Dieletrowetting of a thin nematic liquid crystal layer

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Abstract

We present a mathematical model that describes the flow of a Nematic Liquid Crystal (NLC) film placed on a flat substrate, across which a spatially-varying electric potential is applied. Due to their polar nature, NLC molecules interact with the (nonuniform) electric field generated, leading to instability of a flat film.

Implementation of the long wave scaling leads to a partial differential equation that predicts the subsequent time evolution of the thin film.This equation is coupled to a boundary value problem that describes the interaction between the local molecular orientation of the NLC (the director field) and the electric potential. We investigate numerically the behavior of an initially flat film for a range of film heights and surface anchoring conditions. Outline of the model and the results is presented here; more details can be found in [1].

Motivation

Control of evolution of dielectrowetting fluids on microscale. Example: experiments with interdigitated electrodes leading to a periodic electric field profile, see Fig. 1 [2].

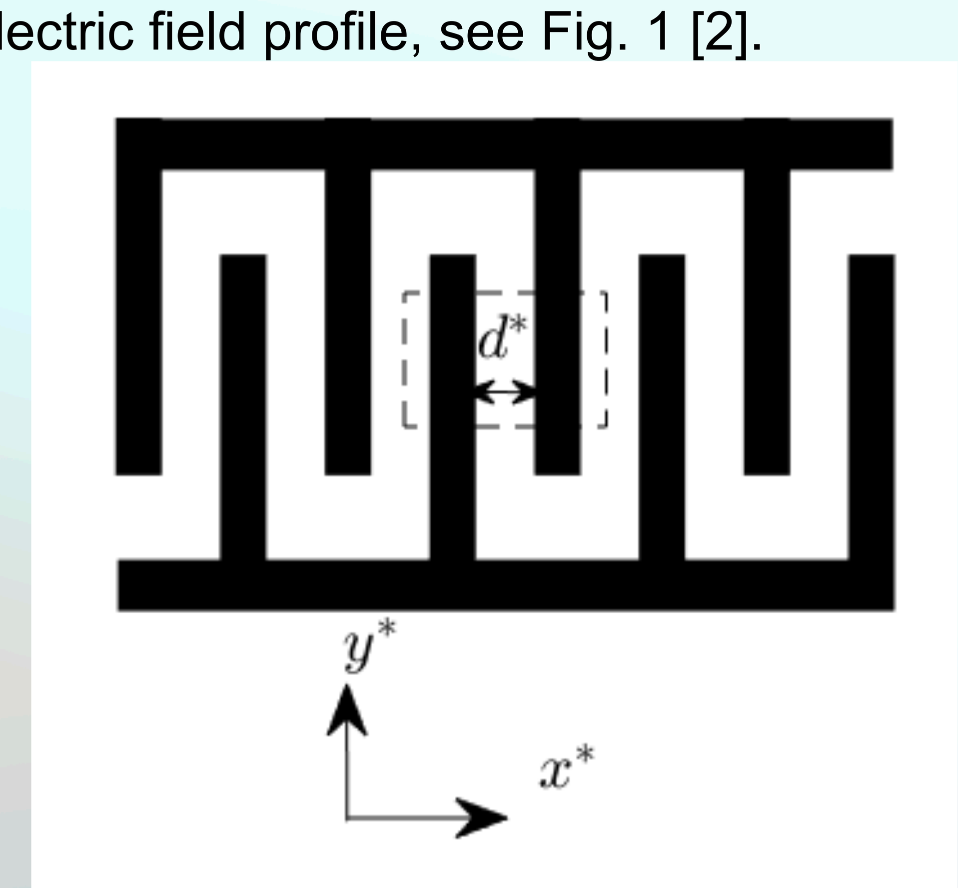

Fig. 1: Typical experimental setup, view from above, with lines showing electrodes embedded in the substrate.

Main assumptions

- NLC film is thin compared to the distance between the electrodes.
- LC director responds instantaneously to the applied electric field (time scale separation)
- Long wave theory describing thin film dynamics is appropriate.
- Leslie-Ericksen formulation describing NLC dynamics applies.
- Anchoring boundary conditions for director hold, with strong (in-plane) anchoring at the solid, and weak (normal) anchoring at the free surface.

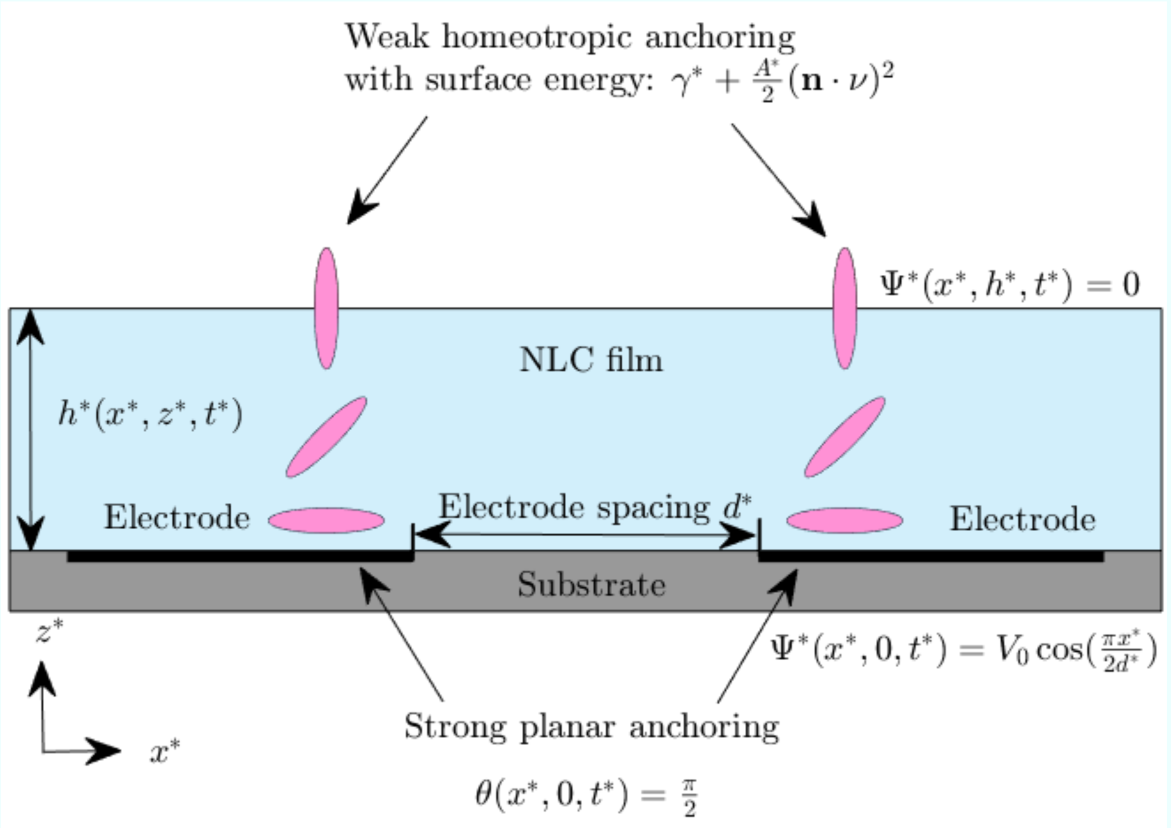

Fig. 2: Sketch of the modeling problem.

Equations

$$\frac{\partial h}{\partial t} + \mathcal{C}\frac{\partial}{\partial x}[h^3 h_{xxx}] + \mathcal{N}\frac{\partial}{\partial x} f(x,h) = 0$$

$f(x,h)$: nonlinear function of h, θ, ψ

ψ: electric potential $\qquad$ θ: director angle

θ and ψ solve following BVP

$$\theta_{zz} - \mathcal{D}\Psi_z^2 \sin 2\theta = 0$$
$$\mathcal{D}\big(\Psi_z(\varpi + \cos^2\theta)\big)_z = 0$$

(with appropriate boundary conditions). The BVP results from Euler-Lagrange equations obtained by energy minimization, see [3]. Here:

$\mathcal{C} \propto$ inverse capillary number

$\mathcal{N} \propto$ inverse Ericksen number

$\mathcal{D} \propto$ dielectric anisotropy relative to elasticity

$\varpi \propto$ dielectric anisotropy

Results

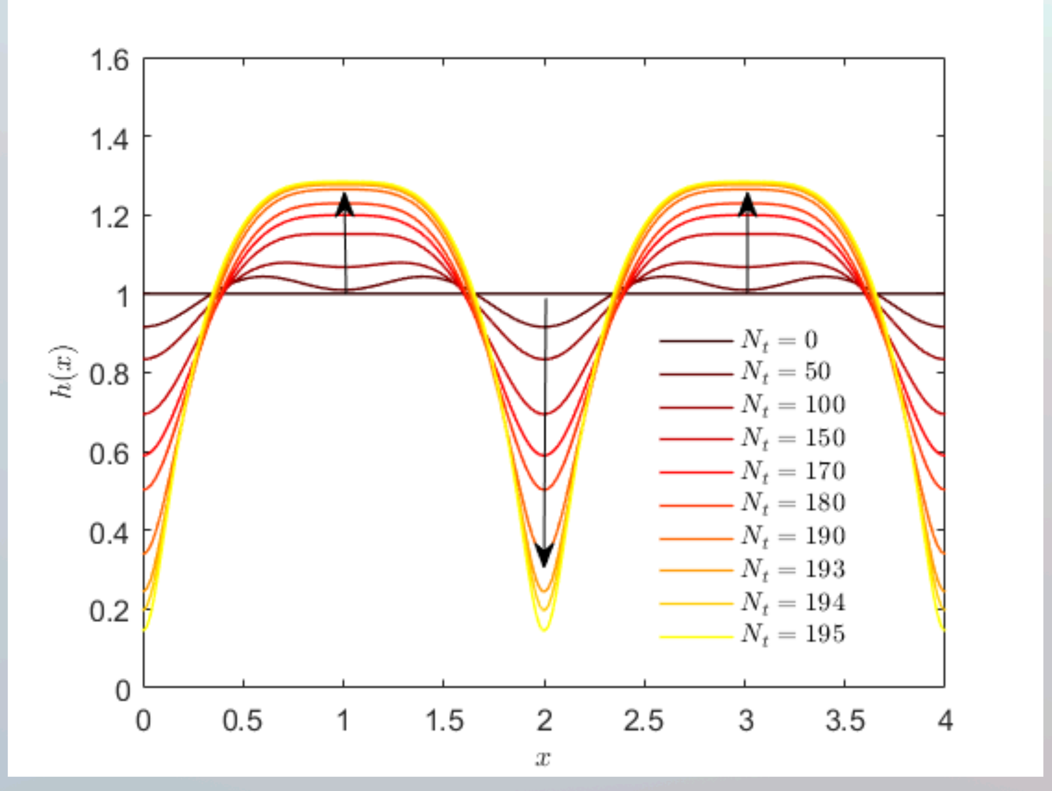

Fig. 3: Film evolution for a representative case; Nt measures the time.

Fluid `escapes' from the regions above the electrodes (at *x= 0, 2, 4)* and collects in the regions in between where the electric potential is small (*x = 1, 3).*

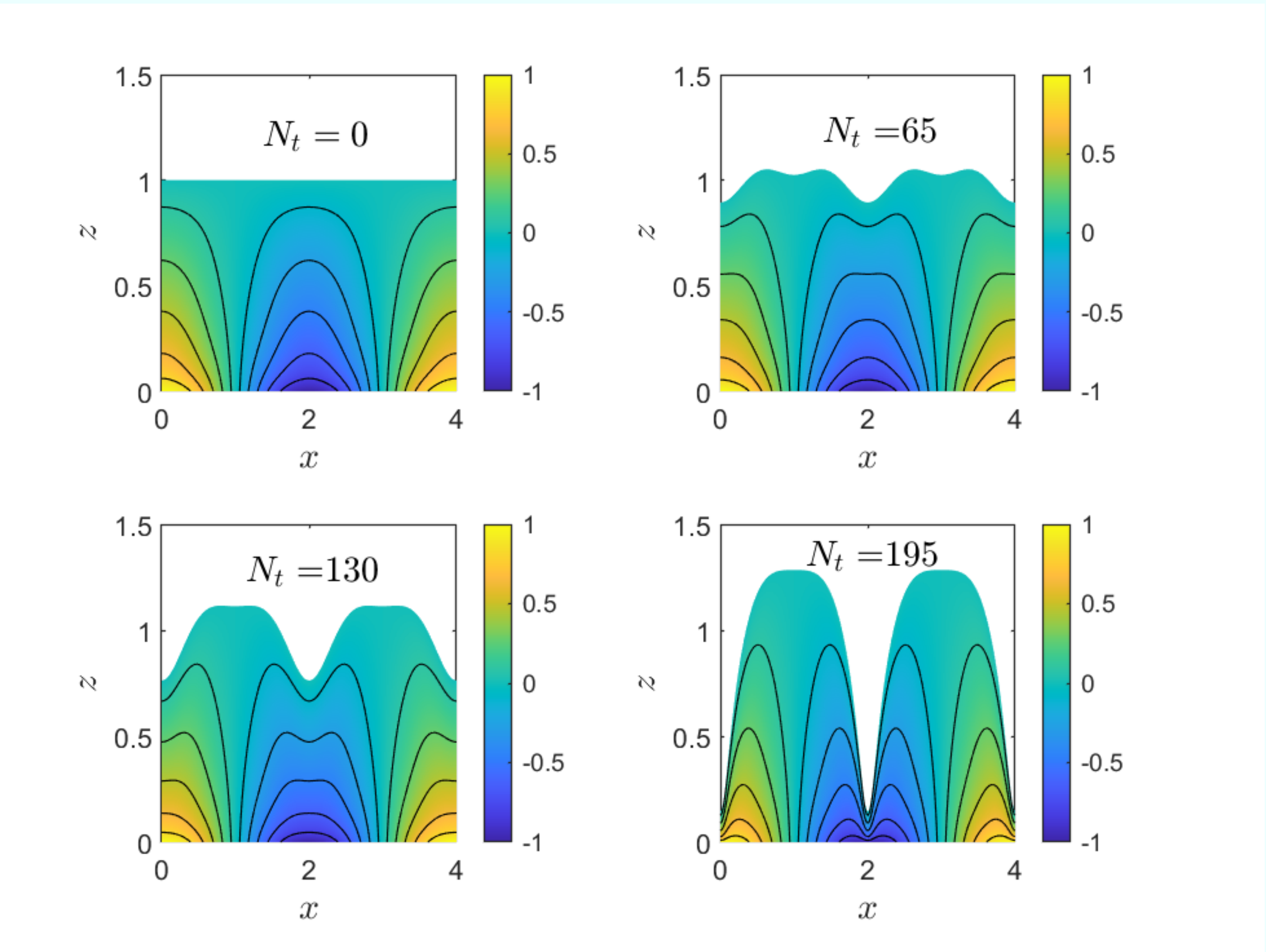

Fig. 4: Electric potential (same parameters as Fig. 3).

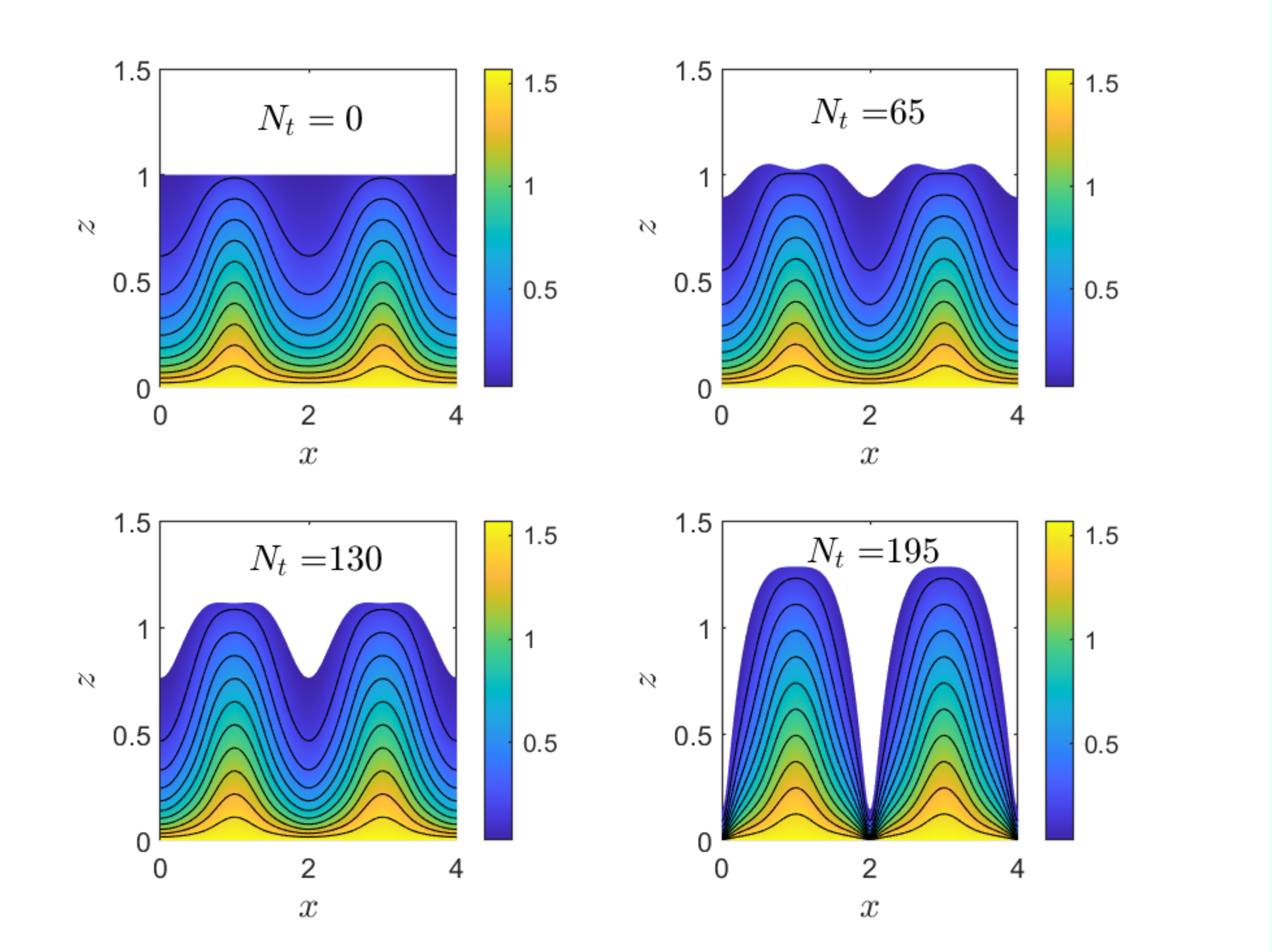

Fig. 5: Director angle (same parameters as Fig. 3).

Summary

Electric field effect can induce instability of NLC films.

Results depend on the relative balance of various relevant forces. More details in [1].

To be done: modeling of the problem where thick film thickness is comparable to the distance between the electrodes.

References

[1] Mema, E., Kondic, L., Cummings, L. J., Phys. Rev. E F **103**, 032702 (2021).

[2] Brown, C., Wells, G., Newton, M., McHale, G., Nat. Photonics **3**, 403 (2009).

[3] Cummings, L. J., Mema, E., Cai, C., Kondic, L., Phys. Rev. E **90**, 012503 (2014).