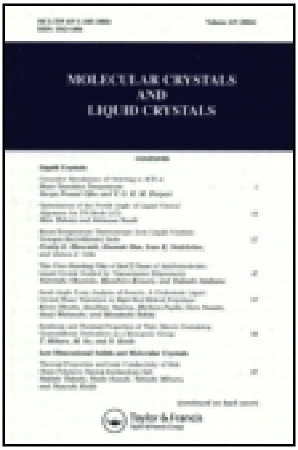

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

Highly Sensitive Photoelectrical Reorientation of Nematic Liquid Crystals

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Version of record first published: 04 Oct 2006

To cite this article: R. Macdonald, P. Meindl & S. Busch (1999): Highly Sensitive Photoelectrical Reorientation of Nematic Liquid Crystals, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 331:1, 483-490

To link to this article: http://dx.doi.org/10.1080/10587259908047549

Mol. Cryst. Liq. Cryst., 1999, Vol. 331, pp. 483-490
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Highly Sensitive Photoelectrical Reorientation of Nematic Liquid Crystals

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A highly sensitive photoelectrical reorientation effect in nematic liquid crystals has been investigated. The effect occurs under the combined application of DC-electrical fields and low power illumination. It was first observed in nematic liquid crystals of discotic molecules[1,2,3] but was recently also obtained with calamitic, i.e. rod-like molecules, as will be shown here. The observed optically nonlinear behavior can be characterized by rather large coefficients up to 0.5 cm^2/W.

Keywords: Nonlinear Optics; Electro-Optical Effects; Light-Valve; Photorefractive Effect

INTRODUCTION

Liquid crystals offer unique nonlinear optical properties which have been intensively studied during the last twenty years. A well-known effect concerns the optical field-induced molecular reorientation[4,5] leading to the so-called "giant" optical nonlinearity which was investigated in undoped and also in dye-doped[6] nematic liquid crystals. The corresponding nonlinear coefficients, i.e. the change of the refractive index per light intensity, are typically 10^{-4} to 10^{-5} cm^2/W in undoped and 10^{-3} cm^2/W in dye-doped nematic liquid crystals[7]. More recently, orientational photorefractive effects were investigated in dye- and fullerene-doped nematic liquid crystals[7,8,9]. This effect occurs under inhomogeneous illumination, usually realized with optical interference patterns obtained by degenerate two- or four-wave mixing[10]. The photorefractive effect is based on photo-induced space charge fields which occur as a consequence of the periodic illumination and spatial modulations in conductivity and dielectric anisotropies.

A related, highly sensitive photoelectric reorientation process was also observed and reported with certain undoped nematic liquid crystals of discotic molecules very recently[1,2,3]. In the present paper, we present first results of this new photoelectrical reorientation effect obtained with undoped nematic liquid crystals of certain rod-like molecules. The effect is also based on the photoexitation of space charges but not dependent on a spatially inhomogeneous illumination of the liquid crystal cell.

EXPERIMENTAL

The investigations were carried out with nematic liquid crystal films of 5 μm thickness, filled into commercially available EHC cells. DC electric fields were applied across the film with the help of transparent ITO (Indium-Tin-Oxide) electrodes which were covered with uniaxially rubbed polymer (PI) layers to provide uniform planar alignment of the sample. The material under investigations was a mixture of 1,4-bis(4-alkylphenyl)butadiynes as shown in Fig. 1. A mixture of the homologues n = 6, 8, and 10 at a ratio of 1:1:1 was used and the temperature range of the nematic phase is 22.5 °C to 77.8 °C.

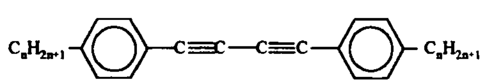

Fig. 1 Molecular structure of the investigated mesogens.

Upon electrical fields exceeding the Fréedericks threshold, reorientation of the planarly aligned liquid crystal and hence the optical axis is achieved, since the dielectric anisotropy $\varepsilon_{\parallel} - \varepsilon_{\perp} > 0$. The resulting changes in birefringence were detected with a linearly polarized weak HeNe laser by monitoring the transmitted intensity components $I_{\parallel}$ and $I_{\perp}$ behind a polarizer (see Fig. 2). The optical axis of the liquid crystal sample was always adjusted to 45 deg with respect to the probe polarization. Furthermore, the probe laser was focussed to a much smaller spot compared with the excitation beam to ensure that the detected change in birefringence was almost homogeneous. An Argon-ion laser beam with wavelengths between 458 nm and 514 nm was used for the optical excitation. It must be noted, that it has been proved that the wavelength of the probe light does not affect the investigated photoelectrical reorientation process.

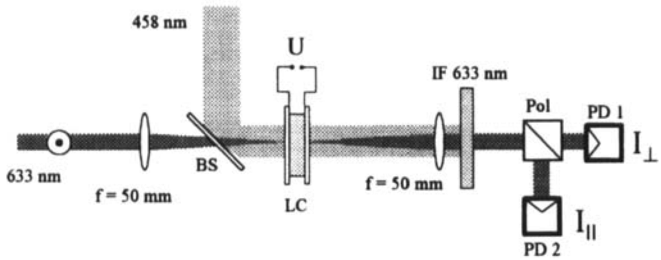

Fig. 2 Experimental Setup

During the experiments the relative intensities $I_\perp$ and $I_\parallel$ are measured as a function of the applied DC-voltage and the well-known behaviour for the transmission of two crossed polarizers containing a medium of varying birefringence in between is obtained. The output intensity oscillates between the parallel and perpendicular state of polarization according to the varying phase shift δ between the ordinary and extraordinary polarized component of the wave. The phase shift δ has been calculated from these transmission curves (see e.g. Ref. 12) and the birefringence can then be obtained as

$$\Delta n = \frac{\delta\lambda}{2\pi d}, \tag{1}$$

where λ is wavelength and d the thickness of the sample.

The effect under investigation appears in an *additional* reorientation when the liquid crystal sample is illuminated with light.

RESULTS AND DISCUSSION

In a typical experiment, the applied DC voltage was first adjusted and fixed to a certain value slightly beyond the Fréedericksz transition threshold. The effective birefringence of the sample was then clearly decreased by additional illumination with the Ar-laser, depending on the light intensity as displayed in Fig. 3. Laser powers of 100 μW or less on a spot diameter of 1.1 mm are sufficient to induce a large change in the birefringence. The nonlinear coefficient $\Delta n/I$, i.e. the induced birefringence per optical intensity, has been determined from these results to -0.5 cm^2/W. For comparison, nonlinear coefficients in anorganic photorefractive crystals[13,14] are in the range of only 10^{-5} to 10^{-6} cm^2/W. Very recently, somewhat larger values have been reported with the discotic mesogenes[1,2] and also for the orientational photorefractive effect in dye-doped calamitic nematics[15].

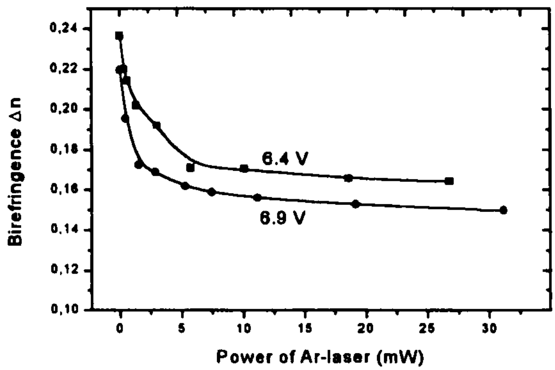

Fig. 3 Photoinduced change in the birefringence

The dynamics of the photo-excited reorientation process were investigated by either gating the voltage or the laser intensity. For purely field-induced reorientation, the observed response times are about 0.1 s. The time constants of the photoinduced reorientation, however, are somewhat larger and range from 1 s to 10 s. As will be discussed in the following, the photoelectric reorientation effect is connected with optically induced space charge fields and the larger response times may result from the recombination of space charges which depends e.g. on the conductivity of the liquid crystal. The calamitic liquid crystals have a low conductivity and, consequently, show response times of 10 s and more. The details for the involved dynamic processes are still under investigations and will be discussed elsewhere.

Furthermore, the photoelectrical reorientation depend on the light wavelength. No effect was observed at 633 nm, as already mentioned above. The nonlinear coefficients increase with decreasing wavelength (Fig. 4). The red edge of the absorption band for the investigated liquid crystal is located at 360 nm. Obviously, the dependence on the wavelength is connected with the absorption of the pump light and the excitation of the liquid crystal molecules.

Comparing the investigated calamitic and discotic mesogens, the nonlinear coefficients due to photoelectrical reorientation were almost one order of magnitude larger[1,2] with the discotic material. However, this comparison is not really fair because the relative spectral position of the Ar-laser excitation was almost 100 nm closer to the absorption band with the discotic molecules. It must be noted further, that the calamitic mixture was obviously prepared with a higher purity resulting in a lower conductivity of about 10^{-11} $\Omega^{-1}m^{-1}$ com-

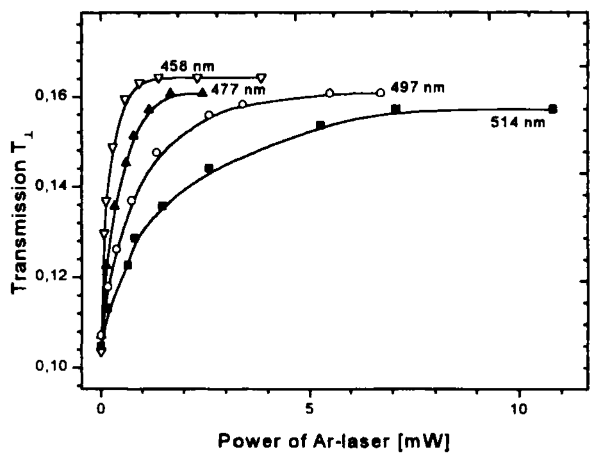

Fig. 4 Dependence of the photoinduced reorientation effect on the wavelength

pared with $10^{-8}\ \Omega^{-1}m^{-1}$ for the discotic samples.

The observed reorientation effect can be explained[1] by space charge fields which result from optical excitation of the molecules and creation of photo-charge carriers of different mobility. The mobility of holes is mainly given by the mobility of ions in the nematic phase and almost negligible compared to the mobility of the electrons. The latters can be assumed to migrate in a conduction band-like electronic state, similiar as in amorpheous semiconductors. As a result, the photoexcited electrons are removed by the external electric field, whereas the ions basically remain at their positions.

A clear proof for the creation of photoexcited charge carriers was found in a pronounced photoconductivity which is shown in Fig. 5.

The additional space charge field $\vec{E}_{sc}$ enhances the electric field across the liquid crystal film. The photoelectric reorientation effect can therefore be attributed to the additional electrical torque onto the molecules. In the case of weak intensities, i.e. without saturation effects, the space charge density $\rho(z)$ can be assumed to be proportional to the local light intensity which is exponentially decreasing across the liquid crystal sample due to absorption, i.e.

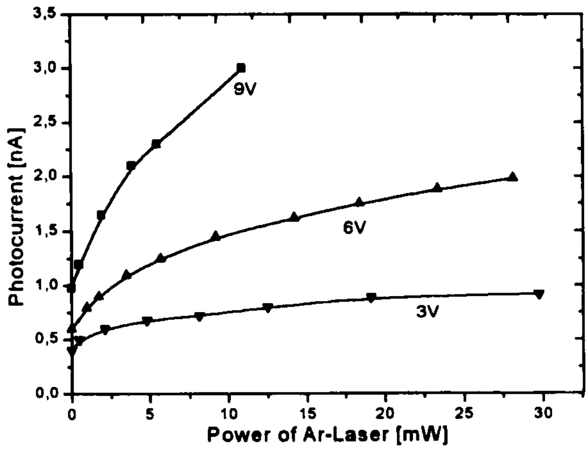

Fig. 5 Dependence of the DC-current across the sample on the Ar-laser intensity for three different voltages.

$$\rho(z) = \rho_0 \exp(-\alpha z) \qquad (0 < z < d); \tag{2}$$

where α is the absorption coefficient. With the well-known Maxwell equation $\vec{\nabla} \cdot \vec{D}_{SC} = \rho$ the electric displacement $\vec{D}_{SC}$ can then be calculated to:

$$\vec{D}_{SC}(z) = \frac{\rho_0}{\alpha}\left[\tfrac{1}{2} - \exp(-\alpha z) + \tfrac{1}{2}\exp(-\alpha d)\right] \cdot \vec{z}_0 . \tag{3}$$

According to eqn. 3 the external electric field is shielded and diminished by the space charge field near the positive electrode ($z \approx 0$) but enhanced in the center ($z \approx d/2$) of the sample where the reorientation mainly takes place, if $\alpha > 0$. The amplitude ρ_0 of the space charge field depends on the input intensity. Furthermore, the absorption coefficient has a strong influence on the space charge field. This explains the dependence of the effect on the wavelength. The used wavelengths are close to red edge of the absorption band of the liquid crystal. Accordingly, the absorption increases with shorter wavelengths and the space charge field becomes stronger in agreement with the experimental findings.

The effective voltage U_{SC} caused by the space charge field was determined by illuminating the sample at different powers and by readjusting the external voltage to a certain birefringence. The difference in the external voltage with illumination and without corresponds to the additional space charge field. A typical value of $U_{SC} = 1.5$ V was obtained at $I = 10^{-2}$ W/cm^2.

CONCLUSION

A very sensitive photoelectrical reorientation effect has been investigated in nematic liquid crystals of calamitic molecules. A considerable reorientation was even induced with very weak light intensities of 10^{-3} to 10^{-2} W/cm^2, supported by DC-electrical fields of 0.5 to 2 V/μm. Huge nonlinear coefficients up to -0.5 cm^2/W have been determined. The effect is explained to result from molecular reorientation by photoinduced space charge fields. In contrast to well-known photorefractive effects, no two-wave mixing and even no coherent light is required. Applications like optically controlled spatial light modulators

and adaptive lenses or all-optical sensors may be realized on the basis of this new photoelectric reorientation effect.

Acknowledgements
We thank Prof. G. Heppke, Ivan-N.-Stranski-Institut, TU Berlin, for supplying the liquid crystals. This research was partially supported by the Deutsche Forschungsgemeinschaft via the SFB 335 "Anisotrope Fluide".

References

[1] R. Macdonald, P. Meindl, G. Chilaya, D. Sikharulidze; "Photoexcitation of space charge fields and reorientation of a nematic liquid crystal of discotic molecules"; *Optics Commun.* **150,** 195 (1998)
[2] R. Macdonald, P. Meindl, G. Chilaya, D. Sikharulidze; "Reorientation of a nematic liquid crystal of discotic molecules by photoinduced space charge fields" ; *Mol. Cryst. Liq. Cryst.* (in press, 1998)
[3] D. Sikharulidze, G. Chilaya, K. Praefcke, D. Blunk; *Liquid Crystals* **23,** 439 (1997)
[4] I.C. Khoo; *Liquid Crystals: Physical Properties and Nonlinear Optical Phenomena* ; Wiley Interscience, New York (1995)
[5] H.J. Eichler et al.; *Physica* **A 174,** 94 (1991)
[6] I. Janossy and T. Kosa; *Opt. Lett.* **17,** 1183 (1992)
[7] I.C. Khoo; *IEEE J. Quant. Electr.* **32,** 525 (1996)
[8] I.C. Khoo; *Optics Lett.* **20,** 2137 (1995)
[9] I.C. Khoo; *Optics Lett.* **19,** 1723 (1994)
[10] B.D. Guenther and I.C. Khoo; *Proc. SPIE* **3143,** 191 (1997)
[11] D. Ianetz, K. Praefcke, D. Singer; *Liquid Crystals* **13,** 247 (1993)
[12] I.C. Khoo; *Optics and Nonlinear Optics of Liquid Crystals;* World Scientific, London (1993)
[13] P. Günther and J.-P. Huignard; *Photorefractive Materials and their Applications I*; in Topics in Applied Physics 61, Springer-Verlag, Berlin (1988)
[14] P. Yeh; *Introduction to Photorefractive Nonlinear Optics;* John Wiley & Sons, Inc., New York (1993)
[15] I.C. Khoo et al.; *Optics Lett.* **23(4),** 253 (1998)