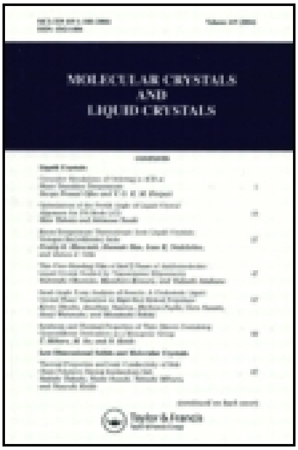

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Characterisation of Photoalignment Materials for Photonic Applications at Visible and Infrared Wavelengths

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Version of record first published: 31 Aug 2006

To cite this article: Romeo Beccherelli, Ilias G. Manolis & Antonio d'Alessandro (2005): Characterisation of Photoalignment Materials for Photonic Applications at Visible and Infrared Wavelengths, Molecular Crystals and Liquid Crystals, 429:1, 227-235

To link to this article: http://dx.doi.org/10.1080/15421400590930971

Mol. Cryst. Liq. Cryst., Vol. 429, pp. 227–235, 2005
Copyright © Taylor & Francis Inc.
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400590930971

Characterisation of Photoalignment Materials for Photonic Applications at Visible and Infrared Wavelengths

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In this paper we discuss the processing and characterisation of Linearly Polymerisable Polymers to align Liquid Crystal Prepolymers for use in photonic application. Preliminary results on uniform retardation waveplates for use in free space optics are given.

Keywords: infrared; liquid crystals; photoalignment; photonic

1. INTRODUCTION

Planar uniaxial alignment of liquid crystals (LC) can be obtained by oblique evaporation of silicon dioxide [1] on a flat substrate. However this process is time consuming and not economical for production. Rubbing of a polymer layer [2], usually a polyamide [3,4] or polyimide, typically with a velvet covered roll, is the most widely adopted method to date to promote uniform homogeneous alignment of LCs over large areas. Unfortunately this process is susceptible to contamination and dust generation. Moreover unwanted electrostatic charges are produced as a side effect of the rubbing action on the dielectric film. Effects

The authors would like to acknowledge supply of materials from Rolic and Vantico.
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of contamination introduced by the velvet cloth could be reduced by depositing PTFE [5,6] by hot friction directly from a PTFE roll.

Particles generated by the rubbing process are a general problem in the manufacturing of structures on the micrometer scale. Hence a contactless and inherently dust free alignment method is most desired. An alternative approach to rubbing is based on Linearly Photopolymerised (LPP) polymers [7] These have shown to be highly effective in aligning low molar mass liquid crystal materials with controlled pretilt for high contrast multidomain twisted nematic liquid crystal displays [8]. This inherently conctactless photoalignment technique not only avoids mechanical stress but also the generation of electrostatic charges that can damage thin film transistors or other circuitry integrated over an active backplane device (e.g., LC on silicon architectures). LPP polymers have also been used to align Liquid Crystal Prepolymers (LCP) that are later polymerised in order to produce custom optical retarders [9,10] cholesteric filters [11] and optical security elements [12]. Surprisingly, all uses of LPP and LCP so far investigated are intended for display-like applications, i.e., operation at visible wavelengths and for light incident on the plane defined by the substrate.

The problems related to dust and mechanical stress encountered in display manufacturing are much more severe in the fabrication of liquid crystal based photonic devices. In this case, even a single1-2 micrometre dust particle in the optical path of a waveguide or of a vertical coupler [13] can introduce a very high level of scattering and destroy the operation of the entire device. Mechanical rubbing is also incompatible with polymeric channel waveguides [14] and other soft materials often used in photonics.

In this report we are focusing on the potential use of these materials in photonic devices useful in optical communication systems.

A detailed discussion of the processing of these prototypal materials together with some first characterisation from their optical properties characterisation both in the visible and inside the telecoms window (1550 nm) is provided.

2. EXPERIMENTAL

2.1. Films Preparation

Linearly Polymerisable Polymers (LPP) in cyclopentanone dispersed are deposited by spin coating, baked in oven at 130°C for 10′ and polymerised in polarised UV light in the [295–330] nm range, with controlled oblique incidence and irradiance. This allows generation of desired pretilt [8].

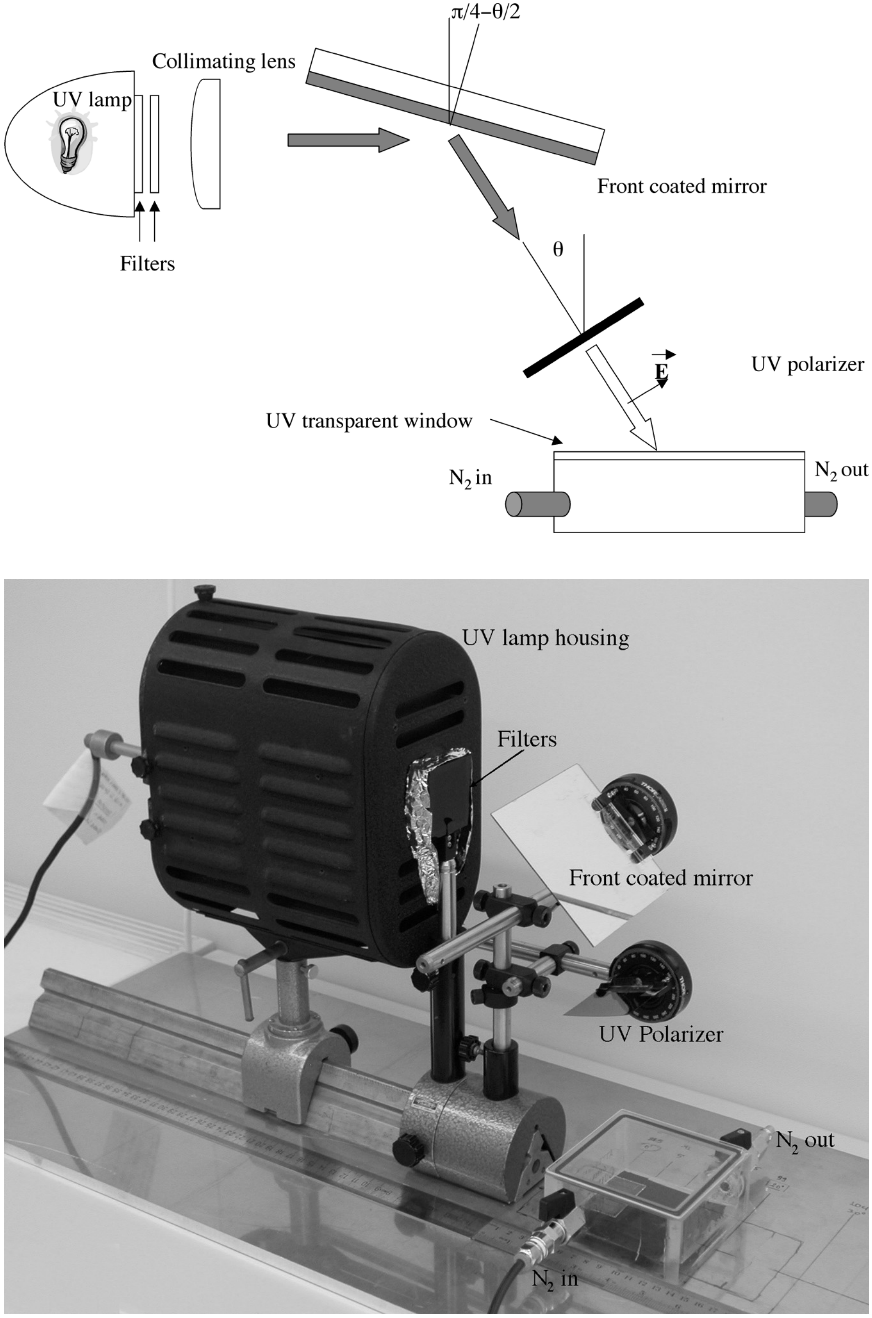

FIGURE 1 Schematic (a) and actual (b) setup of UV exposure. In (b) the collimating lens is not mounted. (See COLOR PLATE XXIX)

Subsequently LCP, also dispersed in cyclopentanone, are deposited atop by spin coating. The solvent does not affect the already polymerised LPP. The uniaxial order of this is transferred to the LCP by allowing the solvent to evaporate at 55°C in vacuum and the substrate to cool down slowly. At this stage the layer, still fluid, already shows birefringence. This order is frozen by polymerising the prepolymer, in nitrogen atmosphere, with unpolarised UV light (365 nm). Typically 0.5–2.3 μm thick LCP aligned on LPP layers are obtained for a single deposition step. These are solid and easy to handle.

In our experimental setup we use a mercury discharge lamp (Osram HBO200), a HNP'B UV polariser from 3 M, sets of Schott filter (WG295 and UG11 for the LPP to extend lifetime of the UV polariser) WG320 and UG11 for the LCP). A collimating lens can be used to increase the irradiance at the substrate.

An illustration of the set-up is given in Figure 1.

2.2. Evaluation of Pretilt

A commonly used method for the determination of the pretilt is the crystal rotation method [15]. This method requires relatively thick (typically >10 μm) anti-parallelly aligned cells to be placed with the axis of the cell at 45° between crossed polarisers. A schematic version of the measurement setup is given in Figure 2. The cell is rotated continuously by Ψ along an axis perpendicular to an incident light beam. This provides a nearly symmetric curve with respect to a value of Ψ. We shall call this Ψ_x. The normalised transmission is given in Eq. (1) [16].

$$T(\alpha_{LC}, \Psi, d) = \sin^2\left[\frac{\pi d}{\lambda} f(\alpha_{LC}, \Psi)\right]$$

$$\begin{aligned} f(\alpha_{LC}, \Psi) = {} & \frac{n_o^2 - n_e^2}{n^2}\sin(\alpha_{LC})\cos(\alpha_{LC})\sin(\Psi) + \frac{n_o n_e}{n^2}\sqrt{n^2 - \sin^2(\Psi)} \\ & - \sqrt{n_o^2 - \sin^2(\Psi)} \end{aligned}$$

$$n^2(\alpha_{LC}) = n_o^2\cos^2(\alpha_{LC}) + n_e^2\sin^2(\alpha_{LC})\, n^2(0) = n_o^2 \qquad (1)$$

where α_{LC} is the pretilt, d is the cell thickness, n_o and n_e the ordinary an extraordinary refractive indexes at the probing wavelength.

From observation of Ψ_x and the knowledge of the refractive indexes of the liquid crystal, the pretilt angle α_{LC} is calculated. However in the case of LCP the thickness required for photonic applications is only a few μm. Furthermore it was shown that the director profile of the LCP is affected by the different interfaces (namely LP and air) thus resulting in a non-uniform profile along the direction normal to the substrate [17]. Hence it is not reliable to extrapolate the behaviour of one layer from layers with different thickness. What matters is that the effective pretilt for a specific thickness is accurately controlled. Conversely to the case of liquid crystal display where a finite pretilt is usually required, in the case of free space IR application it is important to have zero pretilt, while avoiding disclinations [18].

Hence the evaluation of the pretilt from the symmetry point in the transmission curve is not straightforward. It is therefore clear that the most critical point accurate evaluation of the pretilt of liquid crystal filled cells and the of zenithal angle of LCP layers deposited on a single substrate is the accurate determination of Ψ_x. We have built a computer controlled set-up based on the crystal rotation method. This resembles the experimental set-up described in [16]. However accuracy is improved by increasing the angle of rotation (from ±40° to ± 60°), by using collimated monochromatic light from a HeNe laser (632.8 nm) instead of white light or filtered light form a lamp. It is reasonable to assume that the axis of electronic vibration (hypersusceptibility) at 1550 nm is not significantly different from the axis probed with 632.8 nm (the amplitude, indeed, does vary). The use of laser light avoids the effects divergences and of index dispersion and its actual intensity is continuously sampled and used to normalise the readout. This improves accuracy.

While the pretilt is often obtained by looking for the symmetry point of the normalised transmittance curve $T(\alpha, \Psi, d)$ given in Eq. (1), we mentioned that the estimation is quite difficult for low pretilt and thin samples. We therefore fit experimental data to the analytical curve in Eq. (1).

Although the centering and alignment procedure is delicate, it can be reproduced accurately by different operators giving values of pretilt reproducible to within 0.1°.

Typical results are illustrated in Figure 3 for a E7 filled thick cell. The pretilt found is 0.36° with very few, if any, disclinations. Figure 4 shows corresponding results for a LCP layer which is only 2.3 μm thick, as measured with a surface profiler KLA Tencor AlphaStep 500. The LCP layer is on a single substrate.

We have carried out also evaluation of the optical retardation in the visible and IR.

The optical anisotropy Δn is evaluated with Eq. (2) from the measurements of transmitted intensity for a glass plate coated with

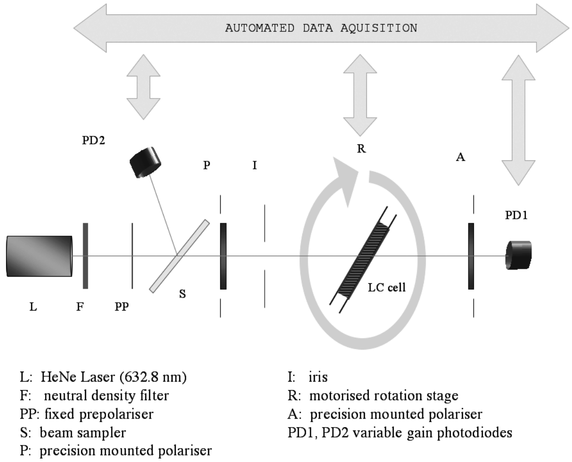

FIGURE 2 Schematic setup for the accurate measurement of the pretilt by the crystal rotation method. (See COLOR PLATE XXX)

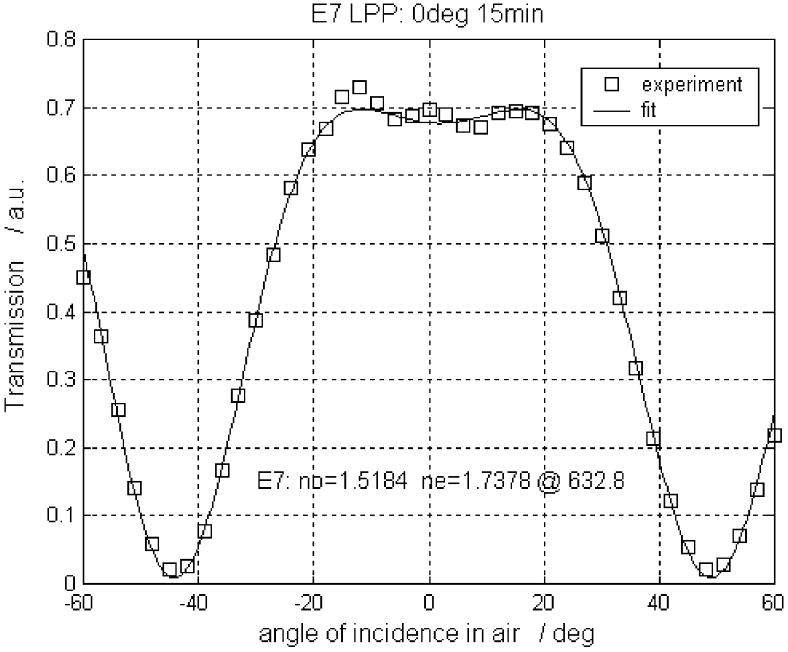

FIGURE 3 Normalised transmission for E7 filled cell taken on the crystal rotation set-up. A cell thickness of $13.6 \pm 1.0\,\mu\text{m}$ was measured interferometrically on the empty cell with a spectrophotometer. The fitted pretilt is $0.6^\circ \pm 0.1^\circ$.

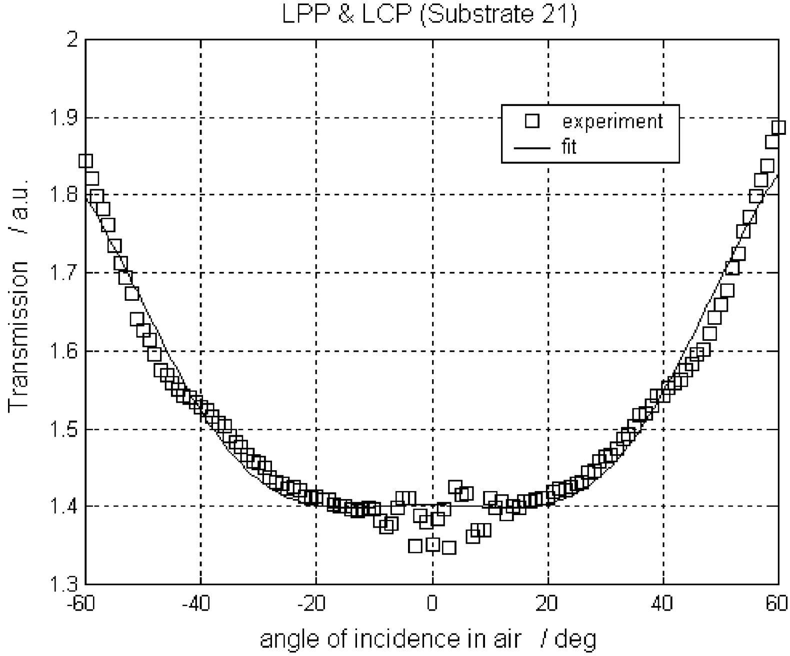

FIGURE 4 Normalised transmission for LPP and LCP single layer on a single substrate taken on the crystal rotation set-up. A film thickness of 2.30 ± 0.03 μm was measured a surface profiler KLA Tencor AlphaStep 500. The fitted pretilt is 0.2° ± 0.1°.

an LPP-LCP layer with optic axis at 45° from crossed ($I_{crossed}$) and parallel polarisers ($I_{parallel}$).

$$\begin{aligned}\Delta n_{eff} &= \frac{\lambda}{\pi d} ATAN\left(\sqrt{\frac{I_{crossed}}{I_{parallel}}}\right)\\ I_{crossed} &= I_0 \sin^2\left[\tfrac{\pi d}{\lambda}\Delta n_{eff}\right]\\ I_{parallel} &= I_0 \cos^2\left[\tfrac{\pi d}{\lambda}\Delta n_{eff}\right]\end{aligned} \tag{2}$$

where $\Delta n_{eff} = f(\alpha, \Psi)\Big|_{\Psi=0^\circ}$

In 2.27 μm thick films we find a Δn of 0.11 and at 632.8 nm 0.10 at 1550 nm respectively. These numbers, and the demonstrated capability to stack multiple layers of LCP, show that useful optical retarders for free space IR optics can be realised.

3. DISCUSSION AND CONCLUSIONS

We have investigated for the first time the use of Linearly Photopolymerised polymers and Liquid Crystal Prepolymers in the IR region. We have found that these have negligible absorption for free space optics in the IR wavelengths relevant to telecommunications (1550 nm). We have demonstrated that high quality retarders can be made by using thin LPP to align on a single substrate LCP layers.

Our current work is now aimed at thorough fully characterise this materials in the IR, to fine tuning of the thickness of this layer to achieve commonly used waveplates ($\lambda/4$, $\lambda/2$) and to explore the application of these materials in guided optics.

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