Fluid filaments

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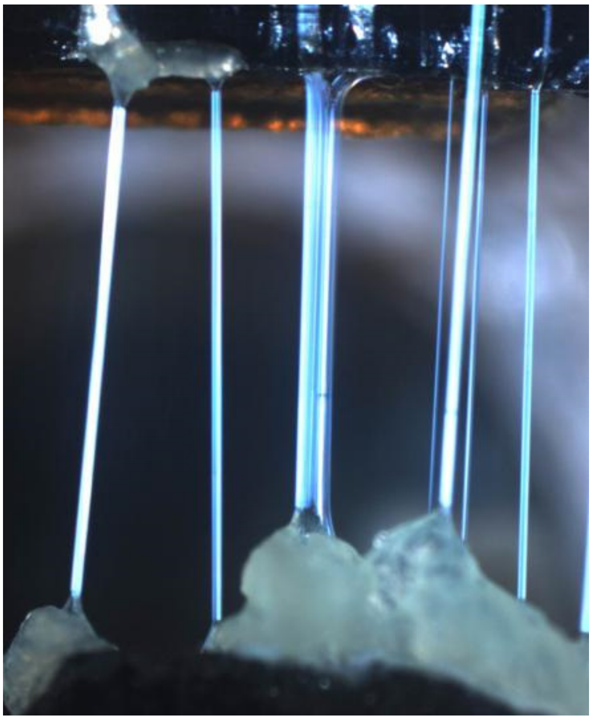
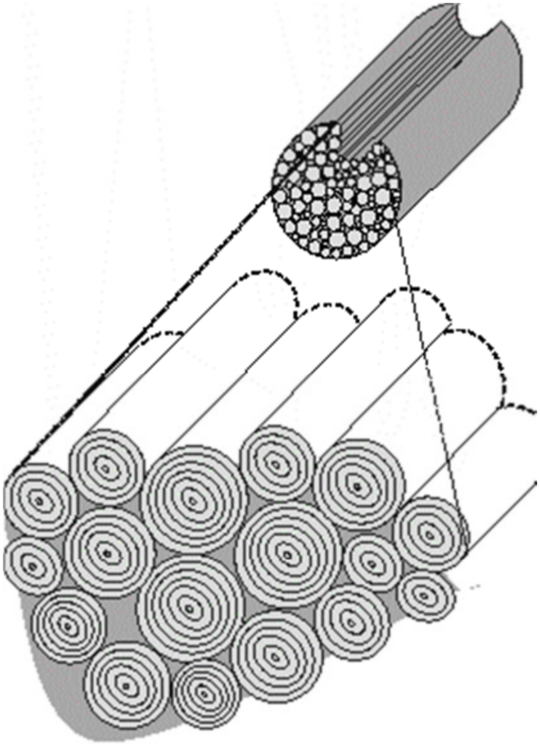
- Structure of freely suspended smectic filaments
- Tension measurements
- Electrical and mechanical field effects, oscillations
- Filaments of columnar liquid crystals

Structure of smectic filaments

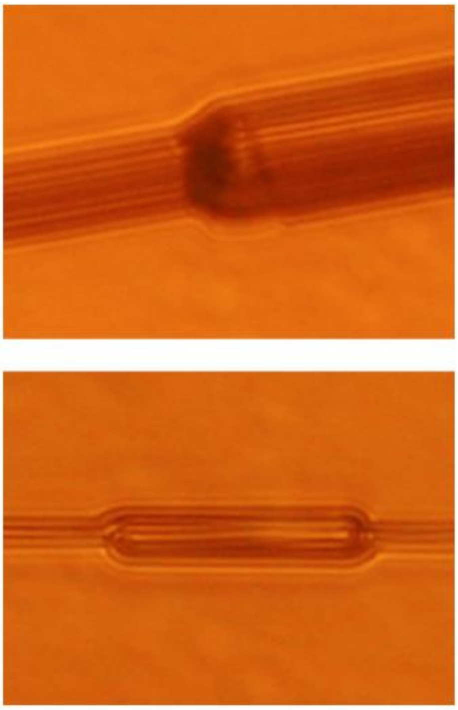
Freely suspended stable filaments with aspect ratios up to several thousands are a peculiarity of some exotic liquid crystalline phases. The filaments form, for example, when material is pulled with a needle from a reservoir. Thereby, the smectic layers align to an ordered structure. This structure stabilizes the filaments against the Rayleigh-Plateau instability, which leads to the decomposition of narrow liquid cylinders to droplets. Not all layered liquid crystal plases possess the ability to form stable filaments. Rather, these structures have so far been found only in materials with a two-dimensional order (e.g., polarization modulated smectic CP).



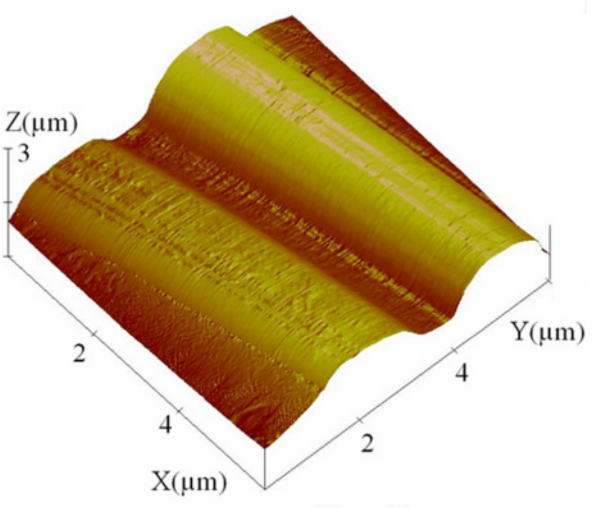
Filaments with diameters from about 2 micrometers to more than 100 micrometers can be drawn with aspect rations of several thousand.



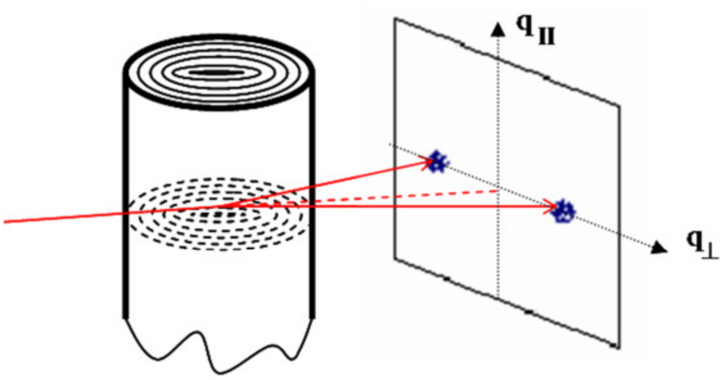
Filaments of the polarization modulated smectic CP phase (PM-smCP) are composed as bundles of thin cylindrical fibers of about 2 micrometers.



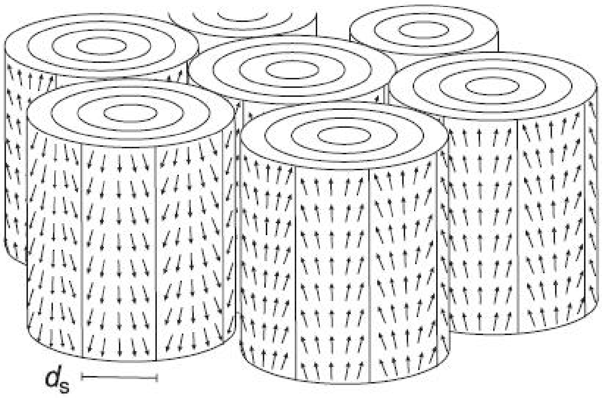
Optical images of filament details, the top image shows a dislocation where the filament thickness changes, the bottom image a thicker region in an otherwise uniform filament. Images were taken in monochromatic light, the stripes are corrugations of the filament surface, blurred by optical interferences [Eremin2005]



AFM profile of the surface of a filament (small selected area) after rapid cooling into the crystalline state. The bulges correspond to individual fibers with diameters of about 3 micrometers on the filament surface.



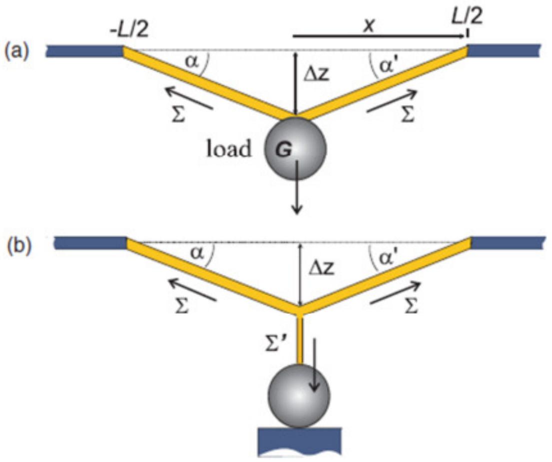
Schematic drawing of the x-ray experiment and the scattering profile, which indicates a molecular layer structure wrapped around the cylinder core.



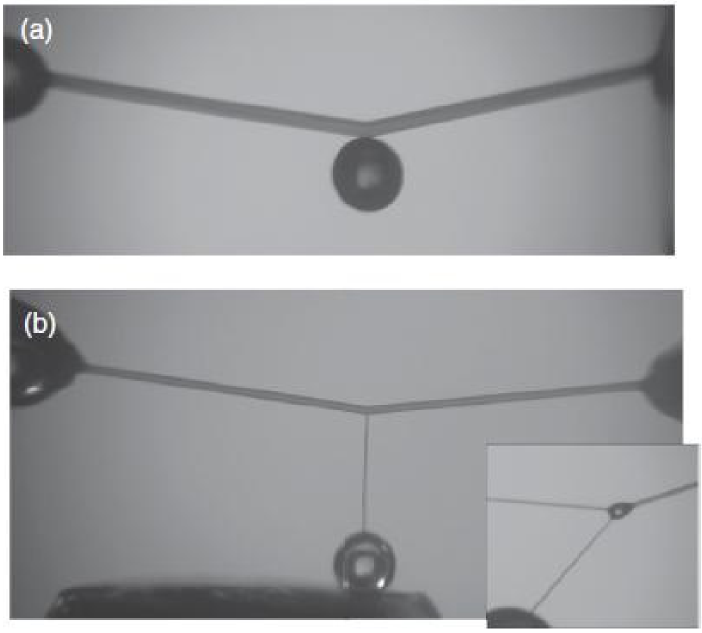
Optical Second Harmonic Generation (SHG) shows that the fiber bundles are electrically polar. The image sketches the model that assumes polarization stripes along the filament axis [Eremin2012,Morys2012].

Filament tension measurements

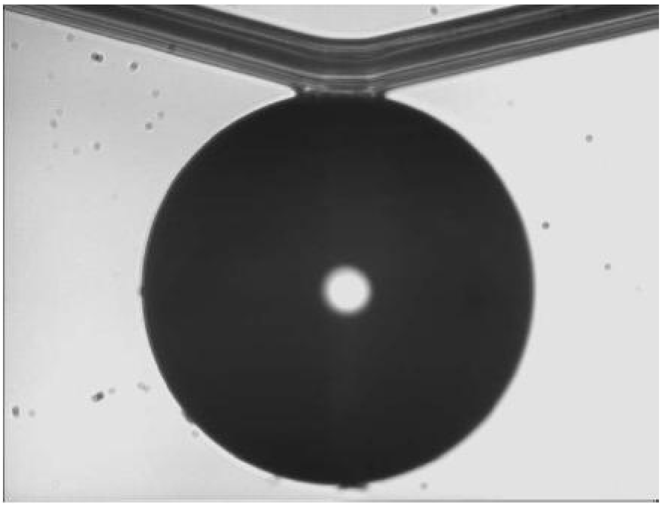
In first approximation, one may assume that the tension of the filaments should be given by capillary forces, i.e. the tension Σ of a filament with radius r should relate to the surface tension as $\Sigma = 2 \pi r \sigma$. Measurements were performed with a newly developed deflection method. When a load is attached (by capillary forces) to the horizontal filament, it deflects such that two straight arms are formed. When the two angles α and α' are equal, the tension is simply found from the known weight G by
$G = 2 \Sigma \sin \alpha$.



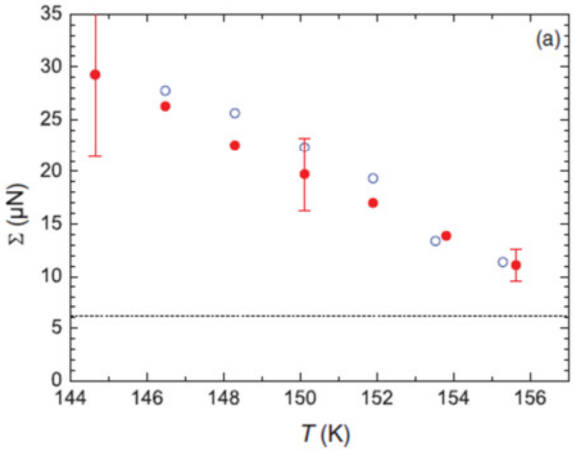
Tension measurements: The weight *G* (submillimeter sized glass or metal bead) is attached to the filament. The three forces, viz. the tensions in the two arms of the filament and the weight of the load (a), or, the tensions in the two legs of the horizontal filament and the tension in the vertical filament (b) balance each other in equilibrium. This yields either the ratio of the known weight of the load to the filament tension (a) or the ratio of tensions of filaments with different thicknesses. [Morys2012PRE,Morys2012Ferroelectrics]



Tension measurements. The above image (a) shows the deflection of the filament by a single load, the bottom images (b) show the equilibria between three filaments with different radii [Morys2012PRE].



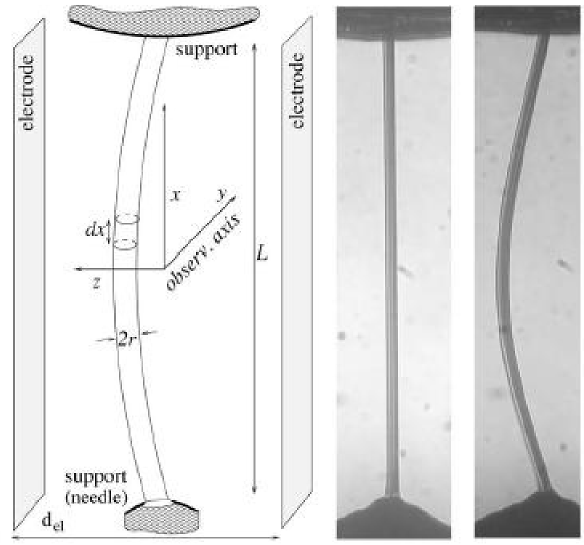
Load attached to a smectic filament by capillary forces.



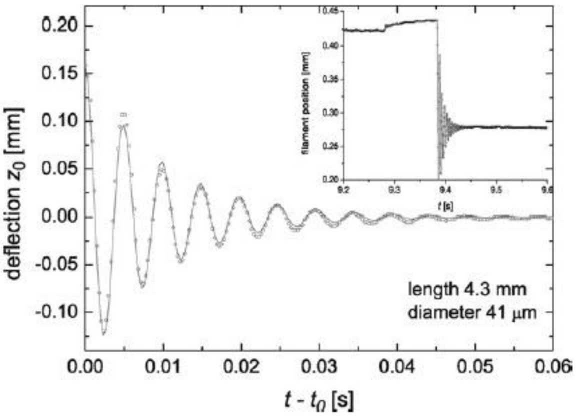
Tension of a filament with 69 micrometer radius: The filament tension increases with decreasing temperature. Only the constant part indicated by the dashed horizontal line can be reasonably attributed to the surface tension effects, the remaining contributions come from the filament bulk. [Morys2012PRE,Morys2012Ferroelectrics]

Filament oscillations

Filaments can be plucked mechanically or electrically. The measurement of eigenfrequencies can be performed either by measuring the free oscillations of the filament after the



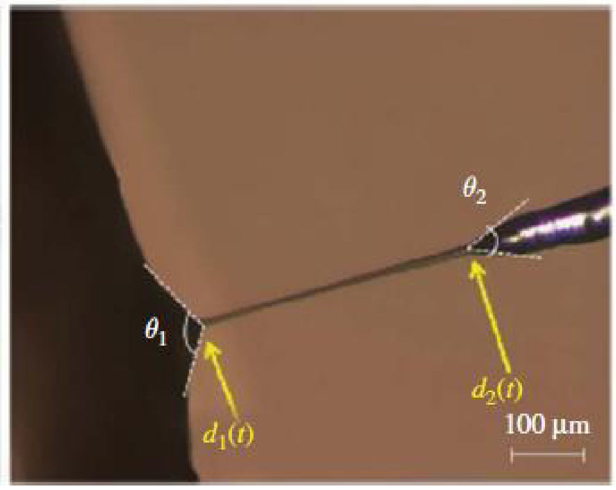
Filament plucked by means of an electric DC field [Stannarius2005]



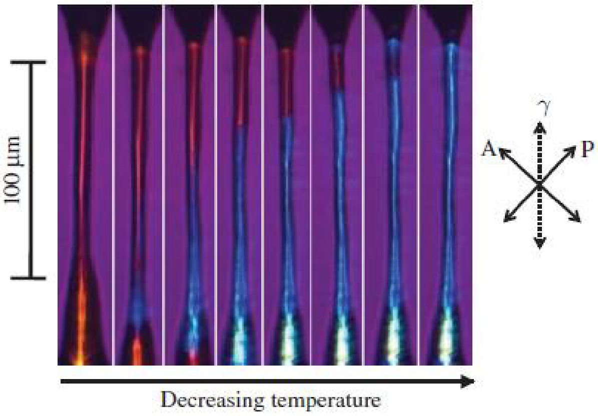
Mechanical oscillations of a filament after electrical plucking. When only capillary forces are assumed as back-driving forces, the resonance frequencies should be proportional to the inverse of the square root of the filament diameter. Actually, thick filaments oscillate much faster than predicted by that model [Petzold2009]

Filaments of columnar liquid crystals

Columnar phases can also form filaments. Their stability is much lower than that of the above mentioned smectic structures. There is evidence that long filaments are not stable. They thin gradually and break, on a time scale of few hours.



Filament of a columnar liquid crystal. Particularly interesting is the connection between the filament and the bulk. The meniscus shape is apparently conical, with a well defined contact angle at the filament base. [Ostapenko2013]



Phase transition in a thin filament. The material undergoes a transition from a hexagonal columnar phase to a body centered orthorhombic columnar phase. The image sequence taken with crossed polarizers and a quarterwave plate in diagonal orientation shows a change in birefringence. The direction of the wave plate slow axis is γ, the time between sequential images is approximately 2 minutes [Ostapenko2013].

A. Eremin, A. Nemes, R. Stannarius, M. Schulz, H. Nadasi, and W. Weissflog. Structure and mechanical properties of liquid crystalline filaments. *Phys. Rev. E*, **71** 031705, (2005).
R. Stannarius, A. Nemes, and A. Eremin. Plucking a liquid chord: mechanical response of a liquid filament. *Phys. Rev. E*, **72** 020702(R), (2005).
A. Nemes, A. Eremin, R. Stannarius, M. Schulz, and W. Weissflog. Structure characterization of free standing filaments drawn in the liquid crystal state. *Phys. Chem. Chem. Phys.*, **8** 469, (2006).
A. Nemes, A. Eremin, and R. Stannarius. Mechanical Properties of Freely Suspended LC Filaments. *Mol. Cryst. Liq. Cryst.*, **449** 179, (2006).
J. Petzold, A. Nemes, A. Eremin, C. Bailey, N. Diorio, A. Jakli, and R. Stannarius. Acoustically driven oscillations of freely suspended liquid crystal filaments. *Soft Matter*, **5** 3120, (2009).
A. Eremin, U. Kornek, S. Stern, R. Stannarius, F. Araoka, H. Takezoe, H. Nadasi, W.Weissflog, and A. Jakli. Pattern-stabilized ”decorated” polar liquid crystal fibers. *Phys. Rev. Lett.*, **109** 017801, (2012).
M. Morys, T. Trittel, and R. Stannarius. Measurement of the tension of freely suspended liquid crystal filaments. *Ferroelectrics*, **431** 129, (2012).
M. Morys, T. Trittel, A. Eremin, P. Murphy, and R. Stannarius. Tension of freely suspended fluid filaments. *Phys. Rev. E*, **86** 040501(R), (2012).
T. Ostapenko, M. Weyland, A. Eremin, M. Lehmann, and R. Stannarius. Filaments formed in the hexagonal columnar liquid crystal phase of star-shaped oligobenzoates. *Liq. Cryst.*, **3** 345, (2013).

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