

Controlled Generation of Nematic Twist Disclinations

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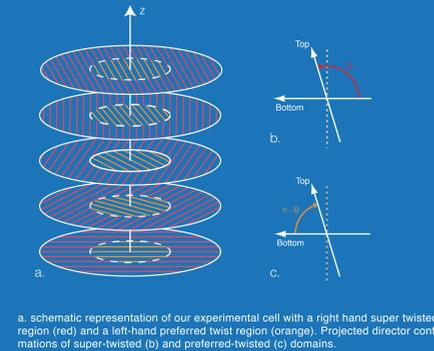
Abstract

Disclination lines play a decisive role in determining the equilibrium structures of topologically constrained liquid crystal systems [1] including cholesteric blue phases, twist grain boundary phases and liquid crystal colloids [2]. The extra energy associated with disclinations is key to stabilizing one particular director structure over another, yet our knowledge of disclination energetics is limited as are characterization methods. So, we have been investigating the nucleation and stability of reverse twist disclinations in nematic liquid crystals. We present a method for the controlled generation of disclination loops and our observations and measurements of their nucleation.

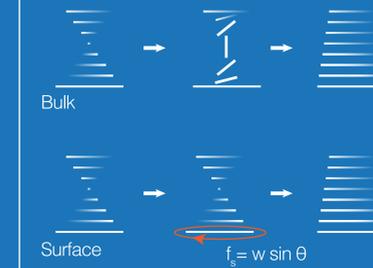
Liquid crystal configuration

In a typical experiment, we use two rubbed polyimide planar aligned substrates. Our method uses a mechanical rotation of the alignment substrate to induce a twist in the liquid crystal bulk. The substrates are initially positioned with their anchoring directions aligned, and then we rotate the bottom substrate $+100^\circ$ (counter-clockwise) relative to the top substrate. At twist angles greater than 90° , the liquid crystal is in a super-twisted state. With a $+100^\circ$ twist, the symmetry of the nematic director allows

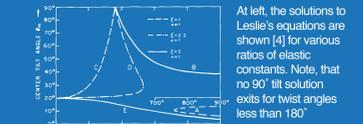
the orientation to follow either a counter-clockwise $+100^\circ$ "super-twist," or a clockwise -80° "preferred-twist." When super-twist and preferred twist domains exist simultaneously in the bulk, a $+1/2$ defect loop divides the two regions [5]. Therefore, the growth of the preferred-twist domain is regulated by the competition of its reduced elastic twist energy and the increased energetic cost of the growing boundary defect, the cell thickness and the relative surface alignment.



Transition Mechanism



In order for a reverse twist domain to be nucleated the super twist must be unwound. Two mechanisms have been proposed (shown left). The bulk mechanism is a tilt to a 90° state with no twist, first proposed by Leslie [3]. Leslie's equations predict a tilt transition at 180° twist, and allow no tilt solution for twist angles less than 180° (see below). Leslie also suggested that reverse twist domains observed at lower twist angles are due to slipping weak surface anchoring.



Experimental setup

System description

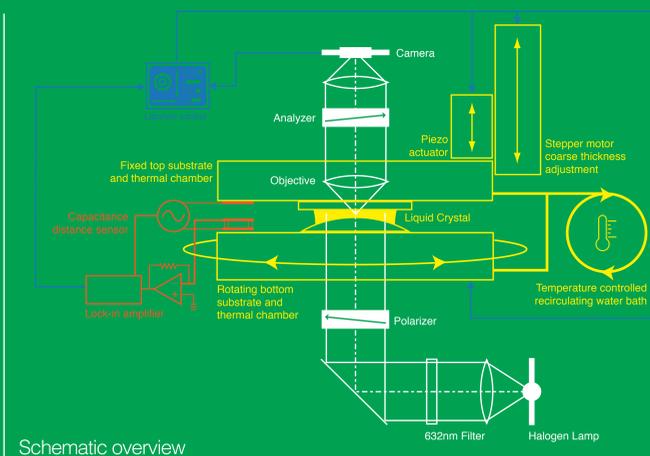
We have designed and fabricated a liquid crystal observation system that can dynamically change the twist angle (θ), thickness (d) and temperature (T) of a liquid crystal sample. The twist angle is varied through a mechanical rotation of the cell's bottom substrate. A stepper motor, piezo actuator and capacitance sensor provide precise closed loop

positioning of the upper substrate relative to the bottom substrate. The temperature is regulated by circulating water through a custom thermal chamber which encloses the liquid crystal sample (fig c).

Mechanical stability was a primary design consideration. The system allows for micrometer tilt adjustment of the bottom substrate relative to both the axis of rotation and top substrate.

An integrated polarizing microscope, illumination system and camera provide for observation.

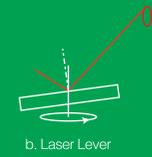
The system is operated and automated using LabView. The software can vary the thickness, twist, take time lapse photo graphs, monitor the distance sensor as well as automate these processes for extended data collection.



Implementation details

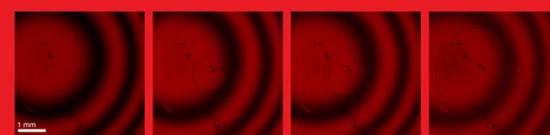
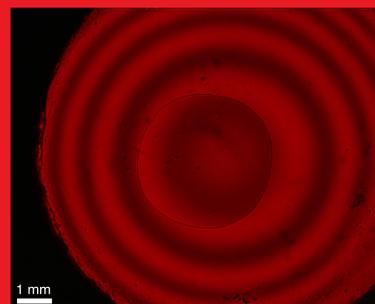
We utilize a convex lens (typically $f=1300\text{mm}$) for the bottom substrate. This has the advantage of localizing the region of minimum thickness to the center of the cell even in the case of non uniform substrate alignment (fig a).

However, it is critical that the bottom substrate be precisely perpendicular to the axis of rotation. This calibration (fig b) is completed with just the bottom substrate installed in the machine. A laser is reflected off the constantly rotating substrate onto a distant screen. The tilt micrometer screws are adjusted until the laser spot on the screen remains stationary through the entire rotation. This is the same laser lever technique used in an atomic force microscope.

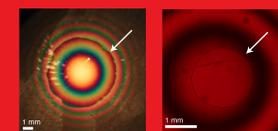


Specification	Absolute Resolution	Displacement Precision
Twist Angle	1 degree	0.001 degree
Thickness	0.5 μm	0.01 μm
Temperature	1°C	0.1°C
Optical	7.7 μm (100x magnification on 110ppi display)	
Rotational flatness	$\pm 1\mu\text{m}/180^\circ$ rotation	

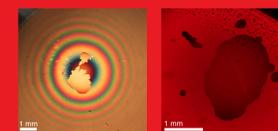
Experimental results



At left, a defect generated by our technique is shown. A $+1/2$ twist disclination defect loop separates regions of opposite handed twist. Above, a time lapse sequence of the nucleation process around a piece of debris is shown. The photos were taken one minute apart. The minimum cell thickness is $20\mu\text{m}$, and the twist angle is 155° .

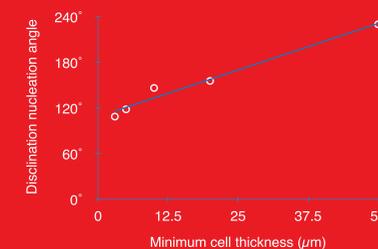


Bulk defects are characterized by a uniform round shape and a visible black defect line.



Slipping at the surface is characterized by an irregular border and an apparent solid friction interaction between the structure and the surface coating.

Bulk vs surface



Above, the nucleation angle of the twist disclination structure is shown as a function of minimum cell thickness. We observe transitions at twist angles much less than the 180° predicted by Leslie's theory. Our observations suggest that this transition cannot be attributed to a slipping at the surface as has been previously proposed.

Nucleation twist angle

Related and future work

We seek to understand that mechanism in which twist disclinations form in the bulk. Contrary to previously proposed theories, our work suggests that the formation of reverse twist domains is not due to a simple slipping of the surface alignment, but involve a tilt mitigated transition in the bulk even at twist angles less than 180° . The formation of defect loops in the bulk are often facilitated by the presence of debris. Initial observations also suggest that flow effects play a crucial role in the transition. Our future work strives to quantify the role of flow in the formation of defects as well as determine the precise mechanism by which the transition occurs. We also seek to map the full energetic landscape of the disclination, including its line energy and the stability and existence of metastable states.

We have also used our experimental apparatus to optically measure the cell thickness, and have used our dynamic manipulation of the cell thickness and twist angle as an extra degree of freedom in constructing a method to characterize other standard material parameters as well.

[1] J. Fukuda and H. Yokoyama, Phys. Rev. E 66, 012703 (2002). [2] De Gennes and Prost, The Physics of Liquid Crystals Second Edition, Oxford Sci Pub. 1993. [3] F M Leslie, Pramana Suppl. No 1, 1975 [4] T J Scheffer, J. Appl Phys. 49(12) 1978. [5] T. Nagaya, H. Orihara, and Y. Ishibashi, J. Phys. Soc. of Japan. 56 (5) 1987