Visualization of the dynamics of domain structure in collinear ferroelectrics

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Changes in the domain structure of collinear ferroelectrics during switching are visualized by using nematic liquid crystals.

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The dynamics of the domain structure underlies the switching of ferroelectrics, the most important feature of their behavior in external fields. An in-depth study of the polarization and repolarization is consequently impossible without direct observation of the changes in the domain structure of a ferroelectric. However, if such observations are not difficult for ferroelectrics with optically distinguishable domain structure (see the survey in Ref. 1, for instance) such a problem is quite complex in collinear ferroelectrics[2] for which the antiparallel (180-degree) domains are, in principle, optically indistinguishable. This explains the large number of attempts to propose methods for observing the dynamics of domains in such crystals.[3-9]

The simple method for visualizing the 180°-domains in uniaxial ferroelectrics of collinear type, triglycine sulfate (TSG) crystals, is proposed in Refs. 10 and 11 by using the superposition of a nematic liquid crystal (NLC) on the surface of its chip. The antiparallel domains appear as "black" and "white" regions in observations with transmitted polarized light in the crystal extinction position. The reason for the contrast was investigated in detail in Ref. 12. However, the black-white contrast (i.e., the different orientation of the NLC layers) does not occur in antiparallel domains on a polished (or etched) surface because of the production by the treatment, of a degraded layer on the crystal surface. We have established that the visualization of both the static domain structure and its dynamics is possible on any treated surface by using a NLC if an electrical field is applied to the ferroelectric crystal.

A cell used for the observations in electrical fields consisted of the crystal specimen to be investigated (0.5 – 5 mm thick) with a thin NLC layer superposed on its surface, where the NLC thickness was set by teflon spacers (1 – 10 μm) and two glass plates, where inner surfaces in this sandwich were coated by a current-conducting SnO_2 layer. Nematic liquid crystals, with both negative (MBBA and a mixture of cyanostilbenes) and positive (a mixture of cyanodiphenyls and tolanes) anisotropy of permittivity $\Delta\epsilon$ were used.

The regions of the domain walls become quite distinguishable in both polarized and unpolarized light when an electrical field is applied to the ferroelectric-NLC sandwich.

A picture of the domains, observed in polarized light in a sinusoidal electric field

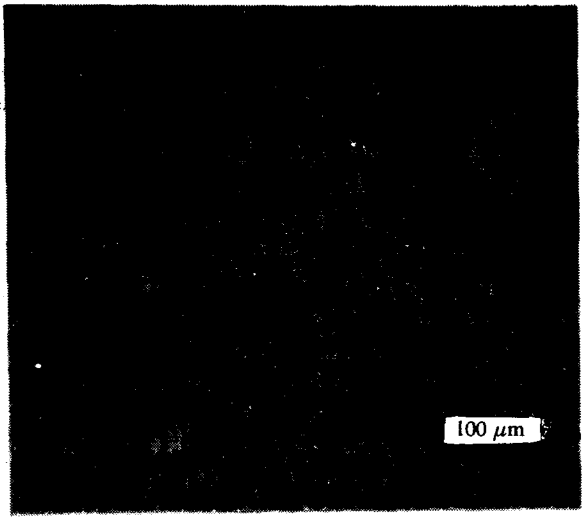

FIG. 1. Domain structure of a DTGSel crystal observed in polarized light by using a NLC ($\Delta\epsilon > 0$) in a sinusoidal electrial field $V = 20$V, $f = 500$ Hz; crystal thickness is 1 mm.

with $V = 20$ V, and $f = 500$ Hz on a section of deuterized triglycine selenate crystal in a direction perpendicular to the $\mathbf{P}_s$ of the crystal, is shown in Fig. 1. In polarized light, the domain wall regions in a NLC with $\Delta\epsilon > 0$ are dark lines (homeotropic orientation) of a width on the order of the thickness of the NLC layer, on both sides of which diffuse light fields of inhomogeneous orientation of NLC are observed (in the crystal extinction position). In NLCs with $\Delta\epsilon < 0$ the wall regions correspond to planar orientation of the NLC molecules, where an electrohydrodynamic (EHD) instability and dynamic scattering start to be observed in these regions at a definite threshold voltage.[13,14]

The appearance of contrast in the domain walls corresponds to a voltage drop exceeding the threshold of the Frederickse effect, if $\Delta\epsilon > 0$, or the threshold EHD effect if $\Delta\epsilon < 0$, on the NLC layer thickness above the domain wall. The voltage drop in the NLC layer above the rest of the ferroelectric remains low.

Such a redistribution of the electrical field potential in the ferroelectric-NLC system is explained by the fact that the ferroelectric impedance is low in regions where repolarization takes place.[6,15] Hence, a definite part of the applied voltage starts to drop in the liquid crystal in these regions of the sandwich.

In order to fix the position of the moving domain walls, it is convenient to apply a weak high-frequency field simultaneously with the repolarizing constant field. The high-frequency field will only produce conditions for the visualization of the existing domain walls.

The domain structure of a unipolar TSG crystal in a sinusoidal electrical field of frequency 500 Hz (Fig. 2a) and its change after the action of a series of rectangular constant field pulses which contribute to the growth of domains of one sign (Figs. 2b

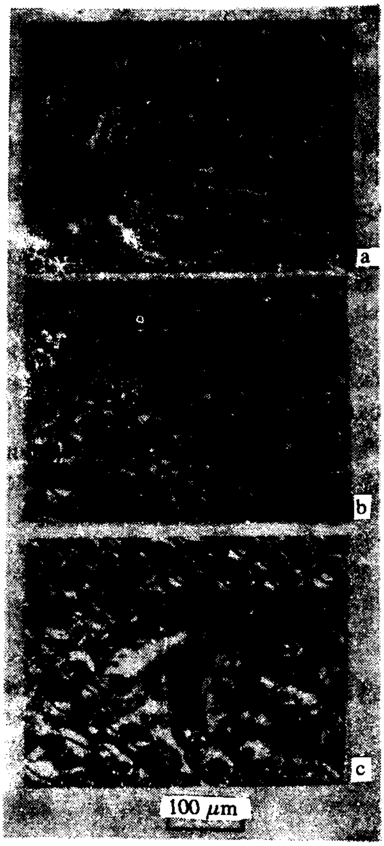

FIG. 2. Domain structure of a TGS crystal observed in polarized light by using a NLC ($\Delta\epsilon > 0$) in a sinusoidal electrical field $U = 60$ V, $f = 500$ Hz; a, b, c—after the action by rectangular constant field pulses $E = 30$ V for 1, 2, and 4 seconds, respectively. Crystal thickness is 1.5 mm.

and c), observed by using a NLC ($\Delta\epsilon > 0$) is shown in Fig. 2. The boundary (dark oval line) separating the region of domains of different sign is visible. Conoscopic crosses are observed in shallow domains (on the order of the thickness of the NLC layer with $\Delta\epsilon > 0$) in polarized light.

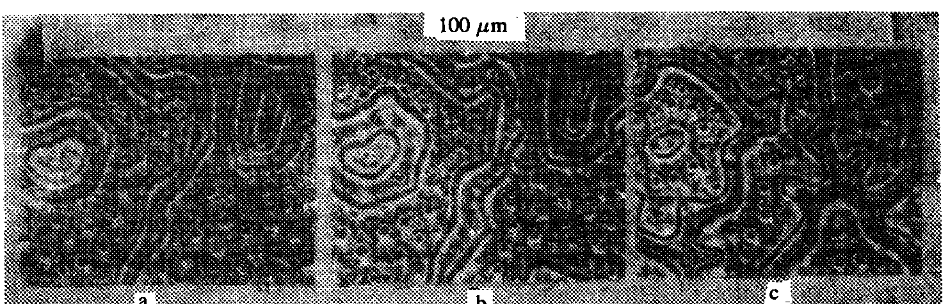

FIG. 3. Domain structure of a GASH crystal observed in polarized light by using a NLC ($\Delta\epsilon > 0$) in a sinusoidal electrical field $U = 100$ V, $f = 1000$ Hz; a,b, c—after the action of rectangular constant field pulses $E = 5$ V for 2, 4, and 8 seconds, respectively. Crystal thickness is 1 mm.

Sequential pictures of the repolarization process for a guanidine aluminum sulfate hexahydrate (GASH) crystal by rectangular constant field pulses, observed in a sinusoidal field of frequency $f = 1000$ Hz, are illustrated in Fig. 3. The deformation of the NLC ($\Delta\epsilon > 0$) in the shallow domains of the GASH crystal is different in nature since it reflects the symmetry of this ferroelectric crystal.

A simple method for visualizing the domain structure and its dynamics in collinear ferroelectrics by using nematic liquid crystals indicates a possibility of studying the behavior of domains during switching. In particular, this method can be effective for the determination of impedance changes in the domain wall region during switching of the ferroelectric since the threshold voltages for NLC are well known.[14]

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