Studies of anchoring conditions for different aligning materials from the dielectric behavior of SSFLC cells.

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ABSTRACT.

The dielectric response of thin surface stabilized ferroelectric liquid crystal cells (QBS structure) with different aligning materials and filled with the same FLC mixture are studied and compared in the low frequency dielectric regime. For the measurements we adopted an improved cell structure with metallized pixel connections. In the FLC material inquestion, Merck SCE 13, only one absorption appears corresponding to a collective mode. It is ascribed to the Goldstone mode in the bulk FLC. From our measurements we calculate the surface anchoring energy density for the different aligning materials and discuss changes induced in dielectric spectra by a DC bias field.

Keywords: surface stabilized FLC cells, cell structure, dielectric spectra, anchoring, surface azimuthal angle.

1. INTRODUCTION.

Effective aligning techniques are essential for obtaining homogenous orientation of the liquid crystal in SSFLC devices. The most commonly used aligning layer is a rubbed polymer which induces an easy axis in the nematic phase. This axis may split or persist to some degree in the smectic C* phase, depending on the compatibility with the cone condition. This work investigates the changes induced in the dielectric behavior of the SSFLC cell by different aligning materials, derived from the measured complex dielectric permittivity, $\varepsilon^*(\omega)=\varepsilon'+i\varepsilon''$. The thin ($\cong$1.8 μm) cells possess a chevron, planary oriented structure without any twist deformations[1,2] (Fig. 1). For materials with $P_S<50\,\mathrm{nC/cm^2}$, far below the transition to smectic A*, there usually exists only one linear dielectric mode in the low frequency range, corresponding to the azimuthal cone angle (φ) fluctuations (the Goldstone mode in a bulk FLC) [3,4]. This mode has a strong dielectric response with a single relaxation time of about 0.15 ms. The possible lower frequency modes for a measuring voltage U> 0.05V are strongly non-linear and correspond to switching phenomena. For the studied FLC Merck SCE 13 mixture (P_s= 31 nC/cm^2) we have not encountered any other signals connected with, for instance, so called domain modes or surface domain modes[4,5,6]. The anchoring energy density, w, and surface azimuthal angle, φ_o, are evaluated with the aid of the theoretical model developed by Panarin et al.[2] for the dielectric response in chevron SSFLC cells. It is expected that the dielectric strength of a chevron structure in an SSFLC cell is given by [2]:

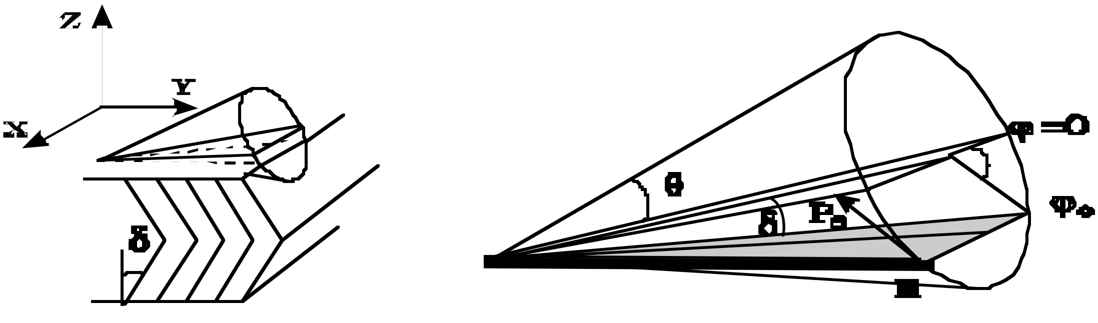

Figure 1. Orientation of the director within the chevron structure. θ is the tilt angle, φ_o the azimuthal position on the cone at the surface, and δ measures the chevron inclination ($\delta\neq 0\Rightarrow\varphi_o\neq 0$[9]). The rubbing direction parallel to Y-axis.

$$\varepsilon_0 \Delta\varepsilon = \frac{P_S^2\, d^2 \sin^2 \varphi_o}{2(2K + wd)} \tag{1}$$

and the relaxation time by:

$$\tau = \frac{\gamma\, d^2 (10K + wd)}{48K(2K + wd)} \tag{2}$$

where $K = K_\phi \sin^2\theta$ is an effective elastic constant, d is the cell gap, P_S is spontaneous polarization, and $\gamma=\gamma_\phi \sin^2\theta$ is the rotational viscosity coefficient [2], and θ is the tilt angle, c.f. Fig.1. We expect different aligning materials to produce subtle changes in w and φ_0 and thus in dielectric parameters, $\Delta\varepsilon$ and τ. By measuring $\Delta\varepsilon$ and τ, w and φ_0 can be evaluated from Eq.1 and Eq.2 provided the FLC material and cell constants are known. However, since the cells are not reusable, it is important to minimize the variation of d from the cell to cell. When trying to evaluate the very small contribution arising from the interactions between the aligning layer and the liquid crystal it is very important to be able to control other effects which could contribute to the dielectric spectra. Among the best known are other possible collective modes, as for instance those connected with twist deformations in the layer ordering and those being due to defects (zig-zag etc.). Thus, it is necessary to control the cell alignment by optical observation and remove the defects or change the ordering by application of, for instance, oscillating electric field. For this purpose the electrodes in our dielectric cells are made transparent. The commonly used electrode material, ITO, has a quite high resistance (80-20 ohm/square) and severely limits the high frequency range of the spectra (the cut-off frequency, Fig. 2). Although the collective relaxation phenomena we study generally show up below the cut-off frequency, there is a necessity of subtracting the ITO electrode contribution to the spectra[3]. This would require two additional parameters and make the results less reliable. In order to eliminate this problem and, thus enhance the spectral sensitivity for w and φ_0, we developed a cell in which ITO is used only as capacitor plates whereas the connections are covered with silver.

2. EXPERIMENT.

The dielectric response of the studied cells was measured with an HP4192A Impedance Analyzer interfaced with a PC computer. Each sample cell was placed in a brass heating chamber possessing a small window enabling microscope observations. The temperature was stabilized within 0.05 K with the aid of a PC controlled electric heater. The DC bias was applied to the cells using an internal feature of the HP4192A.

Dielectric spectra were recorded in the frequency range from 0.01 to 100 kHz [3,4,6]. As aligning materials we used Nylon 6, Nissan Ni2170, Fujitsu CRD 8616 and Teflon [7], producing low pretilt after hard rubbing. The assembled cells where all 1.8 µm thick except Teflon , 2.8 µm. The Merck SCE13 mixture has $\gamma \cong 0.236$ Pa*s , $K \cong 0.149 \times 10^{-9}$ N/m , and polarization P_s=30.6 nC/cm^2 , [2,10]. After filling, the cells did not have any defects in the active pixel area and the alignment was good. In the Teflon cell we observed some zig-zags and small twisted domains at the pixel borders. These defects resulted probably from the non-uniformity in the Teflon layer deposition, which is quite a complicated process[7]. However, since the defects constitute only a minute fraction of the pixel area the results for Teflon can be cautiously compared with other cells.

2.1 The cell construction.

We used a thin layer of chromium (200 ≈) deposited on the ITO-glass and covered with 2000 ≈ of silver in the thermal evaporation process. The metal is in contact with half of the circumference of the circular pixel (about 1 cm^2) on each of the cell substrates (Fig.2b). In such a way the uniformity of the electric field in the pixel is enhanced and the resistance/inductance effects are reduced. In our construction we also avoided the metal-metal overlapping. The resistance from the center of the pixel to the connection is reduced in this way from about 100 ohm (for pure ITO 80 ohm/square) to 0.6 ohm for the same structure but with the metal layer.

In this design band enhancement is clearly visible in the conductance G vs. frequency plots for empty cells, cf. Fig.2a. For the metallized electrode cells the electrode effects begin to show up one order of magnitude above the cut-off limit of conventional ITO electrodes while keeping a huge capacitance, C_o, and a small cell gap. At the highest operation frequencies of our spectrometer

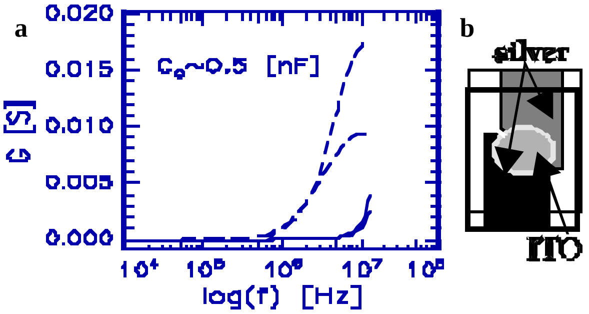

Figure 2. (a) conductance of two pure ITO cells (dashed) and two "metallized" (solid lines) vs. frequency (bridge parallel), (b) schematic view of the metallized cell

(13 MHz) the electrode effect is still only a few percent of that for pure ITO.

The stray capacitance of the metallized cell is also relatively small, usually about 15% of the capacitance measured (established by calibration measurements with CCl_4), and can be further reduced by a more precise design of the electrode geometry. By comparison, the stray capacitance for the same electrode structure made of pure ITO is of 40%. Thus, new electrodes should enable observation of the classic molecular flip-flop processes of the long molecular axis in the FLC materials, usually situated in the MHz region. However such the studies are not the subject of the present work. The results in Fig.2 show that the metallized electrodes give a reasonable compromise between golden and pure ITO structures as far as the kHz-MHz frequency range is concerned, and provide possibility for simultaneous optical and dielectric measurements.

2.2 Measurement results.

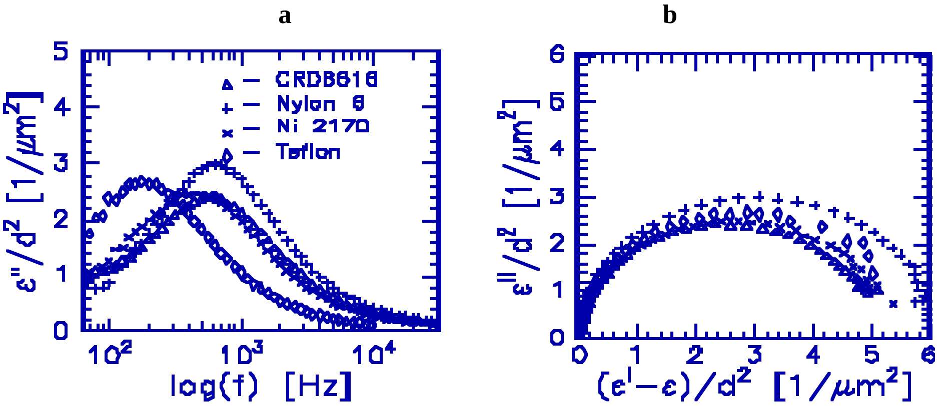

Figure 3. (a) ε”(f) spectra and (b) corresponding Cole-Cole plots for different aligning materials at T=18°C.

Typical ε”(f) spectra are shown in Fig.3a. The complex dielectric permittivity results are well fitted to the Cole-Cole expression[2,3,5]:

$$\varepsilon^*(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon}{1+(i\omega\tau)^{1-a}}, \quad \omega = 2\pi f \tag{3}$$

The Cole-Cole parameter α was usually less than 0.05 and only slightly increasing with temperature, i.e., the mode observed is a single Debye relaxation process. The anchoring energy density *w* and surface azimuthal angle $\varphi_{o,}$ of the FLC were calculated with the aid of Eq.1 and Eq.2 with fitted values of Δε and τ, cf. Table.1. The sensitivity of the dielectric spectra to the DC bias field is also studied, see Fig.4.

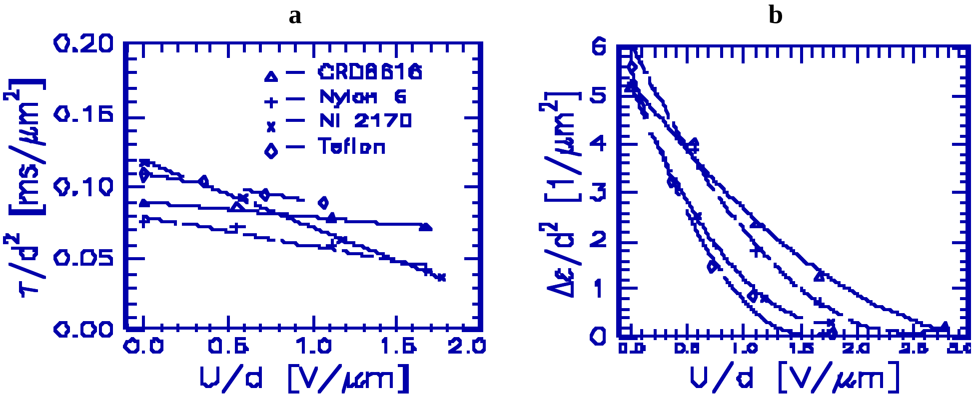

Figure 4. (a) the normalized relaxation time, τ/d^2 and (b) the normalized dielectric strength $\Delta\varepsilon/d^2$ as a function of the DC bias field for different aligning layers. Lines in (a) are linear fits, lines in (b) just guide the eye.

Layer	τ [ms] +/- 3%	τ/d^2 [ms/μm^2] +/-8%	$\Delta\varepsilon/d^2$ [1/μm^2] +/-8%	*d* [μm] +/-2.5%	φ_o[°] +/-15%	*δ* [°] +/-15%	*w* [J/m^2]*10^{-4} +/- 15%
Nylon 6	0.246	0.076	6.0	1.8	90°	29°	3.4
Fujitsu CRD8616	0.287	0.089	5.2	1.8	55°	25°	2.2
Nissan 2170	0.340	0.118	5.2	1.8	40°	20°	1.0
Teflon	0.857	0.109	5.6	2.8	50	20	0.8

Table 1. Calculated anchoring conditions for different aligning layers, T=18°C.

3. DISCUSSION.

The aligning material has a relatively weak influence on the dielectric strength $\Delta\varepsilon$ per se; more substantial variations are observed for the relaxation time τ of the measured Goldstone mode. For the materials studied the anchoring energy is of the order of the FLC elastic constant, *wd/K*≅ 1-2. For the model used, we observed a correlation between the surface azimuthal position, φ_o and the anchoring energy density, *w*. The larger *w*', the larger the surface azimuthal angle[9] φ_o. For the strong anchoring case the director is kept along the easy axis (Fig. 1, Y-axis) leading to high values of φ_o and chevron inclination angle δ, (tan(δ)≅sin($\varphi_{o,}$) tan(θ), Fig.1[2]). The strongest anchoring was observed for Nylon 6. The recently introduced Teflon aligning layer has similar properties (φ_o, *w*) to those of typical commercial polymer compounds although the layer preparation is quite different. However, the lowest anchoring energy was found for this material, which may suggest only a weak presence of the short range ordering forces arising from molecule-molecule interactions. Since very fine grooves are observed in AFM pictures of Teflon aligning layers, the anchoring may, thus, result from the mesoscopic morphological effects and steric interactions, in contrast to polymers where the van der Waals coupling with the alignment layer is an important factor.

The response of the dielectric spectral parameters to the DC bias field is in agreement with the above observation. For weaker anchoring the decrease of dielectric strength is more rapid, which suggests that the dipoles are "easier" to push towards the φ_o position than for the strong anchoring case (Fig. 4b). A structure strongly anchored at the substrates is more difficult to be driven into the quasibookshelf ordering, requiring a large deviation from the easy axis, Y (Fig. 1). The changes in the relaxation time are almost linear [5,6] and have a larger inclination angle for lower anchoring strength, *wd* (note that the Teflon cell was thicker, Eq. 2, Table.1).

The test cell design, thanks to the metallized electrodes, offers much better frequency characteristics in comparison to conventional ITO electrodes and is opening an interesting possibility for future studies of higher frequency modes combined with optical observations in liquid crystal systems.

4. ACKNOWLEDGMENTS.

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5. REFERENCES.

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