Electric Field Dependent Textural Variation inside the Liquid Crystal Droplets with Homeotropic Alignment

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Abstract. The alignment of liquid crystal inside the droplets highly influences the electro-optical behaviour of polymer dispersed liquid crystals (PDLCs). In PDLCs with initial transparent state, LC droplets exhibit homeotropic boundary conditions with darker zone at the centre with ring shaped boundary. In the present work, the textures were observed under parallel and crossed polarizers. The captured information revealed that there are no changes in the central zone of the droplets due to the perfect homeotropic alignment of liquid crystals inside the droplet. The count of the droplets with different ranges was measured using ImageJ software. Further, the effect of electric field on textural variation inside the droplets, measuring the ratio of the size of darker zone to the size of droplet (a/d) was analysed by applying image processing. The response curve was obtained for different range of sizes of droplets from the plot of a/d ratio vs applied voltage and found supportive to the measure of the textural variation inside the LC droplets. Therefore, the a/d ratio can be the valuable parameter for optimizing the parameters such as droplet size, area of darker zone and required voltage for energy efficient PDLC devices.

1. Introduction

In polymer dispersed liquid crystals (PDLCs), liquid crystal (LC) droplets have the geometrical confinement inside the polymer matrix [1-3]. The change in director of LCs provide the certain alignment inside the droplets with specific textures and is significant for control over the electro-optical behaviour of PDLCs. Essentially, textural variation inside the droplets depends on the boundary conditions, size of droplet and physical parameters of LC material etc. In general, various configurations are formed for the nematic LC droplets consisting of tangential boundary conditions such as bipolar and toroidal; and homeotropic boundary conditions such as radial and axial [4-7]. These configurations are accountable for the light scattering, transparency and absorption phenomena occurred in the PDLCs. There are several studies for LC droplets consist of nematic LC with positive dielectric anisotropy which specify the changes in configuration on applied field [8-14]. However, limited work is reported for LC droplets consisted of negative dielectric anisotropy LC [15-19]. Moreover, there is a lack of studies on textural behaviour of LC droplets with homeotropic boundary conditions. Thus, the present work is focused on the configurational behaviour inside the droplets without and with applied field. The image processing has been applied for calculating the count of droplets with varied ranges of sizes and respective ratios of the size of darker zone (a) to the size of droplet (d) with and without applied voltages.
Further, by measuring the ratio a/d, the response curve obtained for different size of droplets under applied voltage was observed in favour of the textural variation inside LC droplets.

2. Experimental section (materials, preparation and characterization)

The PDLC mixture was prepared using UV curable polymer NOA-65 (NORLAND, NJ) and nematic LC MDA003969, (Merck, UK) [20] exhibited negative dielectric anisotropy (Δε = −2.7) at AC frequency ≥ 50 kHz. The LC and polymer were taken in equal wt/wt % in vials and homogeneous mixture was formed by vigorous magnetic stirring as well as heated simultaneously to an isotropic temperature. Hereafter, cell was filled using prepared mixture in between polyimide VA layer coated ITO substrates having 10 µm cell gap controlled using mylar spacer. The cell was sealed and exposed to UV light at wavelength of 365 nm under intensity ~5 mW/cm², for an hour at room temperature for preparing PDLC with homeotropic alignment of LCs. Droplet morphology was observed by polarizing optical microscope (POM) (LV100POL, Nikon Eclipse, USA). The external voltage was applied using function generator (AFG 3021B, Tektronix). The LC droplet images were analyzed by ImageJ software, a Java-based image-processing program developed at the National Institutes of Health.

3. Results and discussion

3.1. Measurement of droplet count and darker zone of LC droplet structure

Figure 1 (a) shows the grouping of number of LC droplets with their varied sizes in terms of major axis diameter and respective variation in a/d ratio measurement of darker zone. The POM texture of PDLC at 0V as shown in Figure 1 (b, c) under crossed and parallel polarizers was processed through ImageJ software and measured the total 194 droplets of different sizes. Further, the count of droplets was distributed into eight bins as per the measured a/d ratios for individual droplet and twelve bins as per the major axis of droplet size. It has been observed that the maximum number of droplets 55 in count were of ~18-27 µm size, 21 droplets were of size 30-36 µm and remaining droplets were for the other ranges. Moreover, this data was categorized into three ranges of a/d ratio such as greater than 0.8, between 0.7 to 0.6 and less than 0.6. It was found that 26 droplets have size greater than 30 µm, 47 droplets have size between 20 to 30 µm and 24 droplets have size between 15 to 20 µm for the respective above three ranges. The droplets with greater sizes were possesses more darker zone along with the increase in a/d ratios and decrement in the darker area was seen as the value of a/d ratio decreased.

![Figure 1](image1.png)

**Figure 1.** (a) LC droplets major axis and respective variation in a/d ratio of darker zone. Histogram also represents of count of droplets for their sizes as major axis (in blue color) and for a/d ratios (in red color). The POM textures of LC droplets under (b) crossed and (c) parallel polarizers at 0V, 20x magnification.
3.2. Electric field dependent textural variation

The POM textures of LC droplets were captured and analysed for the textural variation with and without applied electric field. The three-stage noticeable effect on the LC director’s distortion/reorientation inside the LC droplet was found with the gradually applied voltage. In the OFF state of initial transparent PDLCs [Figure 1 (b)], LC droplets exhibited central darker zone with ring shaped peripheral signature of vertical alignment of LC molecules. Figure 1 (e) also confirmed the perpendicular direction of the director by turning the PDLC cell and seen under parallel polarizers, revealed the nothing changes in the central zone of LC droplet. At low field regions (< 7V), the director configuration at central darker zone and ring-shaped textures were found stable however, distortion in the LC alignment started on applying the voltage ≥7V as shown in Figure 2 (a, d) under crossed and parallel polarizers. On increasing the applied voltages in between the transitional range >7V to 8.5V, the remarkable director turbulation in darker zone can be seen for droplets of sizes in the range between 30-39 µm as shown in Figure 2 (b, c) and Figure 2 (e, f) under crossed and parallel polarizers, respectively. However, below this size’s range of droplets, minor variations were observed and required higher fields >8.5V to achieve noticeable turbulation in darker zone state. When the textures were seen under parallel polarizers, the black bushes were moving inward [Figure 2 (e)] and under crossed polarizers same texture showed the contraction in darker zone towards the centre [Figure 2 (b)] due the gradual switching of homeotropic boundary conditions to planar boundary conditions. At voltages >10V, substantial completion in director configuration adjacent perpendicular to the applied field direction exhibiting the planar boundary conditions in bigger droplets, while the smaller droplets required relatively higher voltage (>15V).

![Figure 2. POM textures of PDLCs consisted of LC droplets with homeotropic boundary conditions under applied voltages ≥7V, >8V and >8.5V under crossed polarizers (a-c) and parallel polarizers (d-f), respectively.](image)

3.3. Measurement of response curve with a/d ratio for different size of droplets

As conversed, it has been observed that the most of the variations inside the LC droplet were observed in the central darker zone under applied voltage. Thus, it developed the essential features with darker central area of the LC droplets formed for normally transparent PDLC, where the director is oriented almost normal to the surface. With that supposition, the ratio of diameter of darker area to droplet diameter (a/d) were measured to quantify the effect of applied voltage on the topological variation inside the LC droplets of different sizes. Consequently, the droplet diameter and darker zone diameter for varied sizes of droplets were measured using ImageJ software for sizes >36µm, <36µm and >27 µm; <27µm and >20 µm; <20µm and >19µm; <19µm and >17 µm. The POM textures of droplet of sizes in
the range of >36µm [Figure 3 (a, b)] and < 36µm to >27µm [Figure 3 (c, d)] under crossed and parallel polarizers were processed for image analysis and measured the a/d ratios under applied voltages (0V to 16V). Figure 3 (e) shows the response curve of voltage vs. a/d ratio for varied sizes of droplets and exhibited the reverse S-shaped behaviour. Under low applied voltage, no variation was found in the darker zone with 0.84735 a/d ratio and rapid contraction in darker zone was observed on applying intermediate voltage (8.4V) with sharp decrease in a/d ratio to 0.22614 and 0.22785 for 36µm to 27 µm range of droplets. However, the droplets with 20-27µm range shifted to lower a/d ratios at 9V of applied voltage. Likewise, the smaller droplet <20 µm require relatively higher voltages than the required for bigger sized droplets. Further, all the droplets of different ranges slowly approach to 0.05, 0.03, 0.02 and 0.01 values of a/d ratio with the orientation of LC molecules from homeotropic to planar state inside the droplets. Thus, as refractive indices matching and mismatching is the important parameter in the PDLCs operation, similarly, the a/d ratio can be another important parameter in controlling droplet size, orientation of LCs with their tunability and functioning at lower applied voltage for preparing the energy efficient electro-optical PDLCs.

Figure 3. The POM textures of droplet under varied applied voltages (0V – 16V) of size (a, b) ≤ 37µm-27µm and (c, d) < 27µm-20µm, under crossed and parallel polarizers. a₁ & a₂ and d₁ & d₂ represent the droplet diameter and darker zone diameters, of droplets with 37.603 µm & 26.747 µm size, respectively
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