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# Dislocation Mobility in Smectic Liquid Crystals

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We measure the edge dislocation mobility in thermotropic smectic compounds by in situ deformation experiments. An array of dislocations is created in a wedged homeotropic liquid crystal cell. As it is well known, the dislocations are visible in polarized optical microscopy near the smectic A-C transition. Under compression the number of layers adjusts to the sample thickness. For slow enough strain variation, we observe the edge dislocations climb and can measure their mobility. We report here some preliminary observations of edge and screw dislocations in smectic liquid crystals and of their dynamics under controlled deformation.

*Keywords:* dislocation mobility; dislocation density; thermotropic smectics

## INTRODUCTION

The aim of this work is to study the plastic properties of smectics in connection with their imperfections. The description of macroscopic plasticity in terms of mobility of imperfections has been mostly studied in the field of crystals[1]. However, quantitative correlations between defects mobilities and macroscopic deformation rates have never been convincingly established because of uncertainties on dislocation velocities and mobile dislocation densities. The smectics appear to be ideal materials for such kind of studies because i) of their periodic and one dimensional character ii) defects can be visualized over the whole sample through optical microscopy[2,3].

In order to observe edge dislocations in smectics two situations are favorable: i) in the thermotropic smectic-A phase, near the smectic-C transition[4]

and ii) in the Lα lyotropic lamellar phase[5,6], by doping with appropriate dyes. We use the technique of Meyer, Stebler and Lagerwall[4]: near the smectic-A to smectic-C transition, the strains associated with a single edge dislocation modify the structure of the sample in a way that the dislocation is made visible by using polarized microscopy.



## EXPERIMENTAL PART

The experimental set-up is composed by a polarized-light optical microscope (Leica DMRP), an oven (with a temperature stability of 1 mK, Instec mK) mounted on the stage of the microscope, and a deformation micro-device, built in house, which was designed to fit the oven. The deformation is produced by a couple of piezoelectric elements which permit a vertical displacement in the range from 1nm to 300nm. For a liquid crystal thin film of a few micrometers thick, the corresponding normal strain component is then : $\Delta\varepsilon \sim 10^{-3}$-$10^{-1}$. The transmitted stress acts on another couple of piezoelectric elements cemented on the opposite glass plate and it is measured using an electrometer. The rate of the deformation is controlled with the slope of the voltage supplied by an arbitrary wave function generator and amplified by a high voltage amplifier. For high frequency processes defects do not show up while for low frequency ones they play an important role. In the latter case, we observe edge dislocation climb which is recorded using a 3CCD camera for further analysis. A detailed description of the experimental set up and of the sample preparation will be given elsewhere[7]. The liquid crystal compound is a fluorinated alkoxyphenyl alkoxybenzoate ester (BDH179) which undergoes the following transitions: C-SmA at 56°C, SmA-SmC at 55°C when cooling, and SmA-I at 79°C.

A typical sample is composed by two optically flat glass plates in a wedge geometry. The plates are treated with a surfactant (silane) to orient the liquid crystal molecules with their long axis perpendicular to the plate surface (homeotropic anchoring), i.e., the smectic layers are anchored parallel to the glass surfaces. The liquid crystal is introduced between the plates by capillarity

and the sample is mounted in an oven. When the sample is in the SmA phase, the wedge geometry gives rise to a tilt subboundary in the middle plane of the sample, made of edge dislocations parallel to the edge of the dihedron. However they do not exhibit any optical contrast. When cooling the sample from the SmA phase, near the critical temperature of the SmA-SmC phase transition, edge dislocations become visible and form a regular one dimensional network (see figure 1). This happens because the strains associated with a single dislocation change the transition temperature. A compressive stress normal to the layers raises the transition temperature and so favors the SmC phase (the rodlike molecular axis is tilted by a polar angle $\theta$ with respect to the layer normal) while a tensile stress lowers it[8].

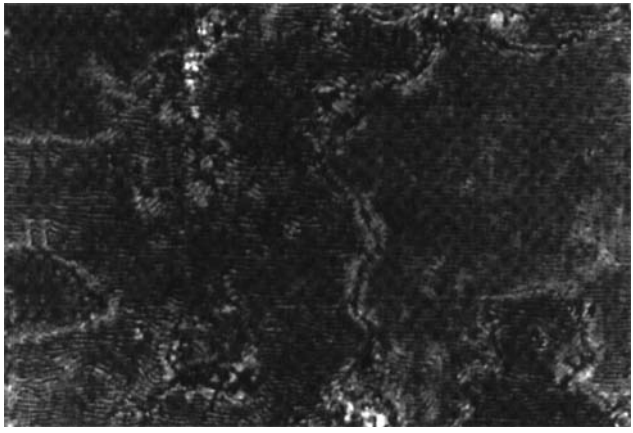

FIGURE 1 Typical edge dislocation array, viewed between crossed polarizers, at a temperature close to the SmA-SmC transition. The period of the dislocation array is about 4μm.

## RESULTS AND DISCUSSION

Figure 1 shows a typical edge dislocation array viewed between crossed polarizers. Domains of different orientations are separated by walls, whose appearance has been discussed elsewhere[9]. The period of the dislocation array is about 4μm. The edge dislocation density is $1.5 \times 10^7 cm^{-2}$ measured in a plane parallel to the smectic layers. The array of dislocations is visible within a temperature range of the order of 1°C depending on the thickness of the sample. The Burgers vector of the dislocations is the product of the angle between the glass plates and the period of the array. The wedge angle is of the order of $\sim 10^{-4}$-$10^{-3}$ rad and is measured by illuminating the cell by a laser beam and measuring the angle of the reflected beams. The Burgers vector thus obtained is of n = 1 smectic layer. The interesting point of this geometry is that under an applied stress along the layers normal (z axis):

$$\sigma_{33} = B \partial u / \partial z$$

where B is the static compressibility ($\sim 10^7$ erg/cm$^3$), the dislocations should experience a Peach-Koehler force[10] parallel to the layers[11-14]:

$$F_x = \varepsilon d \sigma_{33}$$

where $\varepsilon = \pm 1$ according to the sign of the dislocation, and $d$ is the thickness of a smectic layer. In thermotropic smectics one expects *climb* to be easier than *glide* [15], i.e., the motion of a dislocation within a smectic layer, perpendicularly to its Burgers vector, should be easy, due to the easy diffusivity of the molecules from a layer to the next. Climb is a non-conservative effect (it requires displacement of matter through the layers). The dislocations move to relax the stress. Experimentally under compression (see figure 2), we observe that dislocations move in the plane of the grain subboundary towards the thicker part of the sample. For slow enough strain rates (frequencies lower than ~1 Hz), we can observe the climb of edge dislocations and measure their mobility $m$ (defined as

the ratio of the velocity over the stress inducing the displacement: $m = v/\sigma_{33}$). A typical velocity for the dislocation climb is v~5 $10^{-3}$ cm/sec. The mobility for relaxation under constant strain is then of the order of $10^{-8}$ cgs units. Using Einstein relation $mk_BT\alpha^{-2} = D$, where $\alpha^2(\alpha \sim 0.5nm)$ is a typical cross section of a molecule in a plane parallel to the layers, and $D$ a diffusivity, one finds $D \sim 4\times10^{-8}\text{cm}^2/\text{s}$, which is a very reasonable value.

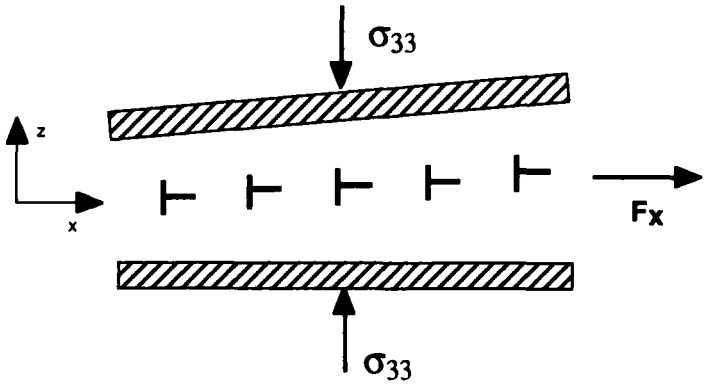


FIGURE 2 Schematic cross section of a wedge-shaped sample, containing a tilt subboundary of edge dislocations, under compression. The dislocations move to the right by the action of the Peach-Koehler force.

Figure 3 shows another edge dislocation array of Burgers vector n = 1. The main difference with respect to the first figure is that now the dislocations are strongly pinned. This pinning results from a higher density of screw dislocations in the latter sample, due to a different sample preparation process[7]. The screws are lying perpendicularly to the plane of the edge dislocation array. The points of intersection between screw and edge dislocations can be readily counted and we can calculate the screw dislocation density which is ~$10^6/\text{cm}^2$. Within the linear theory approximation screw dislocations in smectic A have no self energy (they

have only a core energy) nor do they interact among themselves. Therefore, a high density of screw dislocations can be achieved. When the sample is compressed we obtain a threshold above which the motion of the edge dislocations is no more obstructed by the screws. Near the SmA-SmC transition we have observed that unpinning occurs spontaneously from thermal fluctuations, suggesting that the pinning energy is rather small, probably of the order of Kd, where K is a Frank coefficient and $d$ the smectic layer thickness ($Kd \sim k_B T$ at room temperature in a thermotropic phase of small molecules).

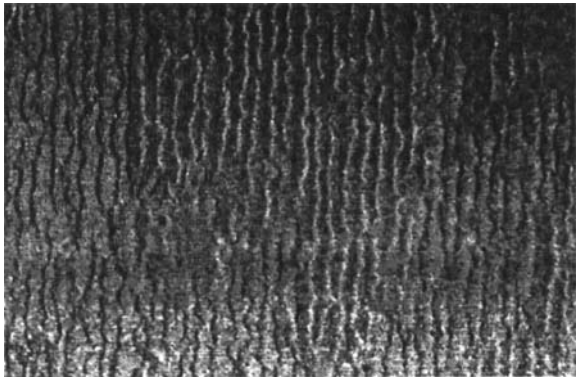

FIGURE 3 Array of edge dislocation in a wedge-shaped sample, viewed between crossed polarizers. The edge dislocations are strongly pinned on screw dislocations.

Another kind of defects in smectics are helical dislocations. Their existence was predicted a long time ago[16] but they have never been observed. When an homeotropic sample is compressed or dilated a screw dislocation, i.e., a straight dislocation line anchored on both boundary glass plates and perpendicular to the layers, change shape creating a loop. The number of such loops increases with the strain. Each loop is equivalent to the removal (compression) or addition

(dilatation) of an extra layer around the dislocation. The existence of the above helical instability of the screw dislocation was suggested by relaxation time measurements of homeotropic smectic samples under compression[17]. Figure 4 shows a helical dislocation we observed in a SmA sample after compression. The diameter of the helix is ~9μm and its pitch is ~6μm. This observation opens the possibility to check directly the hypothesis of edge dislocation multiplication from an helical source during deformation.

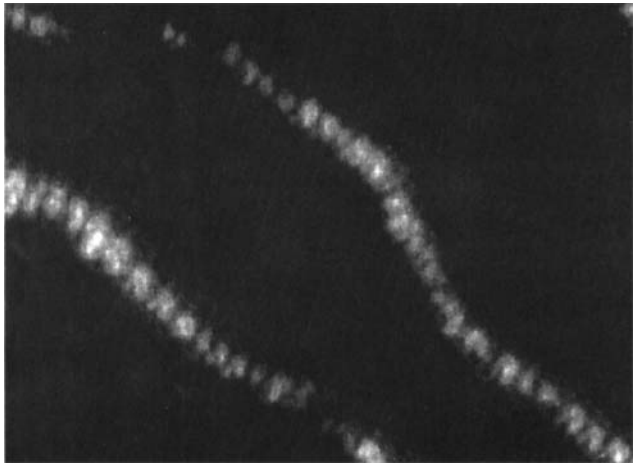

FIGURE 4 An helical dislocation in the smectic-A phase viewed between crossed polarizers. The pitch of the helix is 6μm.

## CONCLUSION

In conclusion, we directly observed edge dislocation climbing under controlled compression, and measured the climb velocity and the screw dislocation density in a SmA liquid crystal. We are presently carrying a detailed

quantitative study of the edge dislocation mobility while defect multiplication under strain will be the next subject of this work. Concerning defect multiplication we have observed the creation of helical dislocations under deformation of the liquid crystal.

**Acknowledgments**

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