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FOCAL CONICS MOTIONS AND PLASTICITY IN SMECTICS A

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Abstract. — Experimental studies on alternative shear with velocity normal to the layers of a
smectic A material with planar boundary conditions are presented. Alternative shear in the
$10^{-2}$ Hz range shows creation and vertical relative motion of two Grand-jean walls in the bulk.
Observations by means of stroboscope at $10^{-2}$ Hz frequency can be interpreted using results obtained
in the $10^{-2}$ Hz range. All these experiments show that plasticity is mainly responsible for the macro­
scopic fluidity of smectic A.

1. Introduction. — A smectic-A liquid crystal is a
layered system with molecules normal to the layers.
We thus find a nematic structure in the layers and a
quasi-solid structure along a direction perpendicular
to the layers. That anisotropy leads to different
behaviours according to the considered direction.
Many people applied stresses to a smectic-A sample.
For instance, in planar geometry (where the molecules
are parallel to the plates) C. Williams and M. Kle­
man [1] showed that, if a quasi-static shear flow with
velocity normal to the layers (the gradient velocity
being parallel to them) is applied, that leads to a
quasi-periodic pattern of dislocations changed pro­
gressively in focal conics. The same result was obtained
by L. Leger [2] by applying an electric field normal to
the layers. In homeotropic geometry (where the layers
are parallel to the plates) R. Ribotta and G. Durand [3]
showed different kinds of instability appearing under
a dilative or compressive stress.
The plastic behaviour of a smectic A was showed
off by Bartolino and Durand [4] in this same geometry.
In this paper, we show the plastic behaviour of a
smectic A with planar boundary conditions and
velocity normal to the layers (Fig. 1). For this purpose,
the smectic is placed between two plates with a strong
anchoring obtained by an oblique evaporation of SiO.

The lower plate is fixed and the upper one is related to
a loud-speaker which gives a displacement parallel
to the molecular orientation.
In previous paper [5], we showed off the appearance
of a quasi-periodic pattern of lines for a small distor­
tion of the smectic at frequency in the region of
$10^2$ Hz. These lines were interpreted as two Grand­
jean walls located in the bulk. The strain relaxation
was relaxed through the vertical relative motion of
these walls. We present here experiments performed
at $10^{-2}$ Hz range and use these results to show that
our interpretation of phenomenon occurring at $10^2$ Hz
is possible.

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Résumé. — Nous présentons les résultats expérimentaux obtenus en appliquant un cisaillement
alternatif à un smectique A en géométrie planaire, le vecteur vitesse étant normal en couche.
A basse fréquence ($10^{-2}$ Hz), on observe la création de deux parois de Grandjean. Le déplacement
vertical de ces deux parois permet de relaxer la contrainte.
Les observations effectuées à l'aide d'un stroboscope à $10^2$ Hz peuvent être interprétées à partir
de résultats obtenus à basse fréquence. Ces résultats expérimentaux montrent l'importance de la plas­
ticité dans la fluidité macroscopique des smectiques A.

Fig. 1. — The geometry for the shear flow.
2. Experimental apparatus. — The loud-speaker is feeded through a low-frequency generator and an amplifier operating from $10^{-4}$ Hz to $10^3$ Hz. The obtained displacement of the upper plate varies from several tenth of micron to several hundred micron. This displacement is controled by means of an electrostatic jauge connected to an oscilloscope and a recorder. The sensitiveness is about 0.01 μm. The sample is placed in an oven with a temperature regulation which allows a very low cooling velocity.

The observation is made by mean of a Leitz microscope between crossed polarizers. A micro-extension piece supplied with an antivibration device for the adaptation of a Leica Camera is fixed on the top of the microscope.

The sample is illuminated by a d.c white source at low frequencies and by a flash synchronized to the loud-speaker at sonic frequencies.

The smectic used is 4-cyano-4 n octylbiphenyl (K24):

$$\text{N} = \text{C} - \phi - \phi - \text{C}_8\text{H}_7.$$  

3. Alternative shear at $10^{-2}$ Hz frequency. — The experimental process is the same that the one we used at $10^2$ Hz. The sample was submitted to an alternative shear, the amplitude of them was slowly increased from 0.

For increasing amplitude of the plate displacement, one gets the following distinct features.

1) For very small tilt angle (smaller than $1^\circ$), the sample does not seem to be affected by the shear.

2) If the motion amplitude is increased (typically 3.5 μm around the equilibrium position for a 160 μm sample thick i.e a tilt angle of order 1.25°), we can see ellipses which successively appear and disappear in the bulk. A careful examination shows that these ellipses are located in two planes (two Grandjean walls) moving up and down in the bulk.

The different steps are the following (Fig. 2):

i) The two walls, with opposite directions of the ellipses, are generated in the bulk practically at the same depth. It must be pointed out that the generation of these walls does not occur at mid-course (Point A) but just after the motion is reversed (Point $A_1$).

ii) The walls move apart during the following half period ($A_1A_2$). Then the plate velocity and the wall motion both reverse, and at the end of the period the walls join and annihilate (Point $A_3$).

The axis ratio ($b/a$) remains constant during the quasi-totality of the motion. For a 160 μm thick sample, $b/a \sim 0.06$, which gives a layer tilt angle of order 2 × 3.6 d°. We can see that the motion amplitude of a Grandjean wall, in this case, equals 24 μ.

The appearance of the walls near an amplitude maximum is not easy to understand. The observed dissymetry is somehow confusing. It seems that smectic layers can tolerate some bending or that anchoring releases at the beginning (first half period). Then, when the displacement is reversed (Fig. 3), layers break in the bulk, giving the Grandjean walls.

The same phenomenon occurs if the shear amplitude is increased up to 10 μm around the equilibrium position. The focal conics excentricity remains quasi-constant and the strain increase due to the upperplate motion is relaxed by the amplitude increase of the walls vertical motion.

3) For higher magnitude of the shear (10 or 11 μm), the situation is quite different (Fig. 4):

We still have generation of two opposite walls after a maximum ($B_1$) but near the other ($B_2$), the two
walls are absorbed by both plates. When the displacement is reversed, the same phenomenon occurs: creation of couple of walls in the bulk at $B_3$ and capture by the plates in $B_4$. This result is easily understood, a $b/a$ ratio of 0.06 corresponds to a displacement of each wall equal to the half thickness of the sample.

Here symmetry is respected. Yet we have again the tolerate bend or the anchoring release, and break of the layers at the displacement reversing (Fig. 5a).

![Fig. 5. — A schematic description of the layers configuration during the shear for higher amplitude: a) the ellipses are not visible on the plates; b) if the magnitude is increased, we can see ellipses on the plates. The direction of these ellipses changes at every alternation.](https://example.com/photo6a.png)

4) When the shear amplitude still increases, the mechanism is quite similar. The difference is that instead of disappearing, the ellipses remain trapped on the plates at each maximum. Then remain there during nearly half a period, and are the replaced by opposite ellipses coming from the bulk at the next maximum (Fig. 5b). The surface trapped ellipses constitute a half Grandjean wall, with the planes of these ellipses very close to the plates. This suggests that, for high tilt angles, the anchoring cannot release enough for relaxing the layers bending.

Look now at the walls generation and annihilation process. The mechanism is quite similar but opposite.

At the beginning of the creation process, we can see, nearly in the same place, the apparition of two systems of opposite ellipses with very large ellipticities. The ellipses of one system seem to be tangent to those of the other one. Then, when the displacement goes on, the two opposite systems go apart so that the ellipses of each wall tend to be nearly tangent to vertical planes containing the hyperbolas of the other wall. It looks like two surfaces gliding one on each other (Fig. 6).

![Fig. 6. — Generation of the two walls: a) at the beginning, the two ellipses seem to be tangent; b) the two walls diverge in such a way the two focal domains remain tangent.](https://example.com/photo6b.png)
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close (Fig. 7a). The aspect is therefore the one represented on figure 7b. Later the two walls go apart and the ellipticities decrease (Fig. 7c). We get in the observation plane the configuration shown on figure 7d.

At this stage other ellipses (or defects looking like ellipses) appear inside the first one. Then, the two walls become independent and the ellipticity remains constant.

During the annihilation process (which occurs at low amplitude), this mechanism is reversed: when the two walls are close enough their focal domains become tangent and the ellipticity increases while the distance between the two walls decreases.

![Fig. 7](image1.png)

**Fig. 7.** — The two focal domains corresponding to two opposite ellipses and their aspects in the observation plane.

![Fig. 8](image2.png)

**Fig. 8.** — Quasi-periodic pattern of lines. The sample was lighted by a flash synchronized to the loud-speaker. The sample thickness was equal to 160 μm and the frequency to 100 Hz: a) the aspect of the lines near the equilibrium position; one can see on the left of the first photograph the ellipses arrangement corresponding to the B-direction on the figure 9b; b) the same lines but the photograph is enlarged; c) the aspect of these lines near a maximum of the amplitude.
4. Alternative shear in the \(10^2\) Hz range. — First results in this range have been already published. The stroboscopic apparatus has allowed us to precise these results. Moreover the results obtained at \(10^{-2}\) Hz range helped us in getting a more precise understanding of the mechanism of the walls relative motion, which allows for stress relaxation. On figure 8, are shown the photographs obtained using a flash synchronized with the displacement.

Let us describe now in some details the model of closed Grandjean wall shown on figure 9a. Call A the upper Grandjean wall and B the lower.

The first point is that A and B focal domains (giving rise to opposite ellipses) must be tangent along a common generatrix.

Another requirement is that upper generatrices of system A (and the lower of system B) must be normal to the outer layers, that is horizontal. As ellipses of each system are related by some translation operation, and, as can be seen on figure 8, they form files aligned along the velocity direction, it follows the external conical domains on each file must have a common horizontal generatrix. The higher density of ellipses is obtained when each cone has its apex on the following ellipse, as shown on figure 9a.

It must be here pointed out that, at maximum course, the planes of the ellipses are not parallel to the plates and therefore that the ellipses are not in the same place (Fig. 9a). The term Grandjean wall is perhaps not perfectly adapted.

When the amplitude of the shear decreases, the two walls draw near to each other and finally join, resuming the situation above described. But the motion goes on and the two walls tend to pass through each other. One can imagine two ways for doing that. In the first one, the two systems glide parallel to the layers. This gives the aspect shown on figure 9c. In the second one, they glide along their common generatrix and one obtains the situation shown on figure 9d. It must be noted that ellipses of systems A and B can cross each other, since they are very elongated and their distorted parts are very small and located on opposite places.

In fact, we can consider these distorted domains as kind of spheres moving up and down in the bulk. The two situations occur (see Fig. 8) but it seems that the first one is prevalent. It can in fact be considered as distorted spheres moving parallel to the layers.

5. Conclusion. — These two experiments at different frequency ranges show that, in a dynamic situation, stresses, at least in planar geometry and with the velocity normal to the layers, are relaxed by means of generation and motion of focal conics. Ellipses and hyperbolas are not the only defect that can be seen in smectic A. One can have dislocations and, in another geometry (the homeotropic one) other kind of focal conics (parabolic focal conics) can appear [7] but anyhow it seems plasticity is mainly responsible for the macroscopic fluidity of smectics A.

References