Nanosecond liquid crystalline technologies for high speed optical communications: electro-optic switching through nanosecond electric modification of order parameter

Volodymyr Borshch[1], Bing-Xiang Li[1, 2], Sergij V. Shiyanovskii[1],
and Oleg D. Lavrentovich[1, *]

[1]Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University, Kent, Ohio 44242, USA
[2]College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
*Corresponding author's e-mail address: olavrent@kent.edu

Abstract: We experimentally demonstrate nanosecond electric modification of the order parameter (NEMOP). Nanosecond electro-optic switching is equally fast for both filed-on and field-off driving what allows using liquid crystals for high speed optical communication devices.
OCIS codes: (160.3710) Liquid crystals; (130.4815) Optical switching devices; (190.3270) Kerr effect.

1. Introduction

Nematic liquid crystals (NLCs) have numerous electro-optic applications enabled by anisotropy of their properties [1]. The optic axis of the NLC is called the director $\hat{\mathbf{n}}$. In typical electro-optic applications, an AC electric field applied to a dielectrically anisotropic NLC realigns the director (Frederiks effect) and thus changes the effective birefringence δn or phase retardance $\Gamma = d\delta n$, where d is the length of pathway of light in the NLC [1]. A desirable mode of operation is to switch large retardance within a short period of time, characterized by a figure of merit [1] $\text{FoM} = \Gamma^2 / \left(\pi^2 \tau_{off}\right)$, where τ_{off} is the relaxation time of retardance to its field-free state. The process of dielectric reorientation is relatively slow, on the scale of milliseconds, especially during the field-off stage. The typical FoM is on the order of a few $\mu\text{m}^2/\text{s}$ [1]. The speed of switching can be accelerated by a variety of approaches [1], such as optimizing the viscoelastic parameters of the NLCs or overdriving. Recently, a different approach to change the optical retardance of the NLC has been proposed [2], based on nanosecond electric modification of the order parameter (NEMOP) [2,3].

2. Experimental results

NEMOP effect allows one to achieve fast nanosecond switching times in the range on tens of nanoseconds, in both field-on and off regimes [3] as demonstrated on Figure 1(a), as well as FoM on the order of 10^4 $\mu\text{m}^2/\text{s}$. In the demonstrated effect, we used an NLC with a negative dielectric anisotropy $\Delta\varepsilon = \varepsilon_{\|} - \varepsilon_{\perp} < 0$ (such as CCN-47), where indices represent the values of the dielectric constants measured along and perpendicular to the director $\hat{\mathbf{n}}$. The electric field is applied perpendicular to the director and does not reorient it, but changes the components of the optic tensor of the LC. Using the experimental geometry depicted on Figure 1(b), one records the NEMOP effect. The nanosecond optical response shown on Figure 1(a) has the characteristic time about 30 ns to both the field-on and field-off switching.

NEMOP effect should be distinguished from the Kerr effect observed in isotropic liquids such as an isotropic phase of mesogenic compounds. In the Kerr effect, the electric field causes uniaxial order of an otherwise isotropic medium. In the NEMOP case, the uniaxial order already exists and the field causes both uniaxial and biaxial modifications of this order. The difference manifests itself in the amplitude of induced birefringence. For example, CCN-47 with $\Delta\varepsilon < 0$ shows a higher field-induced birefringence when its ground state is isotropic, since the field coupling to the transversal dipoles aligns the long axes of the molecules perpendicularly to itself. In NEMOP, the field does not realign the long axes and modifies mostly the orientational order of short axes; as a result, the change in birefringence is due to both uniaxial and biaxial contributions, but the overall change is weaker than in the case of the Kerr effect. In general, by selecting a proper molecular structure, one can favor a larger NEMOP response.

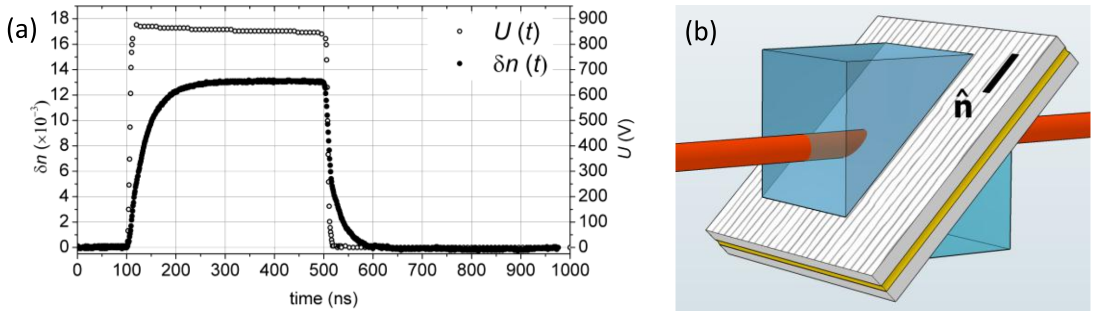

Figure 1. (a) Dynamics of field-induced birefringence $\delta n(t)$ for the nematic phase of HNG715600-100 (filled circles) in response to a voltage pulse *U(t)* (filled triangles). (b) Experimental setup: a test cell sandwiched between two right angle prisms, probed with a linearly polarized laser beam that propagates inside the nematic slab at the angle 45 °with respect to the cell normal.

3. Conclusions

Our study demonstrates that NEMOP enables a large amplitude of fast (nanoseconds) electro-optic response with the field-induced birefringence on the order of 0.01 and a figure of merit (FoM) on the order of $10^4\ \mu\text{m}^2/\text{s}$; the latter is orders of magnitude higher than the FoM of the Frederiks effect traditionally used in electro-optic nematic devices. The amplitude of the NEMOP response achieved is higher than 0.01 for LCs with natural (field-free) birefringence $\Delta n = 0.15$, Figure 1(a). We demonstrate that the electro-optic performance of NEMOP effects depends strongly on the material parameters such as dielectric and optical anisotropy. The level of optimization achieved in this work might be potentially advanced by further exploration of different materials. The NEMOP effect can enable utilization of liquid crystals for ultrafast electro-optic technologies for high speed optical communications and in devices ranging from displays to shutters, limiters, modulators, switches, and beam steerers, as the switchable optical retardance reaches the required levels of half-wavelength.

Acknowledgements. The work was supported by DOE grant DE-FG02-06ER 46331, State of Ohio through Ohio Development Services Agency and Ohio Third Frontier grant TECG20140133, and by China Scholarship Council and Jiangsu Innovation Program for Graduate Education, grant No.CXZZ13_0155. The content of this publication reflects the views of the authors and does not purport to reflect the views of Ohio Development Services Agency and/or that of the State of Ohio.

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