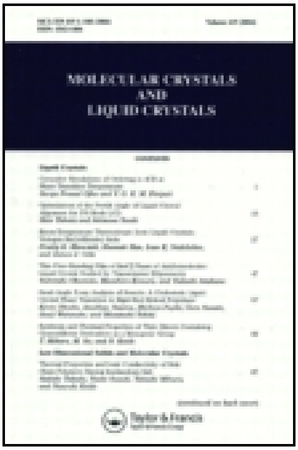

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Polarisation microscopy and dynamic light scattering were used to study the dynamical behaviour of disclination lines in a thin nematic film of 5CB. Our experiments show that the lines exhibit thermally excited diffusive motion with the ends of disclination lines being pinned to the surface. In the dynamic light scattering experiments a process with a broad distribution of relaxation times was observed, which was due to the diffusion of the disclination lines with different lengths and orientations. Polarisation microscopy was used to follow the time dependence of the displacement of a single disclination line, which enabled the measurements of the diffusion coefficient and the line tension of the disclination lines in the samples.

Keywords: disclination lines; thermal fluctuations; polarisation microscopy; dynamic light scattering

INTRODUCTION

Defects in liquid crystals have been subject of interest from the discovery of the liquid crystals until today [1]. Since liquid crystals exhibit a rich variety of phases they are interesting for the fundamental research of phase transitions as well as for studies of behaviour of topological defects in phases with different symmetries. The defects in the liquid crystal can occur during symmetry breaking phase transitions, under external fields, or they appear because of the impurities or confinement of liquid crystal samples in thin films, pores, *etc.* with frustrating surface anchoring. Many

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studies on liquid crystalline systems focus on properties of the defects, such as their structure, coarsening dynamics, their effect on the static and dynamical properties (see for example Ref. [2]).

The simplest of the liquid crystalline phases—the nematic phase—got its name from the disclinations that form threadlike structures. Topological and static properties of these disclination lines have been thoroughly studied and are well understood, while less attention has been given to their dynamical properties. Theoretical studies mostly deal with forces and motion of disclination lines in bulk and in nonequilibrium situations [3,4], although rare studies of dynamical properties of disclination lines in confined geometries also exist [5].

Experimentally the dynamical behaviour of disclination lines can be conveniently studied by polarisation microscopy [6] and dynamic light scattering (DLS) [7]. Only few experimental studies have been carried out so far. Miike *et al.* [7] studied random motion of disclination lines in convective flow and Cladis *et al.* [6] the motion of the line defect under the action of an applied voltage.

In this contribution we present a study of thermal fluctuations of disclination lines in thin nematic film using dynamic light scattering and polarisation microscopy.

EXPERIMENT

The samples used in our experiment were thin planarly aligned nematic cells. The alignment layer was photoactive poly-(vinyl-cinnamate), previously illuminated with linearly polarised UV light. A detailed description of the preparation of alignment layer can be found elsewhere [8]. The glass plates with treated alignment layers were then used for preparation of cells which were filled with liquid crystal 4-pentyl-4′-cyanobiphenyl (5CB) in the nematic phase. The thickness of the cell was determined by interferometric method using a spectrophotometer and the thickness in the region observed in our experiments was found to be approximately 800 nm. The same sample was used for both dynamic light scattering experiment and polarisation microscopy.

In the dynamic light scattering experiment the light source was a He-Ne laser with the wavelength of 632.8 nm. The intensity correlation function was measured using an ALV-5000 correlator that enables measurements over a time range of $10^{-8}-10^{3}$ seconds. We have measured the normalised intensity correlation function $g^{(2)}(\tau) = \langle I(t)I(t+\tau)\rangle / \langle I(t)\rangle\langle I(t+\tau)\rangle$ of light exiting the sample. Besides well defined orientational fluctuations of the nematic director a process with a broad distribution of relaxation times is also present (Fig. 1).

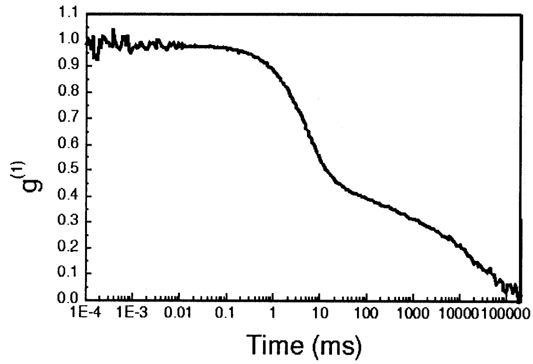

FIGURE 1 Autocorrelation function measured with the dynamic light scattering experiment. Faster relaxation is exponential and it is due to the director orientational fluctuations. Slower process, the dynamics of the disclination lines, has a broad distribution of relaxation times due to the diffusion of the disclination lines with different lengths and orientations.

Microscope image in the observed area of the sample revealed the presence of disclination lines (Fig. 2), so we attribute the process with a broad distribution of relaxation lines to the diffusive dynamics of the disclination lines. However, the analysis of DLS data is rather complicated since one probes simultaneously the disclination lines with different lengths and orientations, *i.e.* the distribution of the orientations and lengths of the disclination lines should be extracted from the miscroscopic image and in the DLS experiment one should ensure that the whole distribution is probed (by for example translating the sample). So we used polarisation microscopy to examine the region shown in Figure 2 instead.

Sequences of images were taken with time delays between successive images of 56 ms, 1 s, 10 s, and 60 s. Comparison of the images taken at different times showed that the disclination lines exhibit diffusive motion, *i.e.*, thermal fluctuations. Single disclination lines were then analysed. First the position of the line $\boldsymbol{r}_i(t)$ at different times t was determined, where i denotes the i-th point of the line (the points are approximately one pixel, *i.e.*, 0.33 μm apart). Then the displacement $\boldsymbol{s}_i(t)$ was calculated (Fig. 3). The fluctuation modes of the disclination line were obtained by calculating the spatial Fourier transform of the displacement $\boldsymbol{s}(q_n, t)$, where $q_n = (n\pi)/l$ and l is the length of the disclination line. Autocorrelation function of the Fourier transform of the displacement

$$G^{(1)}(\tau) = \langle \boldsymbol{s} * (q_n,\, t+\tau)\boldsymbol{s}(q_n, t)\rangle$$

gives then the time behaviour of the modes. The amplitude $G^{(1)}(0)$ as a function of q_n is shown in Inset of Figure 4 with the $1/q^2$ fit. Time

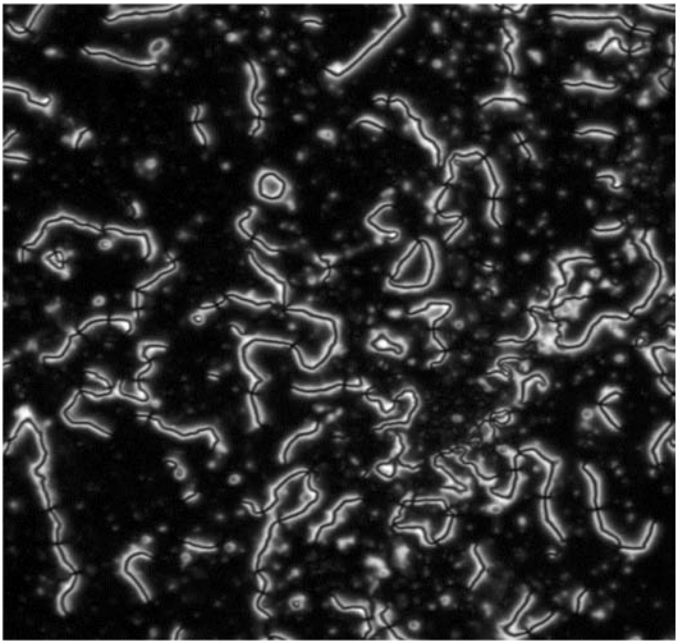

FIGURE 2 The polarised microscope image of a part of thin film with disclinations.

autocorrelation functions of the first three modes are shown in Figure 4. The autocorrelation functions of higher modes are very noisy due to low amplitudes and relatively short measuring times. The relaxation time of first mode τ_R of fluctuations was determined by fitting the corresponding autocorrelation function by a single exponential function. Diffusion

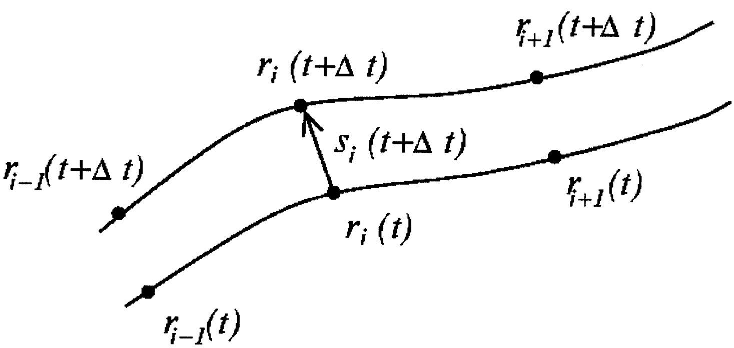

FIGURE 3 The displacement of the disclination line s was determined from two successive positions of the disclination line.

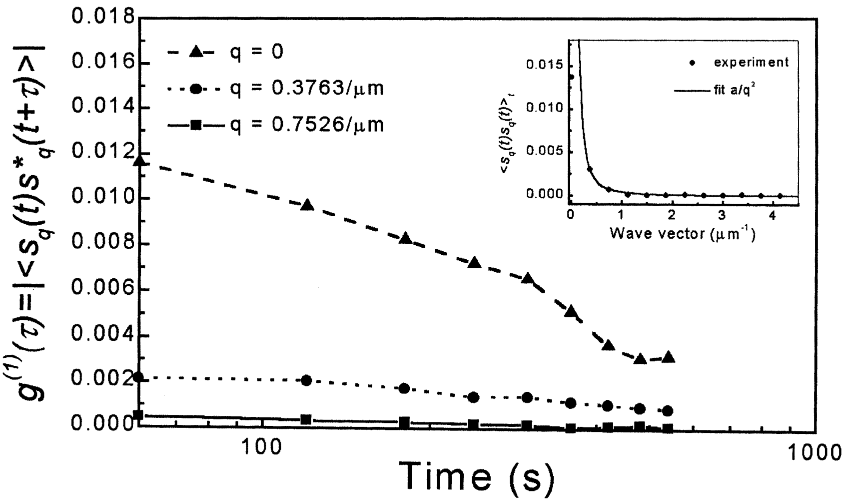

FIGURE 4 Time autocorrelation function of the Fourier transform of the displacement for the first three Fourier components. The length of the disclination line was 8.6 μm. Inset: Dependence of the average amplitude of the Fourier components on the wave vector.

constant was then calculated using the relation $1/\tau_R = D\,q^2$. From the calculated value $D \sim 5 \cdot 10^{-14}\,\mathrm{m^2/s}$, line tension of the disclination line was determined $\sigma = D\eta_{\mathrm{eff}} \sim 5 \cdot 10^{-15}\,\mathrm{N}$, where η_{eff} is the effective viscosity [6].

Measured value of the line tension is smaller than expected from the theory for the disclination line in bulk [4]

$$\sigma = \pi K s^2 \ln(L/a),$$

where K is the Frank elastic constant, s the strength of the disclination, L the size of the system, and a the core size of the disclination line. We attribute this to the surface effects, the edges of the disclination lines are, namely, pinned to the surface and the film thickness is comparable to the size of the disclination so the disclinations can exhibit only two dimensional motion.

CONCLUSIONS

In conclusion, the line tension of a disclination line in a thin nematic film was measured using polarisation microscopy. Obtained value is smaller than expected in the bulk. We attribute this to surface, which affects the restoring force that forces the disclination line back to the equilibrium position after it exhibit thermal fluctuation and probably it also affects the effective viscosity. Dynamic light scattering experiments were also carried out, but the quantitative analysis of the data is rather difficult since one probes simultaneously the disclination lines with different lengths and orientations. However, a long tail in the autocorrelation function seems to be typical signature of the defect dynamics and have been observed in different confined nematic systems [9,10], so the DLS can be used to probe the dynamics of the defects either in systems where the defects are too fast to be probed by polarisation microscopy or in systems that due to turbidity, thickness, orientation *etc.* can not be investigated by a microscope.

REFERENCES

[1] de Gennes, P. G. & Prost, J. (1993). *The Physics of Liquid Crystals*, Clarendon: Oxford.
[2] Lavrentovich, O. D., Pasini, P., Zannoni, C., & Žumer, S. (2001). eds., *Defects in Liquid Crystals: Computer Simulations, Theory and Experiments*, Kluwer Academic Publishers: Dordrecht.
[3] Ryskin, G. & Kremenetsky, M. (1991). *Phys. Rev. Lett.*, *67*, 1574.
[4] Denniston, C. (1996). *Phys. Rev. B*, *54*, 6272.
[5] Rosso, R. & Virga, E. G. in Ref. [2], p. 167.
[6] Cladis, P. E., van Saarloos, W., Finn, P. L., & Kortan, A. R. (1987). *Phys. Rev. Lett.*, *58*, 222.
[7] Miike, H., Kuriyama, Y., Itou, Y., Hashimoto, H., & Ebina, Y. (1985). *Phys. Rev. A*, *31*, 2756.
[8] Vilfan, M., Drevenšek Olenik, I., Mertelj, A., & Ĉopič, M. (2001). *Phys. Rev. E*, *63*, 061709.
[9] Ĉopič, M. & Mertelj, A. (1998). *Phys. Rev. Lett.*, *80*, 1449.
[10] Mertelj, A. & Ĉopič, M. (1998). *Mol. Cryst. Liq. Cryst.*, *320*, 287.