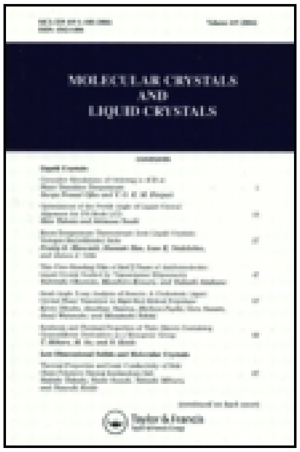

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

Optical Power Limiting by Liquid Crystals in Glass Capillary Arrays

H. J. Yuan [a b] , H. Lin [a] , L. Li [a] & P. Palffy-muhoray [a]

[a] Liquid Crystal Institute, Kent state University, Kent, OH, 44242, U.S.A.

[b] Crystaloid Electronics, 5282 Hudson Drive, Hudson, OH, 44236, U.S.A.

Version of record first published: 04 Oct 2006.

To cite this article: H. J. Yuan , H. Lin , L. Li & P. Palffy-muhoray (1992): Optical Power Limiting by Liquid Crystals in Glass Capillary Arrays, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 223:1, 229-239

To link to this article: http://dx.doi.org/10.1080/15421409208048254

Mol. Cryst. Liq. Cryst. 1992, Vol. 223, pp. 229–239
Reprints available directly from the publisher
Photocopying permitted by license only

Printed in the United States of America

OPTICAL POWER LIMITING BY LIQUID CRYSTALS IN GLASS CAPILLARY ARRAYS

H.J. YUAN†, H. LIN, L. LI, and P. PALFFY-MUHORAY

Liquid Crystal Institute, Kent state University
Kent, OH 44242, U.S.A.

and

†Crystaloid Electronics, 5282 Hudson Drive
Hudson, OH 44236, U.S.A.

(Received November 6, 1991)

ABSTRACT

Optical power limiting has been observed in glass capillary arrays filled with liquid crystals. This behavior is attributed to optical field induced director reorientation and thermal effects. Dielectric measurements have been carried out to understand the director configurations and director reorientations of the liquid crystals in these near cylindrical glass microcapillaries. Different laser pulse durations from a CW Ar^+ laser and glass capillary arrays with different pore sizes have also been used in the optical power limiting measurements. Possible mechanisms are discussed and the relative contributions of different mechanisms are assessed.

INTRODUCTION

Large optical nonlinearities have been measured[1] in the nematic liquid crystal 5CB and in the smectic liquid crystal 8CB. The large optical nonlinearities of liquid crystals may originate from optical field induced director reorientation, thermal effects, conformational effects, electrostriction effects, and electronic effects.[2] The response times associated with these processes range from ~ 1s to < 1ps, and the relative contributions of various processes vary with laser pulse durations. For a given pulse duration, one or more mechanisms may dominate the nonlinear response.

Large optical nonlinearities can be exploited for optical power limiting (OPL) applications. We have measured the optical power limiting behavior of liquid crystals 5CB and 8CB in glass capillary arrays (GCAs) using a CW Ar^+ laser. Laser pulses with different durations and GCAs with different pore sizes were used in theses measurements. The limiting behavior is due to optical field induced refractive index changes in the liquid crystals.

Dielectric measurements on these samples have been carried out to probe director configurations and reorientational effects.

GLASS CAPILLARY ARRAY CELLS

Figure 1 shows the picture of a glass capillary array (taken through an optical microscope) obtained from Galileo Electro-Optics Co. The GCAs consist of parallel glass capillary tubes fused together in a uniform and mechanically rigid matrix. The GCAs with pore diameters of 2μm, 5μm, and 50μm were used in our measurements. The thickness of the GCAs used in the OPL measurements was 0.50mm.

The liquid crystals 5CB and 8CB from BDH were used without further purification. The GCAs were filled with the liquid crystals in the isotropic phase by capillary action. The fully filled GCAs were sandwiched between glass plates. No surface treatment was carried out for either the GCAs or the glass plates.

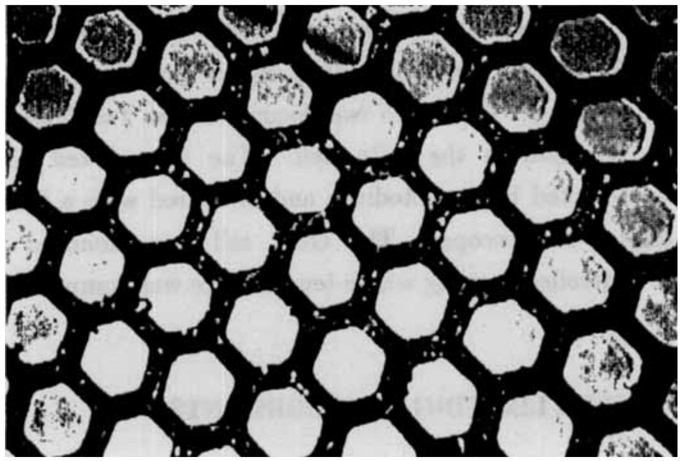

FIGURE 1. Optical micrograph of an empty glass capillary array (GCA) with 50μm pore diameter.

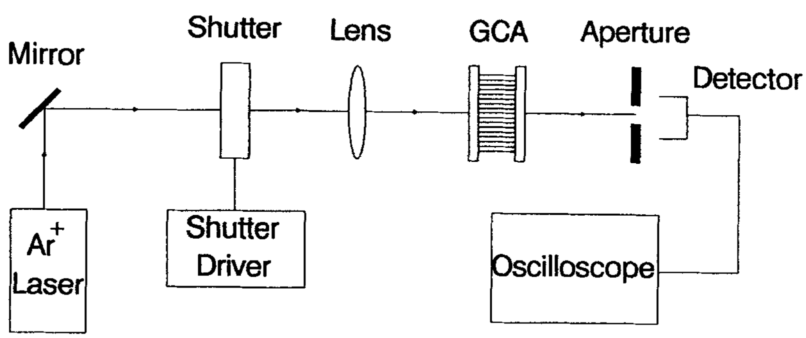

FIGURE 2. Schematic of the experimental setup for optical power limiting measurements. The GCA sample is filled with liquid crystal.

EXPERIMENTAL SETUP

Figure 2 shows the schematic of the experimental setup. A Coherent Innova100 CW Ar^+ laser ($\lambda = 514$nm) was used. The beam was controlled by a Uniblitz VS25 shutter providing nearly square pulses of 10, 15, 30, and 60 millisecond durations. The beam was focused by an f = 50mm f/2 lens to a beam radius of 15μm in the GCA cell. The transmitted power after an aperture was detected by a photodiode and measured with a Hewlett Packard HP54111 digital oscilloscope. The GCA cell was mounted in an Instec temperature controlled housing whose temperature was computer controlled.

OPTICAL POWER LIMITING MEASUREMENTS

The time averaged transmitted power after the aperture was measured as function of the incident power. Figure 3 shows the optical power limiting behavior of the GCA cell with pore diameter of 5μm, filled with 8CB at 23°C, measured with laser pulse durations 15ms and 60ms, respectively. The results show lower threshold power when longer pulse duration is used. The thresholds are $1.3 \times 10^8 W/m^2$ and $4 \times 10^7 W/m^2$ for pulse durations of 15ms and 60ms, respectively.

Figure 4 shows the optical behavior for the GCA cell with 5μm pore diameter filled with liquid crystal 5CB and using the same laser pulse duration of 15ms, but at different sample temperatures. The limiting behavior is enhanced as the cell temperature approaches the nematic-isotropic transition temperature. Both the threshold and output power at limiting become lower as the cell temperature approaches the transition.

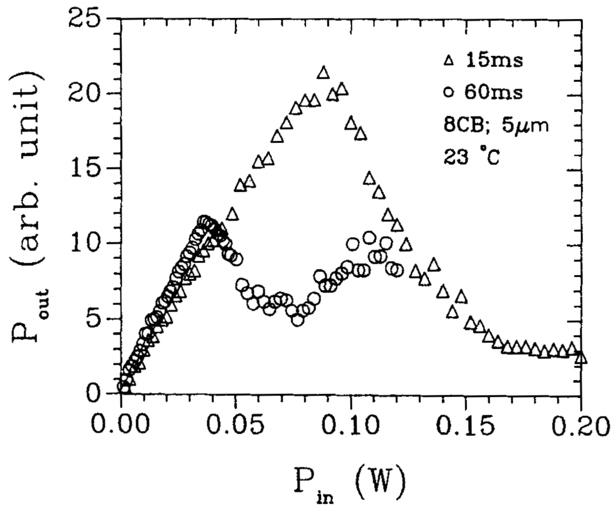

FIGURE 3. Optical power limiting behavior of the GCA cell with $5\mu m$ pore diameter and filled with liquid crystal 8CB. Cell temperature was 23°C. Laser pulse durations of 15ms and 60ms were used.

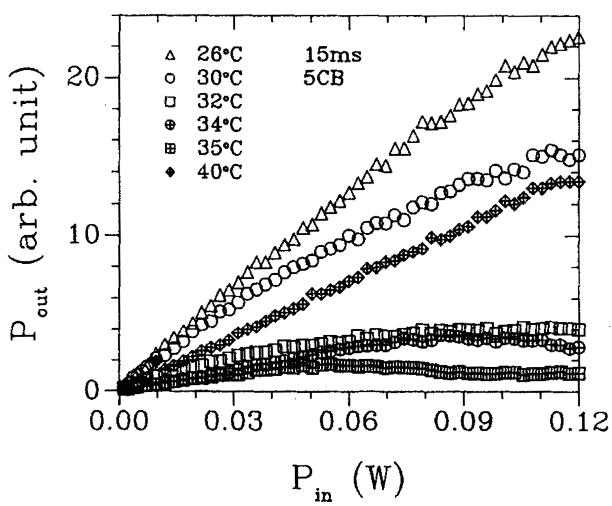

FIGURE 4. Optical behavior of the GCA cell with $5\mu m$ pore diameter and filled with liquid crystal 5CB. Laser pulse duration of 15ms was used. Measurements are shown at different temperatures.

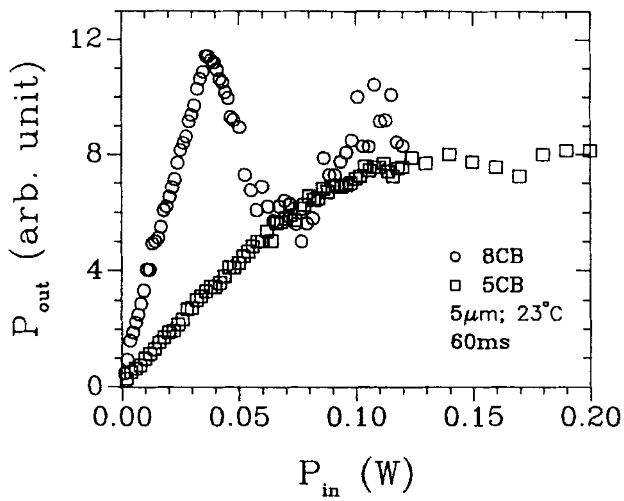

FIGURE 5. Optical power limiting behavior of 5CB and 8CB filled in identical GCAs with 5μm pore diameter measured at 23°C. Laser pulse duration of 60ms was used.

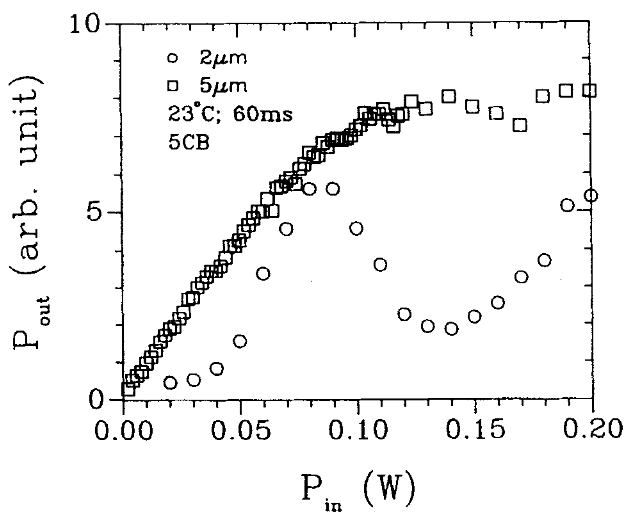

FIGURE 6. Optical power limiting behavior of 5CB filled in GCA cells with 2μm and 5μm pore diameters measured at 23°C. Laser pulse duration of 60ms was used.

Figure 5 shows the optical power limiting behavior of 5CB and 8CB filled in identical GCAs with pore diameter of 5μm at 23°C. Pulse duration of 60ms was used. The threshold for 8CB is about 3 times lower than that for 5CB.

Figure 6 shows the optical power limiting behavior of 5CB filled in GCA cells with 2μm and 5μm pore diameters at 23°C. The thresholds are not very different for these two cells. The large oscillation in the P_{out} versus P_{in} curve is related to temporal oscillations of the transmitted beam.

DIELECTRIC MEASUREMENTS

There are two expected uniform director configurations in a cylindrical cavity.[3-5] Figure 7 shows the axial and radial structures. Previous calculations[3] show that GCA cells with pore diameter $\geq 1\mu$m favor the axial structure.

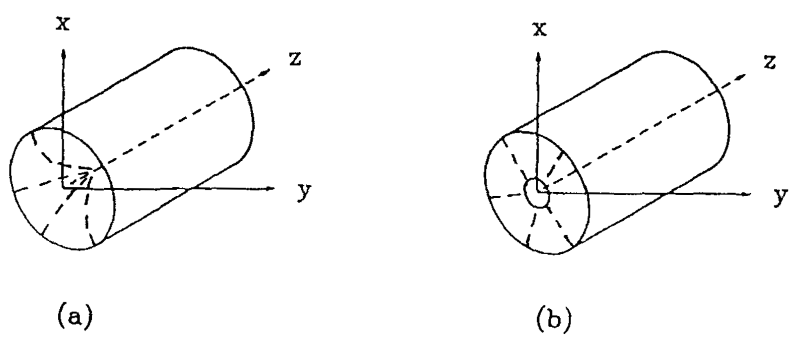

FIGURE 7. Illustrations of different director configurations of a liquid crystal filled in a cylindrical cavity. (a) Axial structure; (b) radial structure.

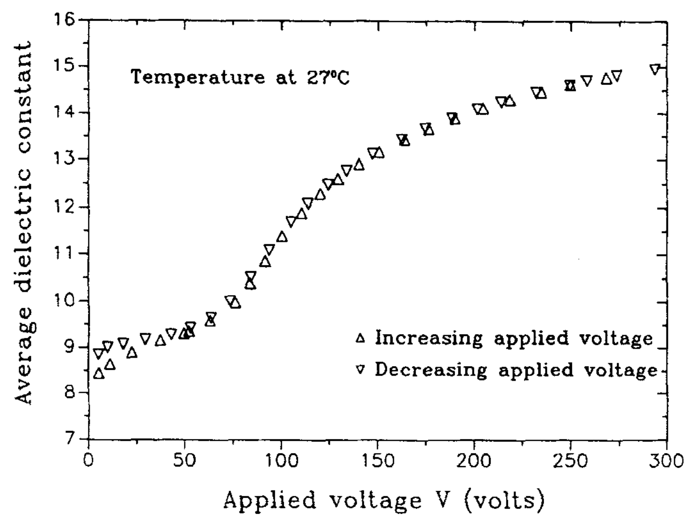

FIGURE 8. Measured average dielectric constant as a function of applied voltage for a GCA cell filled with 5CB. The cell temperature was 27.0°C.

Figure 8 shows the measured average dielectric constant as a function of applied voltage for a GCA cell filled with 5CB. The GCA cell has 50μm pore diameter and is 3mm thick. The temperature of the cell was controlled at 27.0 $\pm$ 0.1°C. Significant director reorientation occurred at $\sim$100V. By minimizing the free energy of the system including elastic, anchoring and external field terms we calculated the director orientation as a function of applied voltage and the results are shown in Figure 9. The lines correspond to different applied voltages. The angle θ is defined as the angle between director and the symmetric axis and R is the pore radius. The finite surface anchoring strength W is chosen to give $(W/K)R = gR = 36$ where K_1 is the splay elastic constant.

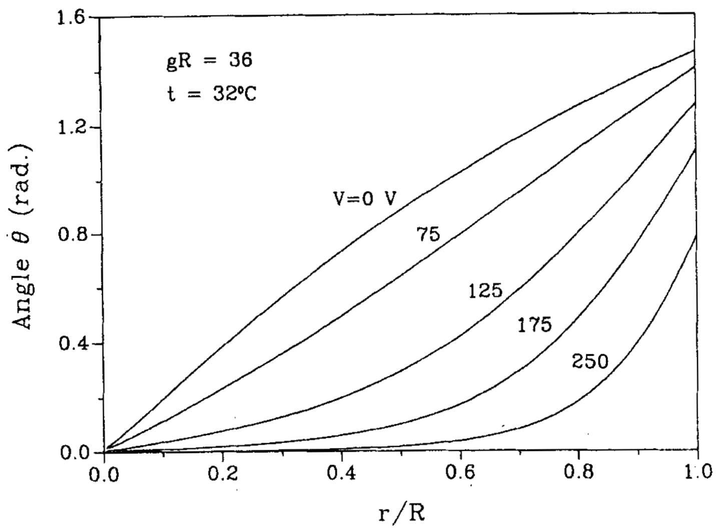

FIGURE 9. Calculated director orientation as a function of applied voltage. θ is the angle between director and cylindrical symmetry axis and R is the pore radius.

DISCUSSION AND CONCLUSIONS

Dielectric measurements indicate that an applied low frequency electric field gives rise to significant director reorientation for $E \geq 3 \times 10^4 V/m$. Although the field directions are different, we expect optical field induced reorientation at fields comparable to this; that is, at intensities $\geq 10^7 W/m^2$.

The optical power limiting due to reorientation and thermal effects can be estimated with known material parameters. The threshold and time constant for thermal effects are

$$I_{th}^{c} \approx \frac{\lambda\, c_V}{2\, \frac{\partial n}{\partial T}\, \alpha\, \tau\, L} \approx 10^8 W/m^2, \quad \tau_{th} \approx \frac{d^2}{D} \approx 3ms; \tag{1}$$

where λ is the wavelength of laser beam, c_V is the specific heat per volume for liquid crystal, $\frac{\partial n}{\partial T}$ is the thermo-optic coefficient in nematic, α is the linear absorption coefficient, τ is the laser pulse duration, L is the sample thickness, d is the laser beam radius, and D is the thermal diffusivity. The threshold and time constant for director reorientation are

$$I_{re}^{c} \approx \frac{c\,K\,\lambda}{(\Delta n)^2\, r^2\, L} \approx 10^8 \mathrm{W/m^2}, \quad \tau_{re} \approx \frac{\gamma\, c}{\Delta n\, I} \approx 10^2 \mathrm{ms}. \tag{2}$$

where c is the speed of light in vacuum, K is the elastic constant, Δn is the birefringence, r is the pore radius of a GCA, γ is the viscosity coefficient, and I is the incident laser intensity. The estimated thresholds are in agreement with our measured values.

The measured thresholds show weak pore size dependence and strong temperature dependence, which suggests that the thermal effects dominate the optical power limiting process in our measurements. We have observed the optical power limiting in isotropic phase with comparable incident intensity, which also suggests that the thermal effects dominate.

For incident intensity higher than threshold we observed oscillation in the transmitted pulse temporal profile and the characteristic time of the oscillation becomes shorter for higher intensity, which suggests that the director reorientation contributes significantly at higher incident intensity. Details of the mechanisms are not understood at this time.

ACKNOWLEDGEMENT

This work was supported in part by DARPA through US Army CECOM Center for Night Vision and Electro-Optics, contract DAAB07-88-C-F421, and by the National Science Foundation Science and Technology Center ALCOM DMR89-20147. The authors would like to thank D. Finotello for providing the glass capillary arrays. The authors would also like to thank G. Hu for help to take part of the experimental data.

REFERENCES

1. H.J. Yuan, L. Li and P. Palffy-Muhoray, Mol. Cryst. Liq. Cryst., **199**, 223 (1991).
2. P. Palffy-Muhoray, in *Liquid Crystals: Applications and Uses*, Edited by B. Bahadur (World Scientific, Singapore, 1990).
3. H. Lin, P. Palffy-Muhoray and M.A. Lee, Mol. Cryst. Liq. Cryst., **204**, 189 (1991).
4. P.E. Cladis and M. Kleman, *J. de Physique*, **33**, 591 (1972).
5. R.B. Meyer, *Phil. Mag.* **27**, 405 (1973).