ON THE PHYSICS OF LIQUID-CRYSTAL BASED SENSORS

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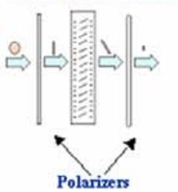
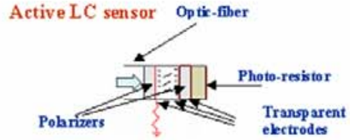
LIQUID CRYSTAL SENSORS



Depending on the nature of the sensor material, Liquid Crystal (LC) sensors can be used for detection of the wide variety of external factors: magnetic and electric fields, chemical and biological substances, temperature, pressure, velocity of the surrounding air, etc.

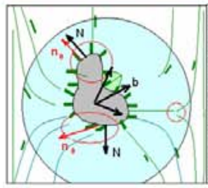
Most of the liquid crystal sensors have universal optical response.

One can consider passive and active LC sensors.



LIQUID CRYSTAL-BASED COLLOIDS (LCBC)

To improve the sensitivity and selectivity of LC sensors, one can introduce into the LC foreign particles or even micro-machines that are sensitive to the external factors.



The interaction of neighboring LC molecules with nano-particles depends on the shape of the particle and the chemical affinity with LC. It defines the boundary condition for the director on the particle surface. The long-range order of the LC "transmits" the actual boundary condition to "remote" molecules of LC and defines their orientation.

If one changes the director field or the elastic properties of LC, then one can

- **MANIPULATE THE EMBEDDED PARTICLES OR ,**
- **USE LCBC AS A SENSOR OF EXTERNAL FIELDS !**

Questions in regards to LCBC are:
- Conditions of LCBC stability
- Interaction with external fields
- Interaction with boundary surfaces;
- Optical effect

LC-SENSOR THEORY

LC free energy:

$$F = F_b + F_S + F_{int} + F_{field}$$

Frank's (bulk) free energy:

$$F_b = \int \frac{1}{2}\left(K_1(\mathrm{div}\,\mathbf{n})^2 + K_2(\mathbf{n}\cdot\nabla\times\mathbf{n})^2 + K_3(\mathbf{n}\times\nabla\times\mathbf{n})^2\right)d\Omega$$

"Suddle-splay" surface energy:

$$F_{S1} = -\int_S \frac{1}{2} K_{SS}\left[(\mathbf{n}\,\mathrm{div}\,\mathbf{n} + \mathbf{n}\times\nabla\times\mathbf{n})\cdot\mathbf{N}\right]dS$$

Rapini's surface energy:

$$F_{S2} = \int_S \frac{1}{2} W\left(1-((\mathbf{n}\cdot\mathbf{\nu}))^2\right)ds$$

Energy of interaction with vector field for non-polarized LC:

$$F_{int} = F_0 + \int_\Omega \frac{1}{2}C_2(\mathbf{n}\cdot\mathbf{h})^2 + \frac{1}{4}C_4(\mathbf{nh})^4 + \ldots = F_{int}\left((\mathbf{n}\cdot\mathbf{h})^2\right)d\Omega$$

Energy of interaction with vector field for polarized LC (ferronematic):

$$F_{int} = -\int_\Omega (\mathbf{\mu}\cdot\mathbf{h})d\Omega$$

Energy of interaction with scalar field:

$$F_b = F_0 + \int_\Omega \frac{1}{2}\left(K_1(\rho)(\mathrm{div}\,\mathbf{n})^2 + K_2(\rho)(\mathbf{n}\cdot\nabla\times\mathbf{n})^2 + K_3(\rho)(\mathbf{n}\times\nabla\times\mathbf{n})^2\right)d\Omega$$

$$F_{int} = \int_\Omega \left(A_1(\mathbf{n}\cdot\mathbf{h}_\rho)^2 + A_2(\mathbf{nn})\cdot\mathbf{R}\right)d\Omega \qquad \mathbf{h}_\rho = \nabla\rho \qquad \mathbf{R}_{ij} = \partial_i\partial_j\rho$$

COLLOID INTERACTION

Interaction of macro-molecules (nano-particles) embedded in Liquid Crystals through the perturbation of long-range order was discovered by S. L. Lopatnikov and V. A. Namiot toward the end of the 1970's. Experimental evidence of this interaction has been provided by P. Poulin, V. Cabuil, and D. Weitz in 1997. This interaction defines stability of LCBCs and opens the way to us LC as a "smart solvents" for self-assembly of small objects.


Interaction of macromolecules injected into a liquid crystal

S. L. Lopatnikov and V. A. Namiot

LC FLAT SLAB (A)

Algorithm of solution

- Minimize the bulk energy for arbitrary boundary conditions without external field
- Minimize the boundary energy without external field
- Incorporate external field
- Calculate optical effect
- Incorporate fluctuations

LC FLAT SLAB (B)

Geometry of the problem:

Frank's (bulk) free energy:

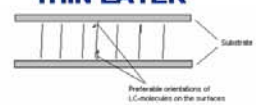
$$F_b = \frac{K_3}{2}\int\left[(1-\gamma\sin^2\Theta)\left(\frac{\partial\Theta}{\partial z}\right)^2 + \sin^2\Theta(1-\beta\sin^2\Theta)\left(\frac{\partial\Psi}{\partial z}\right)^2\right]d\Omega$$

Basic equations for 1-D case:

$$\frac{d}{dz}\left[(1-\gamma\sin^2\Theta)\frac{d\Theta}{dz}\right] + \gamma\sin\Theta\cos\Theta\left(\frac{d\Theta}{dz}\right)^2 - \sin\Theta\cos\Theta(1-2\beta\sin^2\Theta)\left(\frac{d\Psi}{dz}\right)^2 = 0$$

$$\frac{d}{dz}\left(\sin^2\Theta(1-\beta\sin^2\Theta)\frac{d\Psi}{dz}\right) = 0$$

PHASE TRANSITION IN THIN LAYER



If the thickness of the LC-slab is smaller than the correlation length of the LC-substrate contact, the force lines of the molecular field are approximately straight and the effective angle is weighted in respect to energies of coupling of LC molecules with substrate!

This opens the way for the creation of simple LC-based chemical sensors.

ACKNOWLEDGEMENTS

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