Manipulating liquid crystals by pyroelectric effect

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Liquid-crystal droplets are fragmented and moved to desired locations using electric fields generated by a thermal stimulus.

Liquid crystals (LCs) are substances that flow like liquids but have molecules ordered in a crystal-like way. These properties allow LCs to organize themselves in mesophases, states where they present features of both liquid and solid states, under particular conditions. This peculiarity has allowed these materials to find wide applicability in many fields, from display systems to optics and photonics.1, 2

An attractive property of LCs is the ability to modulate their optical properties using electric, optical, or magnetic fields. At present, different techniques exist for manipulating LCs that have found applications in various areas. For example, researchers have extensively studied LC tunable lenses and have designed and experimentally demonstrated many successful configurations.3 Other groups have proposed optical microresonators (light-trapping microspheres that have applications in laser sources)4 and LC-based optical devices such as electro-optic switches and beam scanners.5

Nevertheless, faster and more versatile approaches to modulate the properties of LCs are desirable, particularly in emerging fields of technology. The selective patterning of LCs into optical devices is often achieved by ink-jet printing approaches where a nozzle is scanned onto the target support for precise delivery of LC droplets. However, these techniques make use of expensive systems based on external voltage generators and, due to the scanning-mode operation, are relatively time-consuming.

We found that the spatial self-assembly of LC droplets can be an efficient alternative to these techniques since, under particular conditions, the droplets can be driven to desired locations following electric-field lines (see Figure 1). Our approach is easier to accomplish than the ink-jet printing methods, even over relatively large areas, thus providing a cost-effective and rapid manipulation of LC droplets.

Figure 1. Liquid-crystal (LC) droplets aligned onto a lithium niobate (LN) substrate following electric-field lines that were pyroelectrically generated. Droplet dimensions are of the order of microns or submicrons.

Our method of manipulating LC droplets is non-invasive. Rather than applying an external voltage, we exploit the pyroelectric properties of the periodically poled lithium niobate (LN) crystal used as a substrate. We previously demonstrated that heating and/or cooling this material results in the appearance of surface charges due to pyroelectricity,6 which leads to interesting phenomena.7–9 Because our LC is a polar molecule, it undergoes a force due to the electric fields generated by the surface charges that is able to move the LC droplets.

We start by organizing an LN sample into various configurations by microengineering its ferroelectric domains and covering it with a film of polydimethylsiloxane or PDMS, a hydrophobic polymer (see Figure 2).6 After, we deposit large drops of the nematic LC 6CHBT (1-trans-4-hexylcyclohexyl-4-isothiocyanatobenzene) on the sample and heat it on a hot plate at 90°C—above the nematic to isotropic transition temperature—for 30s. The material is then placed at room temperature under an optical microscope in transmission configuration.10

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Drops of LC are first uniformly fragmented in smaller droplets by heating the sample. Driven by pyroelectric fields obtained by this thermal stimulus, the fragmented drops are self-assembled on the LN substrate according to the ferroelectric domain patterned structures. In particular, during cooling, droplets move outside or inside hexagonal domains, depending on the side of the LN crystal (see Figure 3). When the side of the crystal is Z− (sample A), droplets move outside hexagons. For Z+ (sample B), they go inside.

After a few minutes, fragmented droplets coalesce to form bigger droplets at fixed locations, a behavior attributed to the polar nature of the 6CHBT molecule. In the case of sample A of Figure 2, we obtain almost a single drop for each hexagonal domain. These drops behave as microlenses with focal lengths of tens or hundreds of microns (see Figure 4). The whole sample could be viewed as a dynamical optical microelement able to switch from a diffuser state (fragmentation state) to a microlens array (coalescence state) without the need for an external voltage. Moreover, the birefringent properties of LCs could give an additional value to these devices, such as making microlenses tunable.

In summary, we present a novel approach for manipulating LCs by pyroelectric effect where the strong electric fields generated through a thermal stimulus allow the manipulation of liquids in 2D on a substrate. We observe fragmentation of droplets that migrate to different regions of the sample according to the geometry of the LN substrate and following the electric-field lines. The droplets then coalesce into bigger drops, at which point various effects can occur. For example, there is the possibility of new fragmentation (reversibility of the process),

Figure 2. The periodically poled LN is covered with a polydimethylsiloxane film on the Z− (sample A) and Z+ (sample B) surfaces. Z refers to the axis along which the crystal is cut.
Figure 4. Several minutes after cooling, the droplets coalesce inside hexagonal domains of sample B and behave as LC microlenses. The inset shows an image taken in the focal plane of the lens.

square-matrix arrangements, and lens effects (where LC droplets may focus the light passing through them), and alignment of the LC molecules with the electric field (resulting in the appearance of crosses, called Maltese crosses, when the LC is observed under a crossed polarizer). In the future, we aim to reduce the timescale of the observed phenomena to allow for concrete application in photonic devices. Other future studies will consider so-called polymer dispersed LCs, that is, LCs mixed with PDMS.

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References
14. http://spie.org/documents/newsroom/videos/4574/Video1%5FMerola.wmv Experiment on sample A. Shortly after heating, the LC droplets are uniformly fragmented and cover the whole surface. During cooling at room temperature, droplets move outside the hexagonal domains driven by the electric field generated by pyroelectric effect. Credit: Francesco Merola.