Acoustically induced domain structure in lithium niobate

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A periodic structure of domains with polarization reversal has been observed in a lithium niobate crystal during excitation of a standing surface acoustic wave and simultaneous exposure to a laser beam in the temperature interval 130–150°C. © *1995 American Institute of Physics.*

The production of periodic structures of domains in ferroelectrics has attracted interest in acoustoelectronics and optoelectronics for two decades now, since these structures can be used to generate and detect ultrasonic and hypersonic waves and to generate the second harmonic of laser light with an efficiency well above that of single-domain converters. Research on induced domain structures is also of considerable interest for reaching an understanding of the mechanisms responsible for the formation of ferroelectric domains.

Several methods which have been developed for creating regular domain structures involve heat treatment in a gradient electric field,[1] the application of a scanning electron beam,[2] and spatially periodic doping of surfaces with various ions.[3] The width of the domains in the $LiNbO_3$, $LiTaO_3$, and $KTiOPO_4$ samples which have been studied can be varied from a fraction of a micron to several millimeters. Those methods, however, are quite complicated, so the possibility of inducing periodic domain structures in photorefractive crystals by applying optical radiation has been discussed in the literature for a long time.[4] In particular, so-called holographic gratings with a periodic variation of the refractive index have been created by applying optical radiation in the form of two interfering beams[5] and also by applying uniform optical radiation during the propagation of surface or bulk acoustic waves.[6,7] In both cases, however, it has been found possible to produce only unipolar periodic variations of the electric field in the samples; it has not been possible to produce oppositely directed electric fields in neighboring domains.

In this letter we are reporting what is apparently the first observation of the onset of a regular domain structure in lithium niobate during the simultaneous illumination of the crystals with a laser beam and excitation of a standing surface acoustic wave. The lithium niobate samples, which were *YZ*-cut wafers (with a thickness $d=1$ mm), contained iron ions in a concentration of 10^{-2}–10^{-4} at. %. The standing surface acoustic waves were excited along the *Z* axis by two interdigital transducers at a frequency of 34.1 MHz. The strain amplitudes were $\epsilon \sim 10^{-6} - 5\times 10^{-4}$. The *YZ* surface was illuminated with uniform laser beams at wavelengths of 0.53 and 0.63 μm with intensities ranging from 50 to 500 mW/cm^2. The acoustic and optical treatment was varied in duration from 5 to 50 min. The sample temperature was held constant in the interval 20–160°C (Fig. 1).

The domain structure was observed by using a bridge method to measure the changes (δn) in the refractive index, by scanning a focused beam (10 μm in diameter)

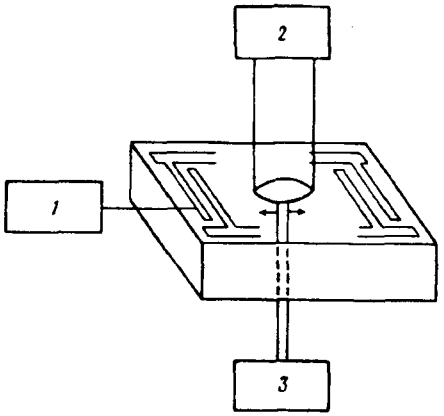

FIG. 1. Schematic diagram of the writing and readout of a periodic domain structure. 1—Generator of surface acoustic waves; 2—high-power lasers; 3—readout laser.

from a low-power helium–neon laser along the Z axis. In the case of the photorefractive effect, the change δn is directly proportional[5] to the magnitude of the electric field induced in the sample, E_i. The sign and magnitude of δn thus determine the direction and magnitude of the field E_i. The values of δn induced by the simultaneous application of sound and light were studied after the samples were cooled to room temperature.

It was observed that at $\epsilon < 10^{-4}$, in the specified temperature interval, the changes δn take the form of a unipolar periodic structure with a period which is a multiple of the length of the acoustic wave (curve 1 in Fig. 2). This effect has been seen repeatedly in previous studies.[6,7] The shape and amplitude of δn depend only slightly on the temperature and the intensity of the light beams. On the other hand, as the strain amplitude in the standing surface acoustic wave is raised to 3×10^{-4}, at temperatures of 130–150°C, we observe a symmetric bipolar variation in the refractive index (curve 2 in Fig. 2). The distortions of the symmetric shape stem from generation of the second harmonic of the surface acoustic wave. The changes δn amount to $\sim 5\times10^{-4}$ during illumination at $\lambda_{ill}=0.67$ μm, and 8×10^{-4} at $\lambda_{ill}=0.53$ μm. These figures correspond to induced fields of 6×10^4 and 9×10^4 V/cm. We believe that this stripe nature of δn corresponds to a change of π in the direction of the field E_i in neighboring stripes, i.e., to the formation of

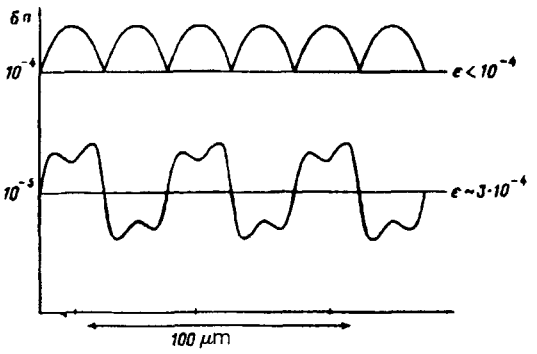

FIG. 2. Structure of the variations in the refractive index. 1—Unipolar; 2—bipolar.

a periodic domain structure. The domain structure which arises is extremely stable. It cannot be erased by intense UV light and repeated heating to 500°C.

The mechanism for the formation of the acoustically induced domain structure in the photorefractive medium can be pictured as follows. During the application of the light, free electrons are excited from impurity centers (Fe^{2+} ions) or structural centers (Nb–V_O centers), which then become redistributed in the field of the standing surface acoustic wave and are later absorbed by trapping centers (Fe^{3+} ions).

A redistribution of electrons gives rise to a unipolar variation of the refractive index, without the formation of a domain structure. As the temperature is raised to 150°C, the mobility of the ions making up the crystal lattice increases. We believe that the motion of these ions in the field of the electron charge gives rise to the domain structure. It has been established previously[4,8] that, as the temperature is raised to 150°C, the field required to change the polarization direction falls to 10^4 V/cm from the 10^6 V/cm at room temperature. Our estimates incorporating the acoustoelectric effect show that the increase in the strain amplitude in the surface acoustic wave makes it possible to substantially increase the electron density at the antinodes of the wave and to create fields from 5×10^4 to 10^5 V/cm. The ions most likely to be displaced are OH^- groups, whose optical spectrum changes slightly during heating.

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