INSTABILITIES OF NEMATIC LIQUID CRYSTALS IN PULSATING ELECTRIC FIELDS

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Received 18 November 1971

The frequency dependence of the thresholf voltage for instability of an MBBA layer in pulsating electric fields is studied. Futhermore the DC level and the duty cycle of the rectangular pulses are varied for a fixed frequency. The behavior is different in the conducting and in the dielectric regime.

If a thin layer of a nematic liquid crystal sandwiched between two planar electrodes is subjected to an electric field, above a threshold voltage V_{th} hydrodynamic flow occurs [1-3]. The resulting optical patterns [1, 4, 5] have been explained on the basis of the Carr-Helfrich theory [6, 7] using the anisotropy in the conductivity. Recently these ideas have been extended to AC fields [8, 9]. We restrict ourselves further to negative dielectric anisotropy ($\Delta\epsilon = \epsilon_{\parallel} - \epsilon_{\perp} < 0$) where a division in two regimes is found [5, 8, 9]: (a) Below a critical frequency f_c there is a "conduction" regime in which the space charges oscillate while the molecular distortions are static. The period of the resulting optical pattern (domains) is of the order of magnitude of the thickness of the sample. (b) At frequencies above f_c there is a "dielectric" regime. Here the distortions of the molecular alignment oscillate while the space charge is time independent. The period of the optical pattern (chevrons) is much smaller than the thickness. The critical frequency f_c is equal to the dielectric (space charge limited) relaxation frequency and is given by $4\pi\sigma/\epsilon$, where σ is the conductivity.

In this letter the threshold voltage is identified, as usually, with the voltage where the domain or chevron pattern becomes visible under a microscope. However, this is rather arbitrary because of the dependence of the contrast ratio on the viewing angle. In general different detection methods can give very different thresholds as recently has been demonstrated in the case of a twisted nematic in a magnetic field [10]. For a comparison of sine waves with rectangular pulses, as is given in this letter, this difference is less important because the same experimental definition of the threshold is used.

The nematic liquid crystal used in N-(p-methoxybenzylidene)-p-n-butylaniline (MBBA). In fig. 1 the results are given for the conduction regime. For square waves we find a reduced critical frequency. For low frequencies V_{th} for square and sine waves are equal if expressed as RMS voltages. In order to study the dielectric regime, MBBA of higher purity was used in which the conduction regime was almost completely compressed to about 20 Hz. The results are given in fig. 2. In contrast to fig. 1 now the threshold voltage for a square wave is lower than the corresponding sine wave.

The whole series of experiments was repeated with samples in which one of the transparant SnO_2 electrodes was isolated from the nematic by a 0.6 μm layer of sputtered pyrex glass. Within the experimental accuracy of a few volts the results did not change. The isolating layers on the electrodes also permit to shift the DC level of the square wave without introducing a DC current. For rectangular pulses between 0 and $\pm V$ and for square waves between $-\frac{1}{2}V$ and $+\frac{1}{2}V$ the same threshold voltage was found.

In a further series of experiments the frequency of the rectangular pulse was fixed at 50 Hz, while its duration was varied. The results are for both regimes given in fig. 3. The thresholds were also determined with isolated electrodes. Again the DC level was found to have no influence. Consequently the DC component must be removed from the threshold voltage $V_{th}(\mathrm{RMS}) = (V_{th}^2 - \overline{V}_{th}^2)^{\frac{1}{2}}$. Starting with rectangular pulses with a duty cycle of $\frac{1}{2}$ (square waves) V_{th} increases upon variation

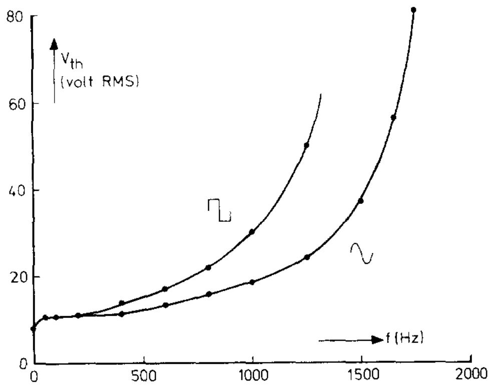

Fig. 1 Threshold voltage versus frequency for a 60 μm MBBA layer (conduction regime: $\rho \approx 10^9\ \Omega$ cm).

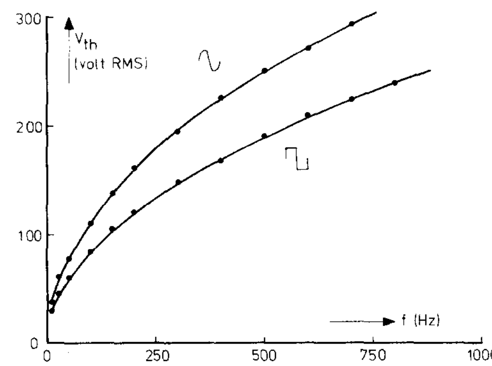

Fig. 2 Threshold voltage versus frequency for a 60 μm MBBA layer (dielectric regime: $\rho \approx 10^{11}\ \Omega$ cm).

of the pulse duration symmetrically to both sides. The harmonic content varies also symmetrically and is equal for pulses with duty cycles of e.g. $\frac{1}{4}$ and $\frac{3}{4}$. For the conduction regime there is only a small increase in V_{th} in agreement with fig. 1. However, if the frequency is fixed at a value closer to f_c the increase is more pronounced. In the dielectric regime also an increase is found in V_{th} upon variation of the duty cycle (fig. 3), while in fig. 2 higher harmonics lead to a decrease in V_{th}.

In order to understand the experimental results the theoretical treatment [9] has to be extended to square waves. Here only a few qualitative remarks will be given. If the frequency of the sine wave and the corresponding square wave is in the conduction regime and not too far from f_c, the frequencies of the higher harmonics of the square wave lie in the dielectric regime. Consequently they do not contribute to the space charge oscillations which leads already to a small increase in V_{th}. Moreover, they have a stabilizing influence through the dielectric torque which also leads to an increase in V_{th} [11]. This explains the relative order of the curves in fig. 1. In the dielectric regime the higher harmonics in the square wave contribute also to the oscillations. As experimentally a decrease in V_{th} (fig. 2) as well as an increase in V_{th} (fig. 3) is found with increasing harmonic content, a fuller theoretical treatment is necessary.

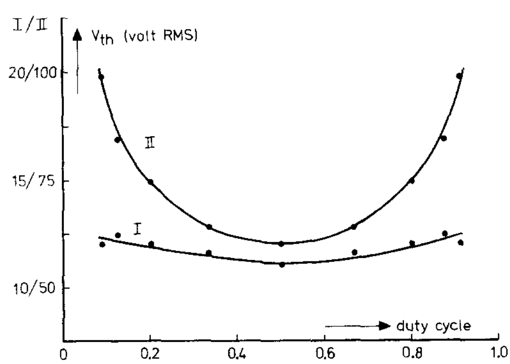

Fig. 3 Threshold voltage for a 60 μm MBBA layer as a function of the duty cycle of 50Hz pulses.
I: Conduction regime, $\rho \approx 10^9\ \Omega$ cm;
II: Dielectric regime, $\rho \approx 10^{11}\ \Omega$ cm.

The synthesis and purification of MBBA by Dr. J. v. d. Veen and helpful comments by Drs. . A. K. Niessen and J. A. Geurst are gratefully acknowledged.

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