.
[b] Contrast is the ratio between the maximum and the minimum transmissions.

scattering angle $\geqslant 0.2°$ pure scattering pattern is obtained. The data obtained for the five samples studied reveal that the scattered light is concentrated at small angles, indicating that the variations of the director over lengths larger than the wavelength of the laser light are the most efficient scatterers. The substrate used in the fabrication of each different cell, has little influence on the light scattering pattern.

We have measured the electrical sheet resistance of all substrates used; the values obtained were 614 Ω/square for the glass coated in our laboratory; 492 Ω/square for rubilite; 256 Ω/square for PET; 272 Ω/square for acetate and 11.9 Ω/square for the commercial glass. As one can see from the transmission coefficient curves, no correlation between the electrical resistance and the optical behaviour of the cells exists.

Figures 2(*a*) and 2(*c*) show that the light scattering pattern of the five cells is not significantly different between 0 V and the applied voltage that leads the cell to have 75% of its maximum transmission. Sample 4 shows, in both cases, the higher level of scattered light.

The angular dependence of the differential cross sections obtained in the different samples shows a similar pattern; as expected, since, in the proposed working mechanism for these systems [6], the conducting substrates are not the main sources of scattering and are not expected to influence it much. Also, as mentioned elsewhere [6], the angular dependences of the differential cross sections obtained for each sample at different levels of electrical excitation differ mostly in the very small angle region, corresponding mainly to transmitted light. The main tendency observed is a decrease in variation with applied voltage with increasing scattering angle, confirming earlier observations that indicate that the large angle scattering is produced by features very little dependent on the electrical excitation applied at these levels of excitation, and so is identified with the scattering occurring at the interface between the rugged HPC film and the nematic liquid crystal.

In conclusion, in this study we have presented the influence of new types of substrates on the electro-optical properties of CPDLC cells. The flexible CPDLCs show good maximum transmission, although the minimum transmission is not the ideal, and this influences the contrast. The best contrast is obtained for the rigid glass cell because it has the lowest minimum transmission. Nevertheless with three kinds of flexible cell, we were able to lower the $V_{on}$ to half of its usual value [6, 7]. Further studies to increase contrast without degrading the maximum transmission and $V_{on}$ are now under way.

This work was supported by PRAXIS XXI, Portugal, under research contract 3/3.1/CEG/2620/95. P. L. Almeida wishes to thank partial support from the PRAXIS programme grant no. PRAXIS XXI BD 17071/98.

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