DEPENDENCE ON PUMP POWER AND CELL THICKNESS OF THE ANCHORING BREAKING TIME IN DYE-DOPED NEMATIC LIQUID CRYSTALS

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We present a study on director reorientation and anchoring breaking time in a pump-probe experiment for dye-doped nematic liquid crystal cells with different pump power and cell thickness. The liquid crystal (LC) used was 4'-n-pentyl-4-cyanobiphenyl (5CB) doped with the dye methyl red (MR). An Ar^+ laser beam were used to irradiate the liquid crystal cells with a parallel beam and the twisted nematic structure was investigated with a He-Ne laser beam. We considered LC cells with thickness equal to 8, 12 and 23 μm filled with 5CB doped with 2% MR. The results had shown that the nematic director is rotated only after a certain time interval, from the moment when the irradiation started. This time is named anchoring breaking time and it decrease as the intensity of the pump power was increased. A linear dependence between the anchoring breaking time and inverse of the pump power was observed for different cell thickness.

Keywords: nematic liquid crystal, photoalignment, anchoring breaking time, cell thickness

1. Introduction

Photoalignment of LC on the different substrates, based on polarized laser light irradiation, is a modern technique for creating liquid crystal displays (LCDs), which will deliver images with higher quality [1]. Some study was focused on the behaviour of a ferrocholesteric liquid crystal in magnetic and laser external fields, taking into account the influence of the molecular anchoring to the solid boundaries [2,3,4].

The photoalignment processes have considerable advantages when

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compared with the conventional rubbing processes; this is because it is a noncontact method and could create surfaces with specific anchoring energy [5]. This non-contact method also does not induce a mechanical stress on the polymeric surfaces of the inner cell surfaces.

Many prototypes of photonic LC devices have been created based on the photo-alignment process [6]. Numerous reports have shown the creation of holographic devices based on photoaligned nematic LC [7,8]. The photoalignment permits the reorientation of the nematic director of a cell already filled with LCs.

If only the nematic LC is used to fill the test cell, a high intensity light beam is needed to rotate the director of the nematic structure formed inside the cell [6]. By adding a small concentration of dyes, the interaction of the LC mixture with the light beam will highly increase.

The light-induced dye adsorption on the control surface (Sc), leads to the accumulation of dye molecules on the substrate. The new created twist nematic structure will be locked in by the previously described process. At nanometric scale, a highly uniform orientated layer like a ripple structure is created and another unwanted deposition of molecule aggregates [9].

The previous research of our group had identified the appropriate parameters for creating the large surfaces covered with ripple structures based on the adsorption of the methyl-red dye from the mixture [10]. The transmitted intensity of the probe beam was recorded *in situ* by a pump-probe experiment, in high intensity regime, so precious information regarding the moment in time when the nematic director starts to rotate, and also the cis-trans relaxation behavior, were obtained by Palarie et al. [10] and Varut et al. [11].

Furthermore, in *situ* measurements shown that the nematic director is rotated back-and forth, for a short period of time, when the pump laser polarization is parallel to induced easy axis. An orthogonal setup will exhibit a completely different behavior [12].

Also from the irradiation process dynamics point of view, we observed that anchoring breaking time increases, with the roughness of the control surface (S_C) [13]. A systematic study regarding the influence of the concentration of the dye, performed by Palarie et al. [14], had shown that the MR concentration in 5CB doped with MR need to be greater than a threshold value. For a pump power of 12 mW, the value of MR concentration had to be greater than 0.79 % by wt. If the pump power is increased to 20 mW, the threshold stops to exist.

2. Experimental details

The experiments were realized at a temperature of 25^{o}C by using standard sandwich glass cells (2x2 cm useable aria) filled with a mixture of a nematic LC 5CB and *azo* dye MR as a dopant. An alignment film of polyvinyl alcohol (PVA),

was deposited on the inner surfaces of the cell through spin-coating method [9]. An easy axis was induced by unidirectional rubbing of both surfaces (Figure 1B). These inner rubbed surfaces of the cells were aligned parallel one with each other, which imposed a planar alignment of the nematic director inside the LC cells. In Figure 1A the experimental setup is exposed with permission of autors [11].

Each cell was placed perpendicular to the exciting beam of an Ar^+ laser (of type INNOVA 308C) working at wavelength $\lambda = 476.5$ nm, with a TEM_{00} beam diameter of 1 mm.

The pump power, *P*, was measured with a power-meter Field Max II-Top, from Coherent. The pump powers chosen for this experiment had values between 5 and 30 mW. The irradiation time was, in general, 9 minutes long. The mean intensity of the pump beam, in the irradiated areas, had a 250 mW/cm^2, rough value. This value indicates a high intensity regime irradiation.

The transmittance of each cell irradiation zone was probed by 1mW power JDS Uniphase 1508-0 Novette He-Ne laser, at 632.8 nm. The laser beams from the both lasers were concentric and had opposite directions. The polarization direction of the probe laser beam was established by the polarizer P_1, parallel to the easy axis imposed through rubbing of the PVA layer.

From the point of view of the *in situ* analysis of the irradiated zone, the cell was practically placed in a cross-polarizer configuration. The pump laser wavelength was chosen to be heavily absorbed by the MR and the probe laser had a wavelength for which the MR dye has a low absorption (Figure 1C). Three cells were used for this study; the cell thickness was 8, 12 and 23 μm respectively. The cells were filed with 5CB + 2% MR and irradiated immediately after the filling process.

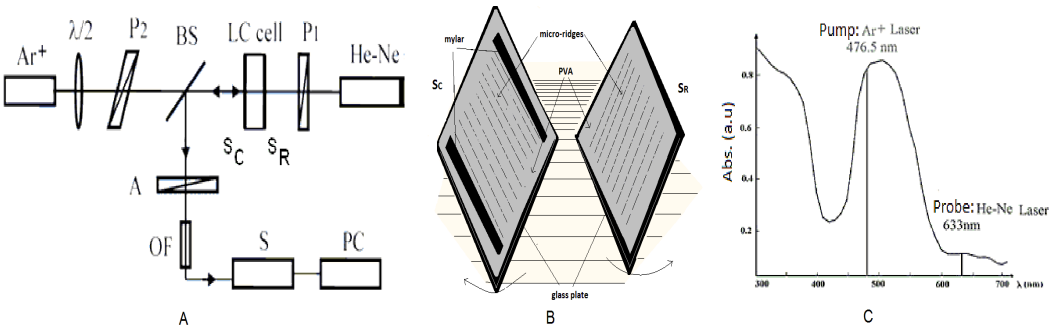

Fig. 1. A) Experimental setup; B) The graphic representation of LC cell; C) Absorption spectrum for MR dye, the wavelength of the lasers are also shown.

2. Results and discussions

By putting an amount of energy in the dye- LC mixture, different processes take place. The most important process is light absorption which gives

birth to another process of isomerization of the dye. The *trans*-isomer is converted to *cis* by light absorption, a processes characteristic to *azo* dyes. The *cis*-isomer comes back to *trans*-form after an interval of time through a relaxation process. This is the reason what we considered a threshold pump power, and from earlier measurements [15] we know that this threshold depends by cell thickness and dye concentration.

At lower intensities, laser pump do not accumulate enough *cis*-isomer to create sufficient optical torque needed to break the LC-bond with substrate (PVA). For a pump power less than 5 mW was not possible to identify a value for anchoring breaking time (t_b) so the signal remained relatively constant. All the pump powers used were greater than 5mW to ensure that we are above the threshold. At a higher pump power, a high concentration of MR *cis*-isomer will accumulate and give rise an optical torque that will make the twist the nematic (TN) structure and the adsorption of the dye on the PVA substrate.

In Fig. 2A, 3A and 4A, we shows the experimental values for probe intensities vs. time for 8, 12 and respectively 23 μm cell thickness. The breaking time (t_b) was determined using same procedure described in paper [16].

The anchoring energy is a constant value depending on the substrate type (PVA layer) and, especially, by its surface. In Figure 2B, 3B and 4B we plot a linear dependence of the braking time, t_b, versus inverse of laser power.

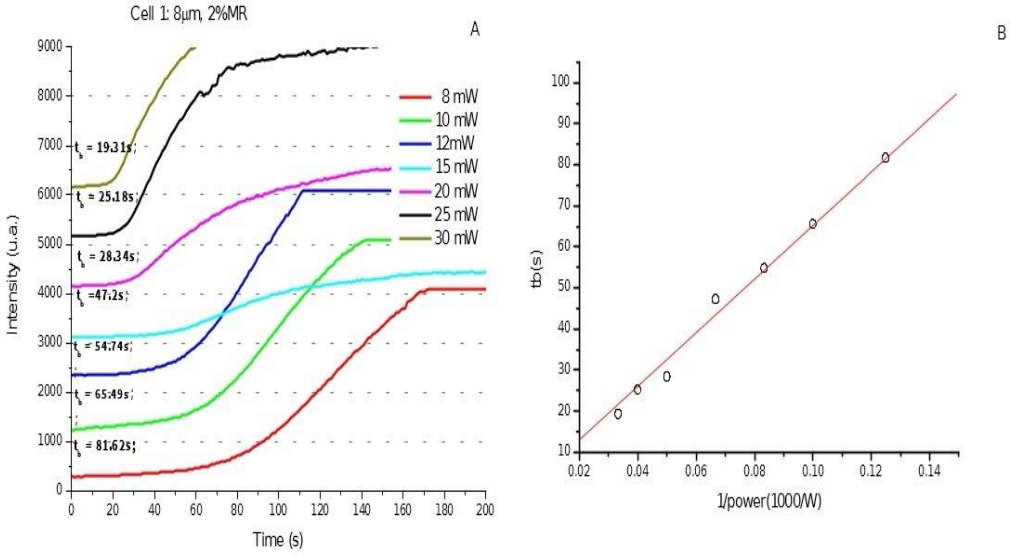

Fig. 2. A) Time evolution of probe signal for 8, 10, 12, 15, 20, 25, and 30 mW for 8 μm cell thickness. B) Linear dependence of t_b on the inverse of pump power $t_b=651.92/power$, $R^2=0.9974$.

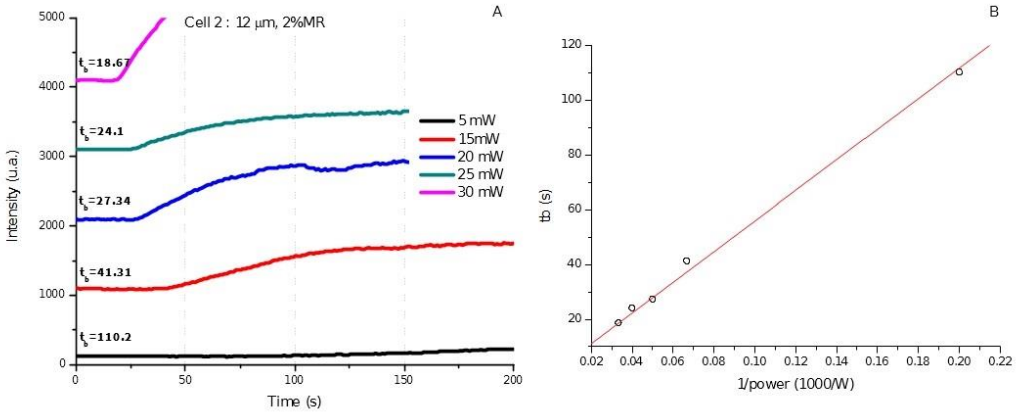

Fig. 3. A) Time evolution of probe signal for 5, 15, 20, 25, and 30 mW for 12 µm cell thickness. B) Linear dependence of t_b on the inverse of pump power $t_b=558.79/power$, $R^2=0.9982$.

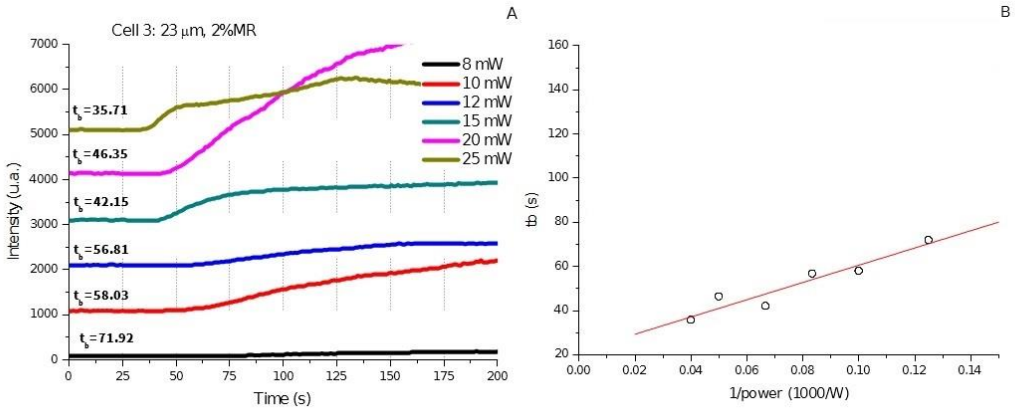

Fig. 4. A) Time evolution of Pump-probe signal for 8, 10, 12, 15, 20, and 25 mW for 23 µm cell thickness. B) Linear dependence of t_b on the inverse of pump power $t_b=390.61/power+21.55$, $R^2=0.8884$.

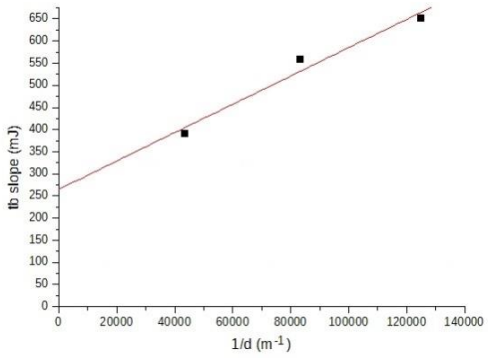

Fig. 5. Reciprocal cell thickness dependence of the "tb slope" parameter extracted from the linear fit of the anchoring breaking time vs. inverse pump power from Figure 2B, 3B, and 4B, *tb slope=0.0032/d+265.33*, $R^2=0.9379$.

This good linear dependence gives us a strong reason to generate, in the next paragraph, a theoretical model for this behavior. Making the approximation that the absorbed energy is used to break the anchoring energy (E_A), we can write that, at t_b time:

$$E_A = \frac{kP_A t_b}{S}\ , \tag{1}$$

where: P_A – the laser power absorbed by the irradiated volume, k – efficiency constant, S – Surface of the irradiation area.

Taking into account that the Lambert-Beer law for laser beam is:

$$I = I_0 10^{-\varepsilon(\lambda)\cdot c\cdot d}, \tag{2}$$

where: I_0 - incident light intensity, I - transmitted light intensity by the cell material, c - MR dye concentration, d - cell thickness, ε(λ) - molar attenuation coefficient.

Knowing that the laser beam diameter is constant (~1mm), and assuming that $I=P/S$, we obtain:

$$P = P_0 10^{-\varepsilon(\lambda)\cdot c\cdot d}\quad . \tag{3}$$

The absorbed power, P_A, can be written like this:

$$P_A = P_0[1 - 10^{-\varepsilon(\lambda)\cdot c\cdot d}]. \tag{4}$$

Assuming that P_A is used by dye to create a sufficient optical torque needed to break the anchoring of the nematic structure (on Sc surface) and rotate the LC, by transferring energy in the nematic structure with some efficiency given by k,

$$t_b \cdot \mathrm{P}_0 \cdot \left[1 - 10^{-\epsilon(\lambda)\cdot \mathrm{c}\cdot \mathrm{d}}\right] = \frac{E_A \cdot \mathrm{S}}{k}. \tag{5}$$

We obtain linear form of $t_b=f(P_0)$,

$$t_b = \frac{E_A \cdot S}{k} \cdot \frac{1}{[1-10^{-\varepsilon(\lambda)\cdot \mathrm{c}\cdot \mathrm{d}]}} \cdot \frac{1}{P_0}, \tag{6}$$

with parameter "tb slope" independent to t_b

$$t_b\ slope = \frac{E_A \cdot S}{k} \cdot \frac{1}{[1-10^{-\varepsilon(\lambda)\cdot \mathrm{c}\cdot \mathrm{d}}]}. \tag{7}$$

When [-ε(λ)c d]->0, the function $1/[1\text{-}10^{-\varepsilon(\lambda)c\,d}]$ is well approximated by $\frac{ln10}{\varepsilon(\lambda)\cdot \mathrm{c}\cdot \mathrm{d}}$. Then, we obtain, in this approximation, the linear dependence of slope vs. reciprocal cell thickness:

$$\mathrm{tbslope} \simeq \frac{E_A \cdot \mathrm{S}}{k} \cdot \frac{\ln(10)}{\epsilon(\lambda)\cdot \mathrm{c}} \cdot \frac{1}{d}. \tag{8}$$

From Fig. 2B, 3B and 4B we extract "t_b *slope*" parameter for each cell with different thickness and we use this for confirm above assumption: linear dependence of t_b *slope* vs. *1/d*, (see Fig. 5).

The theoretical model, represented by eq. 6, can be used to estimate the laser pump efficiency of the dye molecule (k) and also to estimate molar attenuation coefficient. Above all of this, we can calculate accuracy of the theoretical model for all experimental data. . Using nonlinear regression of eq. 6,

we obtain above parameters: $\frac{E_A}{k} = 0.5966\,J$, $\varepsilon(\lambda)\cdot c = 0.153\cdot 10^6 m^{-1}$ with good confidence, R^2=*0.9861* (see Fig. 6).

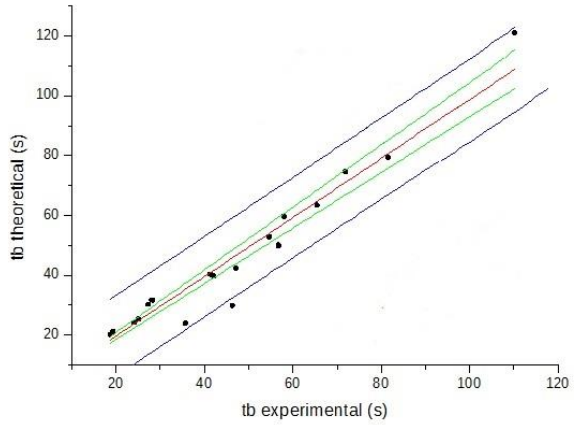

Fig. 6. Theoretical t_b versus experimental t_b. Red line -linear dependence, green lines - confidence bands 95% and blue lines - prediction bands 95%.

4. Conclusions

The study results indicate that the anchoring breaking time, t_b, decrease with the increases of the pump power, for a cell thickness fixed. We remark a good linear dependence of t_b and the inverse of pump power.

The slope of this linear dependence decreases if the thickness of the cell increases. More than that, the slope of t_b vs. *1/P* is proportional with reciprocal thickness. Based on this observation we develop a theoretical model for evolution of t_b with *P*, *c* and *d*. In the next paper, remain to explore this model relative to the dye concentration, *c*. Our results are in a good agreement with the result reported in paper [17].

Acknowledgements

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