Microscopic Studies and Simulations of Bloch Walls in Nematic Thin Films

Jung Ok Park
Center for Advanced Research on Optical Microscopy, School of Polymer, Textile and Fiber Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA
404-894-6528, jung.park@ptfe.gatech.edu

Jian Zhou[1] and Mohan Srinivasarao[1,2,3]
[1]School of Chemistry and Biochemistry,
[2]Center for Advanced Research on Optical Microscopy, [3]School of Polymer, Textile and Fiber Engineering,
Georgia Institute of Technology, Atlanta, GA 30332, USA

Abstract
The director profiles of the Bloch walls are directly visualized using fluorescence confocal polarizing microscopy. Both pure twist Bloch walls and diffuse Bloch walls are analyzed. Polar anchoring energy was measured from optical simulation of the transmitted light interference pattern or the fluorescence intensity profile of a pure twist wall..

1. Objectives and Background
A nematic phase of liquid crystals (LCs) shows long range orientation ordering, whose average orientation direction is referred to as the nematic director, $\boldsymbol{n}(q,f)$, where q and f are the tilt and azimuthal angle of the director, respectively. A wall defect in a nematic phase is a continuously distorted region with finite thickness, which usually forms during a fast realignment process of the nematic phase. Since the nematic molecules can rotate in two opposite directions to align their long axis to be parallel or antiparallel to the external field direction, if the transition process is fast enough, a 180° inversion wall may form due to the opposite rotations of the adjacent nematic domains.[1]

We formed Bloch walls by quenching nematic thin films from planar anchoring state to homeotropic anchoring state. It was possible to prepare both pure twist Bloch walls and diffuse Bloch walls, since the anchoring strength was varied by choosing different polymer surfaces.[2,3] The 3-dimensional director configuration images were analyzed and the polar anchoring energy was measured.

2. Experiment
Nematic fluids we used were 5CB ($\Delta n \sim 0.2$), TL205 ($\Delta n = 0.22$) and MLC6608 ($\Delta n = 0.083$). The LC/polymer films were prepared by photo-polymerization-induced phase separation method reported previously,[3] using *n*-octyl acrylate, iso-octyl acrylate, and 1,1,1-trimethylol propane triacrylate. The film contains large polygonal LC domains of 30-50 μm in width. The film thickness was controlled by glass microbeads (5 and 15 μm diameter).

The wall defects in nematic phase are usually unstable and collapse by themselves. However, they can be stabilized when they are confined by the boundary surfaces,[4] as in our study. With the fluorescence confocal polarizing microscopy, one is able to observe the director configuration of nematic liquid crystal domains.[5,6]

3. Results
3.1 Microscopic Observation of the Director
A Bloch wall in a composite film of TL205 and poly(iso-octyl acrylate), observed between crossed polarizers with a monochromatic light source, shows interference fringes parallel to the wall (**Figure 1(a)**). A schematic director configuration is shown in **Figure 1(b)** for a Bloch wall, consisting of 180° twist deformation along the x direction, with the wall thickness, *d*, and the sample thickness, *h*.

Since the birefringence of MLC6608 is very small, optical aberrations in confocal imaging of its nematic film was negligible.[6] By controlling the film thickness with respect to the dimension of wall width, pure twist Bloch walls and diffuse walls have been obtained.

In a pure twist wall (**Figure 2(a), (b)**), the profiles of the fluorescence intensity across the wall at the different depths of the film are basically identical, suggesting that the director variation along z axis is negligible.[4] This pure twist wall has the width of ca. 6 μm, comparable with the size of h.

In a diffuse wall (**Figure 2(c), (d)**), the width of the wall is a function of z, smallest near both top and bottom substrates, and largest at the middle depth of the film. The fluorescence intensity profiles taken across the wall at two different depths show dramatic change, suggesting that the tilt angle of the LC director varies along z axis. Our result is therefore consistent with Kleman's prediction: a diffuse wall is more stable when the extrapolation length b is smaller than h.[3]

3.2 Simulations of Pure Twist Bloch Walls

The polar anchoring energy, $W_s(\theta)$, represents the work that is needed to rotate the director from the easy axis, and is usually assumed to satisfy a phenomenological formalism by Rapini-Papoular: $W_s(\theta) = W_s \sin^2(\theta - \theta_0)$,[7] where θ_0 is the tilt angle of the easy axis of the surface. The director across the pure twist Bloch wall subject to homeotropic anchoring varies as $\tan(\theta/2)=\exp(-2\pi/(bh)^{0.5})$.[8] From the simulations of the fluorescence intensity profiles, the extrapolation length b was estimated as 1.4 μm.

For the simulation of the interference patterns of the walls, a sample made from nematic fluid 5CB and poly(n-octyl acrylate) was used. The transmitted intensity of a normally incident beam through an LC sample between crossed polarizers is given by $I \sim \sin^2(ph(n_{eff}-n_o)/l)$,[9] where n_{eff} and n_o are the effective refractive indices for extraordinary ray and ordinary ray, respectively, and λ is the wavelength. The term n_{eff} is given by $n_{eff}=n_e n_o/(n_o\sin^2\theta + n_e\cos^2 q)^{0.5}$.[10]

The calculated interference patterns at two wavelengths match well with the experimental data and one example is shown for 458 nm excitation in **Figure 3**. Using the extrapolation length b obtained from the curve fitting, the polar anchoring strength was estimated to be 2.6×10^{-6} J/m^2 from the relation of $W=K_{22}/b$.[11]

4. Summary

Three-dimensional director configurations of Bloch walls of two types, diffuse walls and pure twist walls, have been, for the first time, directly visualized using FCPM imaging. The results are consistent with the theoretical prediction [3], which states that pure twist wall is stable if the apparent extrapolation length b is greater than or comparable to the sample thickness, while diffuse wall is stable if h is much greater than b.

The simulations of the optical patterns of a pure twist Bloch wall support the director-field model of this type of wall and also provide a more accurate measurement of polar anchoring energy, although the method is limited to measuring weak anchoring energy up to 10^{-5} J/m^2 due to the fact that the wall defects are unstable under strong anchoring conditions.

5. Acknowledgements

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6. References

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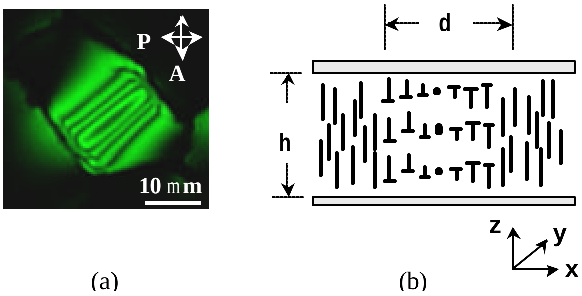
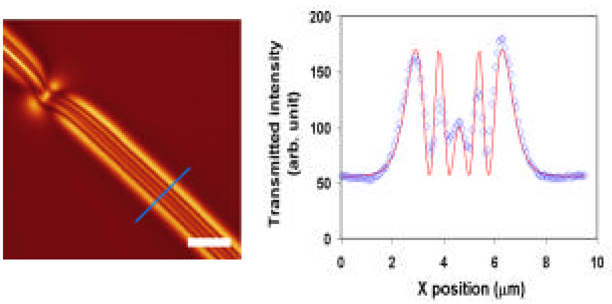
[11] K_{22} of 5CB at 24°C is 3.9 pN, adopted from P. A. Breddels, and J. C. H. Mulkens, *Mol. Cryst. Liq. Cryst.*, 1987, *147*, 107-112.



(a) (b)

Figure 1. A pure twist Bloch wall. (a) A polarized microscope image of a wall, in a film of TL205-poly(iso-octyl acrylate) composite, under crossed polarizers with monochromatic illumination of 532 nm. (b) Schematic drawing of the tilt angle variation through the wall along *x* direction. The head of the nail sign, "T", represents the end of the nematic director below



(a) (b)

Figure 3. Interference patterns of a Bloch wall in a film of 5CB/poly(n-octyl acrylate) composite with monochromatic illumination of 458 nm. (a) The images are taken in a transmission mode of a laser scanning confocal microscope and (b) the transmitted light intensities were taken along the lines across the Bloch wall as indicated in (a). The dots are measured intensities and the lines are simulated in (b). The film thickness *h* is 5 μm as measured by the confocal microscopy. The scale bar is 5 μm.

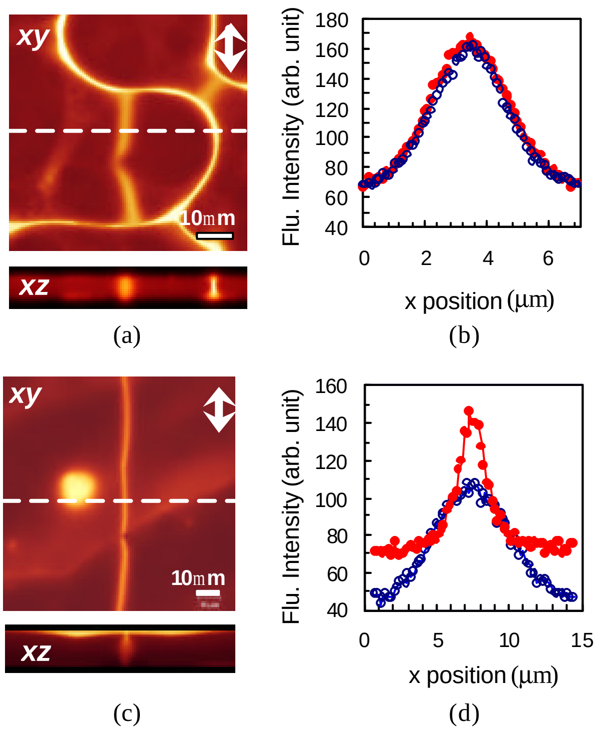


Figure 2. (a) and (c): Confocal fluorescence images (*xy* and *xz* sections) of a Bloch wall with the extrapolation length (a) comparable to the sample thickness (8 μm) and (c) much smaller than the sample thickness (18 μm). *xz* section was taken at the position indicated by the dashed line in *xy* section, and *xy* section was located at 1 μm below the top LC/polymer interface. The imaging temperature was 23°C and anchoring transition temperature T_t was 35°C. The white arrow represents the polarization of the excitation laser. (b) and (d): The fluorescence intensity profiles across the wall were taken at 1 μm (filled circles) and 5 μm (open, blue), respectively, below the top interface.