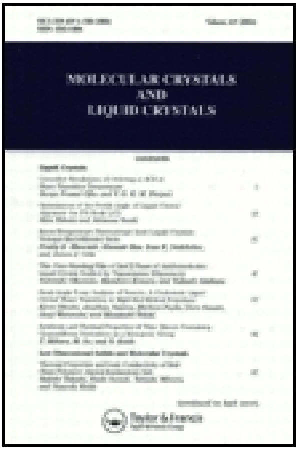

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Hysteretic Behavior of a Reversely-Pretilted Weakly-Anchored Large-Pitch Cholesteric and a Finger-Print Embedded Into a Homeotropic Matrix Under Different Sweeping Rates of an AC Voltages

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Hysteretic Behavior of a Reversely-Pretilted Weakly-Anchored Large-Pitch Cholesteric and a Finger-Print Embedded Into a Homeotropic Matrix Under Different Sweeping Rates of an AC Voltage†

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The structural transformations of an initially planar Grandjean-like texture with a weak θ-polar anchoring and a reverse pretilt of the liquid crystal at the boundaries are studied under the influence of an AC voltage with a sweeping rate of 0,02 V/sec, 0,2 V/sec and 2 V/sec. At a sweeping rate larger than 1 V/sec, the liquid crystal oscillate with a large dynamic hysteresis between the Grandjean-like and homeotropic orientations passing through a conical deformation. The increase of the voltage at a sweeping rate smaller than 1 V/sec led to a textural hysteresis resulted in Helfrich's instability, a 90° rotation of the helix and a total unwinding. The decrease of the voltage however, caused after a relatively fast dielectric reorientation the formation of domains of Rault-Cladis with a zig-zag form which after relaxation in usual fingers disappeared into the initial Grandjean-like orientation. Dynamic hysteresis was also observed in electrically-excitated finger-print embedded into a homeotropic matrix-homeotropic pseudonematic phase transformation.

Keywords: large-pitch cholesteric, homeotropic orientation, planar orientation, electro-optic behavior, dynamic hysteresis and textural transformations

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I. INTRODUCTION

The dynamic behavior of large-pitch cholesterics (Chs) under an AC voltage excitation hitherto has been insufficiently investigated[1-5] although this problem is very important both from scientific and practical points of view. Recently we have investigated the electro-optic behavior of weakly-anchored large-pitch Chs.[6] In this paper we present the experimental investigation of the dynamic behavior of the cholesteric-nematic (Ch-N) phase transition under a different sweeping rate of the excitating voltage up and down. We address ourselves to the two important cases of planar and homeotropic surface orientations of the liquid crystal (LC) which have determined either a weakly-anchored planar Grandjean-like texture or a finger-print texture embedded into a homeotropic matrix. The dynamic electro-optic behavior of weakly-anchored large-pitch Chs with planar surface orientation is described in the first part of this work. With raising of the voltage planar Grandjean-like texture—Helfrich's instability—a 90° rotation of the helix (a finger-print texture)—a homeotropic pseudonematic textural transformation was studied. At a decrease of the voltage after a fast dielectric reorientation we have observed domains of Rault-Cladis with a zig-zag form. Depending on the sweeping rate of the voltage, some of these textures can be avoided while other can appear. In the second part we focus our attention on the dynamic electro-optic behavior of large-pitch Chs with a homeotropic surface orientation resulted in a finger-print–homeotropic pseudonematic transformation.

II. Preparation of weakly-anchored large-pitch cholesteric layers

For clearness let us recall some of our recent considerations.[6] The large-pitch Chs have a pitch which is comparable to or larger than the thickness of the LC cell. In the case of homeotropic or high-tilted surface orientations of the Ch layers the pitch cannot be larger than 2–3 times the thickness of the LC since its further increase at a fixed value of the cell thickness would lead to the unwinding of the Ch and to the formation of a homeotropic pseudonematic. On the other hand, the influence of the surface coupling between the glass plates which confine the LC and the very LC is important only for the case of large-pitch Chs. The further decrease of the pitch when the ratio p/d, where p is the pitch and d is the thickness of the LC layer, is smaller than 0,2 leads to formation of confocal textures with many disclinations and/or dislocations of the Ch planes which are weakly influenced by the surface anchoring. Virtually the importance of the surface interactions between the boundaries and the cholesterics for the electro-optical behavior has been pointed out only in several papers.[6-10] The causes for this insufficient study probably are connected with the larger elastic torques of the cholesterics relative to those of the nematics which dictate the formation of the various Ch textures. For instance, the homeotropic surface orientation of the LC is capable of total unwinding of the Ch only in the case of thin Ch films with a thickness below 10 microns. Inversely, in the case of the nematics, the homeotropic surface orientation of the LC is able to form a homeotropic nematic for significantly thicker LC layers. Consequently, the formation of weakly-anchored large-pitch cholesteric layers is difficult and is connected with the way of the surface treatment.

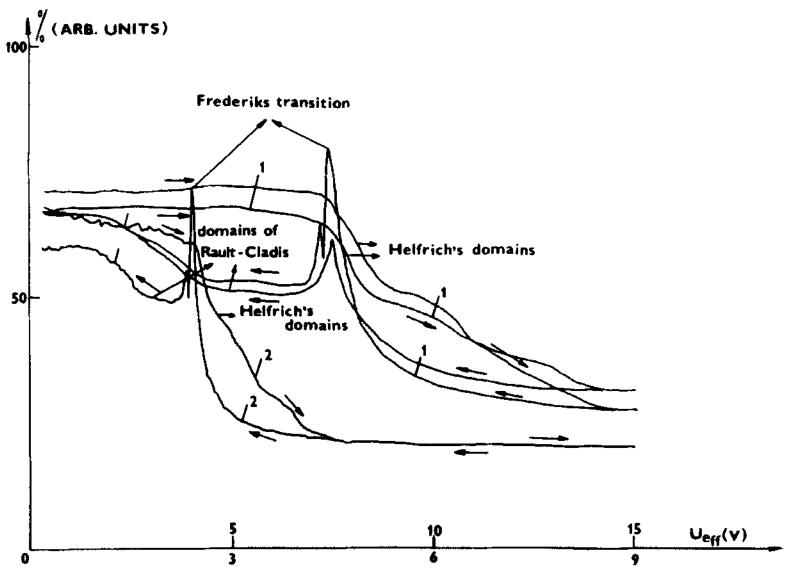
The simple technique for the preparation of weakly-anchored large-pitch Chs is described elsewhere.[6] The soap treatment of the electrodes together with the direction of the rubbing is able to predetermine the sign of the θ-polar surface deformation angle.[6] The reversely-pretilted θ-polar surface orientation of the LC usually determines a weakly-anchored planar Grandjean-like texture and the high-tilted surface orientation: a finger-print texture. The finger-print texture can be obtained without utilization of soap as well.

The Ch-N mixture under study consisted from 89% wt MBBA and 10% wt 5CB which were the nematic hosts and 1% wt CC which was the cholesteric guest. The equilibrium cholesteric pitch was measured to be around 12 microns. The thickness of the LC cells determined by Mylar spacers was around 15 microns, i.e. it was in the range of the cholesteric pitch.

III. Hysteretic behavior of a reversely-pretilted weakly-anchored large-pitch cholesteric

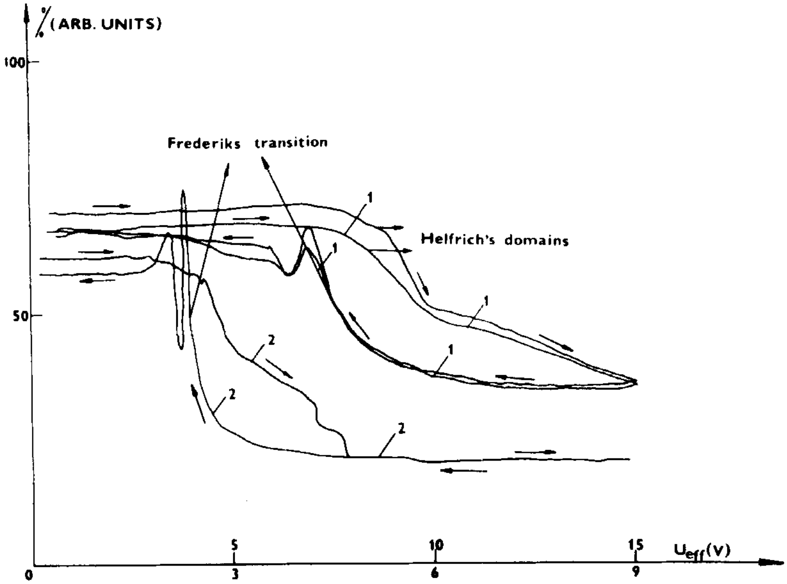
In the following we are going to present the hysteretic curves of a Ch LC with an initial Grandjean-like orientation obtained under the action of an AC voltage with a frequency of 10 kHz linearly scanning the LC cell with a different sweeping rate by a special constructed electronic device (see also Ref. 2). Meanwhile let us mention that hysteretic electro-optic curves of large-pitch Chs have been already obtained by Schadt and Gerber[4] and by Gerber.[5] The hysteresis studied by these authors has been obtained after the relaxation of various Ch textures. On the other hand, the weak surface anchoring of the Ch layers responsible for the slow relaxation of the LC director led to the experimental observation of a new dynamic hysteresis which is typical only for the reorientation of the LC director.[6] Indeed, we APRIORI know that the LC cannot immediately follow the fast change in the voltage due to the bulk rotational viscosity. Many relaxational curves of the LC have been obtained under the action of a voltage with various forms. For instance, the relaxational hysteresis is very pronounced for a rectangular form of the exciting voltage.[11] Hysteretic electro-optic curves of a twisted N layer with strong anchoring have been obtained by Vlad.[12] The low frequency of the voltage however, being in the order of 0,5 Hz, clearly shows that part of this hysteresis has been determined by the electrode polarization.[13] Hysteretic electro-optic curves of weakly-anchored twisted N layers were recently obtained as well.[14]

The recordings shown in Figures 1a, 1b, and 1c are dynamical measurements of the field-induced optical changes during the Ch-N phase



a

FIGURE 1 Dynamic hysteretic curves recorded after the application of an AC voltage with a frequency of 10 kHz linearly scanning a large-pitch Ch-N mixture consisting of 89% wt MBBA–10% wt 5CB and 1% wt CC with a pitch of 12 microns and a thickness of 15 microns. The rubbing direction is along the bisectrix of the crossed nicols. The curves designated by 1 and 2 correspond to the case of an applied maximal voltage of 9 V rms and 15 V rms, respectively. The arrows indicate the sweeping direction of the cell voltage. Initial Grandjean-like orientation of the LC:
a) A sweeping rate of the voltage of 0,02 V/sec; b) A sweeping rate of the voltage of 0,2 V/sec; c) A sweeping rate of the voltage of 2 V/sec.



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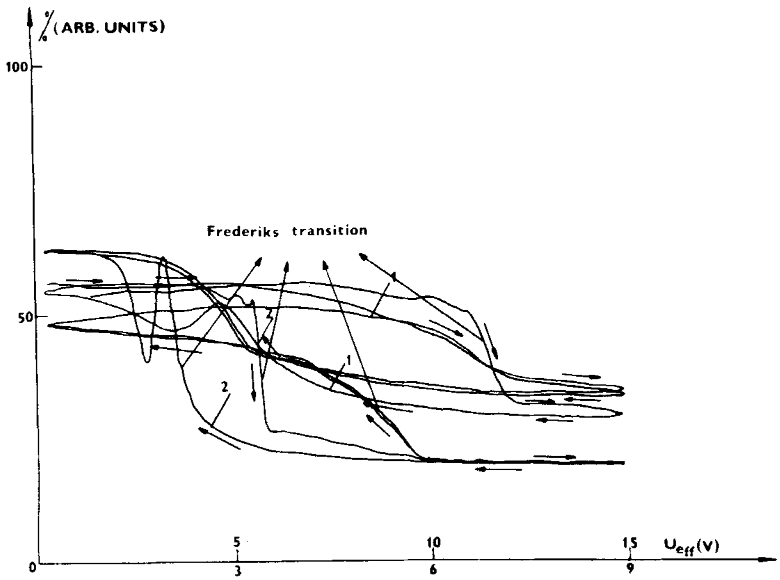

c

FIGURE 1 (*continued*)

transition in large-pitch Ch cells with a reversely-pretilted orientation and weak anchoring. Due to the weak anchoring of the LC layer the nearly complete homeotropic alignment occurs at much lower voltages than in the experiment performed by Schadt and Gerber[4] and by Gerber.[5] Analogous intermediate textures such as Helfrich's domains and finger-print domains occur for increasing fields. Our experimental curves were obtained under the action of an AC voltage of 10 kHz with a value between 0 V and 9 V rms (the hysteretic curves obtained by this voltage were designated by 1) or between 0 V and 15 V rms (the curves designated by 2). The arrows indicate the sweeping direction of the cell voltage. The sweeping rate of the voltage was 0,02 V/sec, 0,2 V/sec and 2 V/sec. To obtain further insight into the field-induced distortion of the Ch phase and its influence of the optical appearance we investigated the Ch textures in transmission under a polarizing microscope. In this way, the experimental curves shown in Figure 1a might be divided into two parts. At the increase of the voltage one notices the formation of the Helfrich's domains followed by a 90° rotation of the Ch screw axis and the total unwinding of the Ch. At the decrease of the voltage however, after a fast dielectric reorientation, domains of Rault-Cladis with a zig-zag form appear being obtained near the Ch-isotropic phase transition where the surface anchoring of the Ch layers had been weak and conically degenerated.[15] In our experiment the domains were obtained inside many bands divided by parallel fingers. At the further decrease of the voltage the Rault-Cladis domains were transformed into usual fingers which finally disappeared into the initial Grandjean-like orientation. The curves designated by 1 and 2 and illustrated in Figure 1a show that there is a difference in the relaxation when the maximal value of the voltage is 9 or 15 V rms. This difference is more pronounced for the case of higher voltages well above the threshold voltage showing the appearance of the Helfrich's domains and being around 3 V rms. On the other hand, the threshold voltages for the Helfrich's domains at the increase of the voltage and the dielectric reorientation at the decrease of the voltage were almost independent on the maximal value of the applied voltage. At increasing of the sweeping rate of the voltage up to 0,2 V/sec, the domains of Rault-Cladis disappeared as can be seen from Figure 1b. Finally, at a sweeping rate of 2 V/sec the Helfrich's domains also disappeared and the LC oscillated between the initial Grandjean-like orientation and the final homeotropic orientation passing through a conical deformation which is illustrated in Figure 1c. It is clear that these hysteretic curves

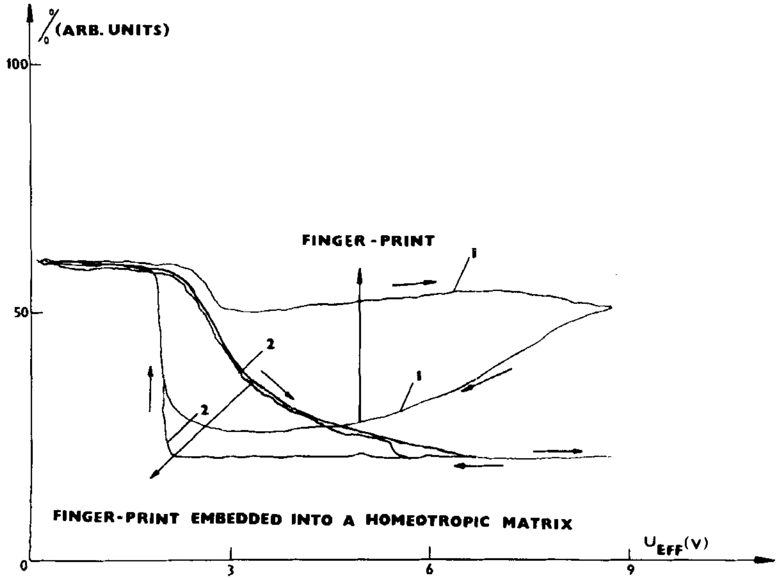

FIGURE 2 Dynamic hysteretic curves recorded after the application of an AC voltage with a frequency of 10 kHz linearly scanning a large-pitch Ch-N mixture consisting of 89% wt MBBA–10% wt 5CB and 1% wt CC with a pitch of 12 microns and a thickness of 15 microns. The rubbing direction is along the bisectrix of the crossed nicols. The curves designated by 1 correspond to the case when the initial texture is a finger-print determined by the reversely-pretilted orientation of the LC at the boundaries whereas the curves designated by 2 correspond to the case when the initial texture is a finger-print embedded into a homeotropic matrix and determined by the high-tilt of the LC at the boundaries. The former texture is metastable and after the first cycle the orientation became a finger-print embedded into a homeotropic matrix which at the further increase of the voltage is transformed into a homeotropic pseudo-nematic. The arrows indicate the sweeping direction of the cell voltage.

are purely dynamic and show the slowness in the relaxation of the LC director relative to the sweeping rate of the AC voltage.

IV. Hysteretic behavior of a finger-print embedded into a homeotropic matrix under an AC voltage excitation

The Ch layers were prepared without the utilization of soap. The rubbing determined finger-print when the orientation of the LC at the boundaries was reversely-pretilted or finger-print embedded into a homeotropic matrix when the orientation of the LC at the boundaries was highly-tilted. The dynamical hysteretic transformations of

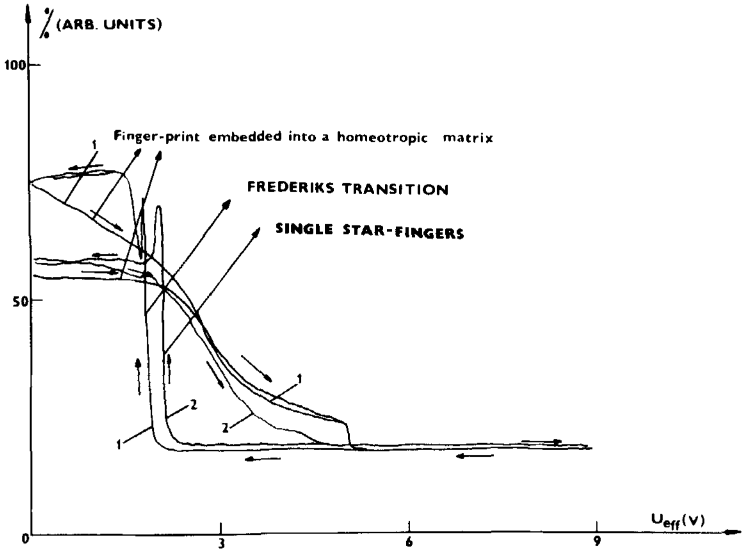

FIGURE 3 Dynamic hysteretic curves recorded after the application of an AC voltage with a frequency of 10 kHz linearly scanning a large-pitch Ch-N mixture consisting of 89% wt MBBA–10% wt 5CB and 1% wt CC with a pitch of 12 microns and a thickness of 15 microns. The rubbing direction is along the bisectrix of the crossed nicols. The initial texture is a finger-print embedded into a homeotropic matrix. The curves designated by 1 correspond to a sweeping rate of 0,2 V/sec while the curves designated by 2 correspond to a sweeping rate of 0,02 V/sec. The arrows indicate the sweeping direction of the cell voltage.

these two typical textures for a sweeping rate of 0,2 V/sec are shown in Figure 2, curves 1 and 2. It is immediately seen that the finger-print texture embedded into a homeotropic matrix is more stable. The further change of the voltage up and down again yielded the dynamic hysteretic curve, designated by 2. Let us note that this curve was already obtained by Greubel for a sweeping rate of the voltage approximately 0,3 V/sec.[16] The dynamic curves for a sweeping rate of the voltage of 0,02 V/sec and 1 V/sec, 2 V/sec and 3 V/sec are illustrated in Figures 3 and 4, respectively. At the increase of the sweeping rate of the voltage the hysteretic area increases and the form of the hysteretic curves become very complex. This hysteresis is a combination between the Greubel's hysteresis and the new dynamic hysteresis due to the difference in the relaxation of the Ch director and the sweeping rate of the voltage. This large hysteresis depends crucially on the rate of the scanning.

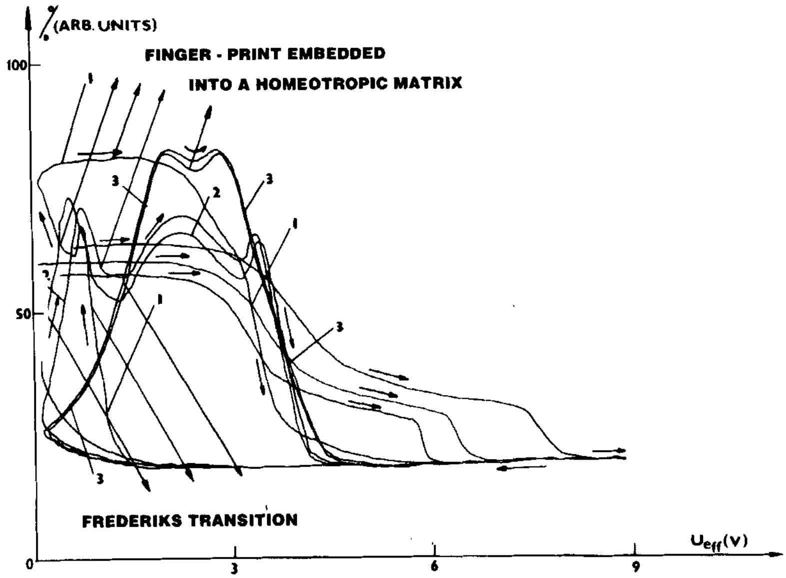

FIGURE 4 Dynamic hysteretic curves recorded after the application of an AC voltage with a frequency of 10 kHz linearly scanning a large-pitch Ch-N mixture consisting of 89% wt MBBA–10% wt 5CB and 1% wt CC with a pitch of 12 microns and a thickness of 15 microns. The rubbing direction is along the bisectrix of the crossed nicols. The initial texture is a finger-print embedded into a homeotropic matrix. The curves designated by 1, 2 and 3 correspond to a sweeping rate of the voltage of 1 V/sec, 2 V/sec and 3 V/sec, respectively. The arrows indicate the sweeping direction of the cell voltage.

Discussion

Let us start with a discussion of the Ch textures observed in our study. The Helfrich's instability in large-pitch Chs has been widely studied both theoretically and experimentally (a great part of these papers are cited in our recent study[6]). Additionally it is necessary to mention the results obtained during the last two years.[10,17,18,19] The undulations of the Ch planes observed in our experimental cells were characterized by the low threshold voltage indicated the weak anchoring of the Ch layers. Furthermore, at increase of the voltage the domain stripes were directly transformed into fingers which again demonstrated the weak anchoring of the LC. Due to this weak anchoring the nonuniform Ch-N phase transition studied by Yu and Labes[8] was not observed. Meanwhile let us mention that the dynamics of the finger transformation into a homeotropic pseudonematic now is dis-

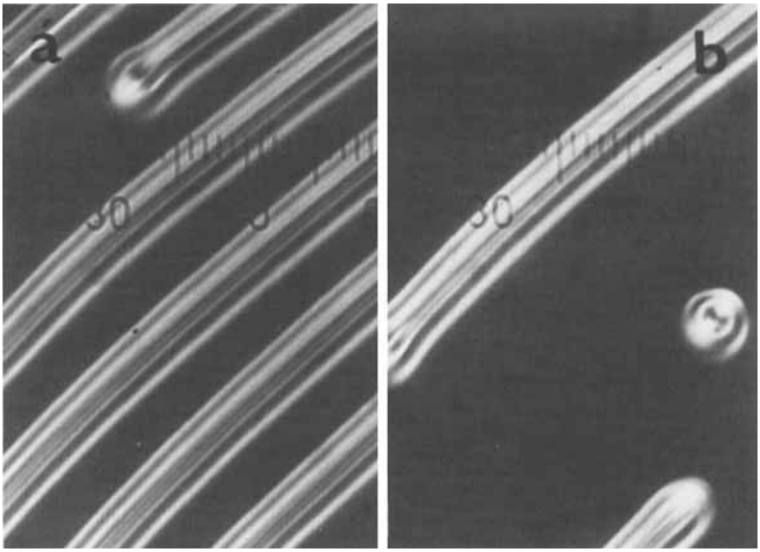

FIGURE 5 Uniform nonlinear disappearance of fingers into a homeotropic pseudonematic in a large-pitch Ch-N mixture consisting of 89% wt MBBA–10% wt 5CB and 1% wt CC with a pitch of 12 microns and a thickness of 15 microns:
a) An applied voltage of 3 V rms, crossed nicols, 10 divisions correspond to 54 microns;
b) An applied voltage of 4 V rms, crossed nicols, 10 divisions correspond to 54 microns.

cussional and evidently is different in the various cases.[1] For example, the photos shown in Figures 5a and 5b and illustrating the way of the finger disappearance under voltage application clearly demonstrate that in our experiment the LC in the fingers is oriented in agreement with the recent models of Stieb[20] and Hirata et al.[21] There were only normal disclinations in one of the two ends of the fingers as is illustrated in Figure 5a and again is confirmed by the further relaxation of some of the fingers into bubble domains shown in Figure 5b.[20] The textural transformations of the finger-print into a homeotropic pseudonematic at increasing fields revealed their strongly-nonlinear first order phase character confirmed also by the large dynamic electro-optic effect observed in our experiment. The relaxation of the homeotropic pseudo-nematic at decrease of the voltage however, was accompanied by large nonuniform undulations of the Ch planes[8] illustrated in Figures 6a and 6b. As a consequence, the appearance of the Rault-Cladis domains in a dynamic regime (the domains shown in Figures 6a and 6b were taken in a static regime) is governed by the surfaces. In addition, the fairly well reproducible experimental results and the possibility for obtaining of slightly changing hysteretic curves at the cycling of the voltage demonstrated that the exact way in which the fingers are nucleated from the walls has been avoided. Let us mention that the dynamic electro-optic effect which might be eventually obtained from Ch textures with disclinations in the plane of the electrodes would be different.[22,23]

The dynamic electro-optic hysteretic curves shown in Figures 1–4 point out that after applying the voltage the LC is taken out of the equilibrium state into a hysteretic state displaying a reproducible hysteretic area at the increase or decrease of the voltage. This hysteretic area depends crucially on the threshold and maximal values of the voltage and on the sweeping rate of the voltage and at certain conditions may be maximal (see Figures 1–4).

The structural transformations of an initially-planar Grandjean-like texture with a weak θ-polar surface anchoring and a reverse pretilt

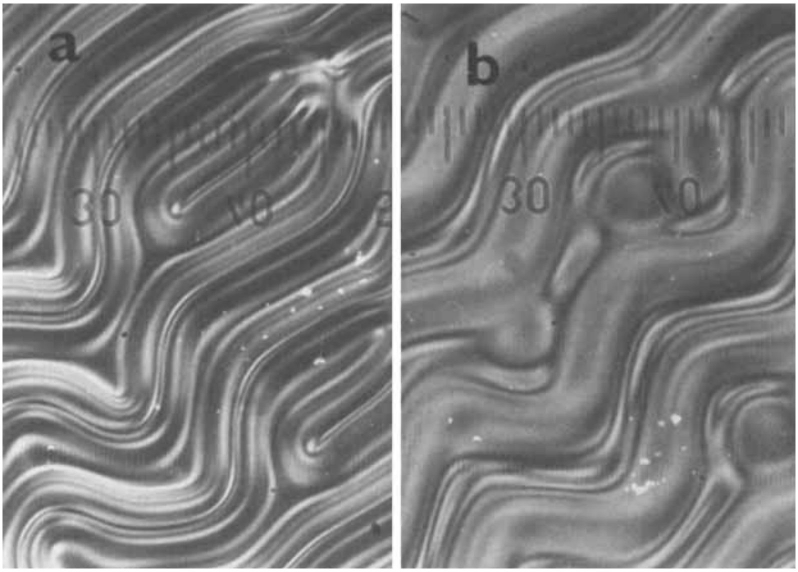

FIGURE 6 Nonuniform nonlinear appearance of fingers in a large-pitch Ch-N mixture consisting of 89% wt MBBA–10% wt 5CB and 1% wt CC with a pitch of 12 microns and a thickness of 15 microns:
a) An applied voltage of 2 V rms, crossed nicols, 10 divisions correspond to 54 microns.
b) An applied voltage of 1 V rms, crossed nicols, 10 divisions correspond to 54 microns.

of the LC at the electrodes under the influence of an AC voltage with a different sweeping rate of 0,02 V/sec, 0,2 V/sec and 2 V/sec unambiguously show textural and/or dynamic hysteresis. At a sweeping rate larger than 1 V/sec the LC oscillate with a large dynamic hysteresis between the Grandjean-like and homeotropic orientations passing through the conical deformation.[24-27] Virtually these dynamic electro-optic hysteretic curves were obtained in a conoscopic regime.[14,28] On the other hand, the decrease of the sweeping rate of the voltage linearly scanning the Ch layers, led to the transformation of the Helfrich's domains into finger-print domains at the increase of the voltage and to the transformation of the Rault-Cladis domains into finger-print domains at decreases of the voltage. Of course these important values of the sweeping rate will change certainly with the change in the LC thickness, the p/d ratio and the surface orientation or anchoring of the LC.

Although the dynamic hysteresis displayed by the nematics or cholesterics has been known a many years ago, this problem hitherto has not been studied in detail. The hysteresis evidently is connected with the viscosity of the LC. However, the hysteresis crucially depends on the anchoring of the LC as well. For instance, the weak surface anchoring permits the slow relaxation of the LC and consequently facilitates the easier observation of the hysteresis. Different roles play the rotational bulk viscosity, the back flow, the surface rotational viscosity in the case of weak anchoring, the LC orientation at the surfaces and the thermal fluctuations, etc. It is worthwhile to mention that the excitation of the Chs in a dynamic regime permits at some sweeping rates of the voltage the avoiding of typical Ch textures such as the Helfrich's domain or the finger-print domains and at the same time facilitates the observation of some new textures such as the domains of Rault-Cladis which have been rarely observed. On the other hand, this way of voltage excitation permits the investigation of the conical deformation usually hindered by the various Ch textures.

The aim of this paper was to demonstrate the existence of the dynamic hysteresis. On the other hand, there are possibilities for the eventual application of this effect in the LC matrices with storage. For instance, the dynamic hysteresis can aid for the eventual erasing of the static storage or can replace the usual 1:2 or 1:3 voltage supply with more simple. The great simplicity of the surface preparation technique and the fairly well reproducibility of the experimental results permits the application of this novel effect in the large-area LC displays working with large-pitch Chs.

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