Dynamics of azo-dye-doped liquid crystals

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Two novel approaches enable better insights into liquid-crystal photoalignment.

Because of their potential importance for photoalignment, azo-dye-doped liquid crystals (ADDLCs) have been studied extensively over the past decade. Photoalignment of liquid-crystal (LC) molecules can avoid unnecessary contamination due to mechanical rubbing. When ADDLC cells are exposed to certain wavelengths, azo-dye molecules on a surface diffuse, adsorb, and desorb sequentially because of photoisomerization.¹⁻⁵ This causes LC-structure reorientation by excited dye molecules. In related studies, the optical characteristics of ADDLC photoexcitation have been obtained on the basis of pump-probe twist-nematic experiments.^{1,2} To better understand the transient as well as the permanent behavior of ADDLCs, here we present two novel approaches to observe the reorientation of LC molecules on short⁵ and long timescales,⁶ respectively.

The dye-adsorbed layer is formed during photoalignment. The dye molecules can interact with the surrounding LC molecules through intermolecular forces. As a result, the LC's director (i.e., the LC structure's preferred direction) is reoriented perpendicular to the pump field.⁷ After irradiation of the sample for a sufficiently long period, a ripple structure is generated parallel to the pump field.⁷ To explore the structural variation of the dye-adsorbed layer, we channeled unpolarized light into a traditional pump-probe twist-nematic experiment, (which is generally used for observing light scattering during formation of the dye-adsorbed layer). The transmitted probe light was scattered during photoexcitation because of the dye's adsorption. Because the ripple structure is formed gradually, it is regular, thus enhancing the dye's surface anchoring (see Figure 1). At the same time, Rayleigh scattering from isolated (or separated) dye-adsorbed grains changes to Mie scattering since the regular ripple structure has a similar spatial scale as the wavelength of the incident light. The increase in transmission intensity is more centralized for Mie than for Rayleigh scattering in the presence of the regular ripple structure.⁸ After the ripple structure

Figure 1. Reorientation angle, $\phi(t)$, and transmitted intensity (in arbitrary units, a.u.), $T(t)$, for an irradiation time of 40hr. Inset: Experimental setup. ADDLC: Azo-dye-doped liquid crystal.

has formed, the dye molecules' adsorption increases the depth of the grooves, which in turn enhances the surface-anchoring coefficient. The Mie scattering does not vary significantly because the spacing of the ripple structure remains the same in the optical view. Our experimental results verify that the formation of the ripple structure correlates with light scattering induced by adsorption of dye molecules on the surface.

Attenuated total-reflection (ATR) measurements are highly sensitive to variations in the dielectric constants close to the surface (approximately 100nm from the surface in LC systems) within the depth of the evanescent wave, which is not affected by the elastic continuum.⁹ Our pumped-ATR experiments result in improved measurements compared to the traditional ATR approach. We channeled green pump light—accompanied by a red probe beam—into the ATR structure in the so-called 'pumped-ATR' experiment (see Figure 2). A lens expands the pump light to ensure that the incident area of the pump beam contains that of the probe beam. For real-time analysis, we observed the reflec-

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Figure 2. Response time, T_r , of the photoexcitation of the ADDLC cell in the pumped-ATR experiment. Inserts: Configuration of the pumped-ATR experiment (left), and fixed angle used for the in situ pumped-ATR experiment (right). ITO: Indium tin oxide. DMOAP: *N,N*-dimethyl-*N*-octadecyl-3-aminopropylmethoxyl chloride. *p*-wave: 'primary' (elastic) wave.

tivity at a fixed angle of incidence, i.e., at the front of the surface-plasmon resonance at half the maximum ATR reflectance. As the green light begins to affect the local region of the ADDLC cell, the response time of the reorientation of LC molecules is very fast (<2 ms), as shown in Figure 2. Using the pumped-ATR method, the response time is about four orders of magnitude faster than in the transmitted pump-probe experiment. This is caused by elimination of the influence of the elastic continuum throughout the ADDLC cell, and it provides evidence of photoexcitation.

In summary, we recorded the change of the surface morphology in an ADDLC sample on the basis of measurements of the material's light-scattering properties. The transformation of Rayleigh to Mie scattering indicates the formation of a regular ripple structure. The fast response of the pumped-ATR experiment in the ADDLC cell provides evidence of ADDLC photoexcitation. We will next study ADDLC dynamics in more detail and obtain the corresponding physical parameters (e.g., anchoring characteristics). We will also further develop the advanced in situ ATR technique and use the pulse laser to excite ADDLCs to explore the transient behavior of LCs on surfaces.

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References

1. O. Francescangeli, S. Slussarenko, F. Somroni, D. Andrienko, V. Reshetnyak, and Y. Reznikov, *Light-induced surface sliding of the nematic director in liquid crystals*, **Phys. Rev. Lett.** **82**, p. 1855, 1999.
2. F. Simoni, L. Lucchetti, D. E. Lucchetta, and O. Francescangeli, *On the origin of the huge nonlinear response of dye-doped liquid crystals*, **Opt. Express** **9**, p. 85, 2001.
3. A. G. Chen and D. J. Brady, *Real-time holography in azo-dye-doped liquid crystals*, **Opt. Lett.** **17**, p. 441, 1992.
4. C. R. Lee, T. S. Mo, K. T. Cheng, T. L. Fu, and A. Y. G. Fuh, *Electrically switchable and thermally erasable biphotonic holographic gratings in dye-doped liquid crystal films*, **Appl. Phys. Lett.** **83**, p. 4285, 2003.
5. K. Y. Lo and C. Y. Huang, *Observation of transient reorientation of dye-doped liquid crystals by pumped attenuated total reflection*, **Appl. Phys. Lett.** **89**, p. 081114, 2006.
6. C. Y. Huang, Y. R. Lin, K. Y. Lo, and Chia-Rong Lee, *Dynamic process of the photoalignment in dye-doped liquid crystals*, **Appl. Phys. Lett.** **93**, p. 181114, 2008.
7. A. Y. G. Fuh, C. C. Liao, K. C. Hsu, and C. L. Lu, *Laser-induced reorientation effect and ripple structure in dye-doped liquid-crystal films*, **Opt. Lett.** **28**, p. 1179, 2003.
8. E. Hecht, **Optics**, 4th ed., (Addison Wesley, San Francisco), 2002.
9. K. Y. Lo, C. Y. Huang, T. H. Chu, C. J. Hsu, C. H. Lin, and A. Y. G. Fuh, *Variation of nematic liquid crystal on a silver surface*, **J. Opt. A-Pure Appl. Opt.** **8**, p. 501, 2006.