scattering. It is possible the observed effect decreases the photocurrent in the intervals between the resonances and thus leads to an increase of the oscillation amplitude.

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Acousto-optical properties of a nematic-crystal layer with homogeneous orientation

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We investigate the change in the structure and in the optical characteristics of a layer with homogeneous arrangement of the molecules of a mixture of the nematic crystals MBBA and EBBA acted upon by acoustic oscillations of frequency 3.2 MHz. It is shown that such layers can be used as an active element of a device for displaying acoustic information. Photographs are presented of acoustic images obtained with the aid of such a device, the operation of which is based on the effect of light scattering.

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INTRODUCTION

The effect of acoustic oscillations on the optical properties of thin layers of nematic crystals with homotropic molecule orientation has been discussed in the literature many times.[1-3] In this paper we report, for the first time, acousto-optical phenomena in layers with homogeneous orientation and their possible use in devices for the display of acoustic information.

DESCRIPTION OF SETUP

We used a cell in the form of a thin layer of oriented nematic material N-8 (mixture of MBBA and EBBA), sandwiched between an acoustically transparent lavsan polyester film 90 μ thick with a light-reflecting coating on one side and an optically transparent glass plate 2 mm thick and 60 mm in diameter on the other. The homogeneous orientation was obtained by producing a microrelief on the surface of the film. This cell (1) was mounted in the end cover of a water-filled cuvette (2) at a distance 200 mm from an acoustic radiator (3), in such a way that the acoustically transparent surface faced the radiator (Fig. 1a). The optical part of the installation consists of a light source (4) (LG-36A He–Ne laser or an incandescent lamp), a semitransparent mirror (5), polaroids (6, 7) and a photomultiplier FÉU-31A (8). The signal from the photomultiplier was

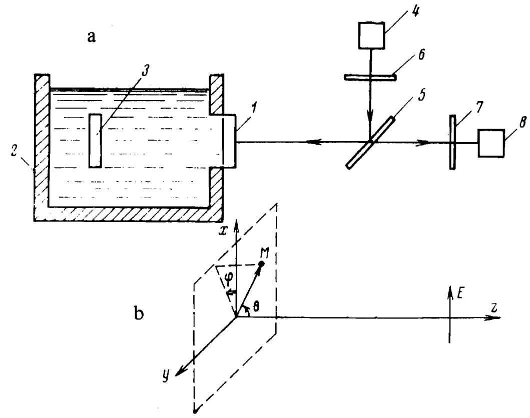

FIG. 1. Block diagram of setup.

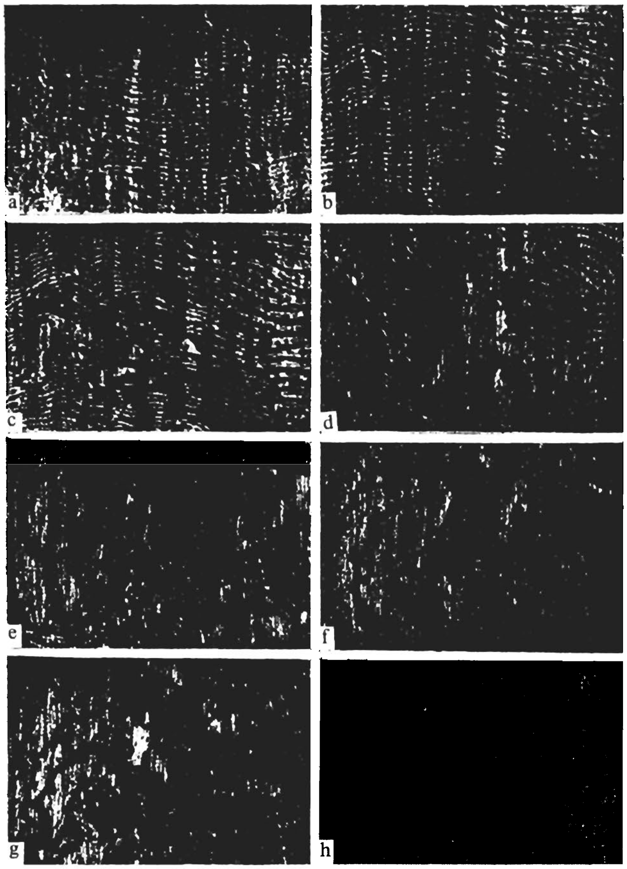

FIG. 2. Dynamics of variation of the texture with increasing acoustic intensity: a) 66, b) 90, c) 135, d) 176, e) 230, f) 290, g) 360, and h) 800 mW/cm^2. f=3.2 MHz, layer thickness 40 μ (magnification 40×).

registered with an x-y recorder (XY-Schreiber 2200). The light intensity was regulated with a set of neutral filters. The acoustic intensity was measured by the radiometer method. All the measurements were carried out at a frequency 3.2 MHz and at room temperature.

For convenience in representing the obtained results, we tie-in a coordinate system x, y, z with the plane of the layer of the cell (Fig. 1b). The position of the observation point M is determined by the radial angle θ reckoned from the normal (z axis) to the plane of the layer, by the azimuthal angle φ between the x axis and the projection of the radius vector R between the observation point and the origin on the xy plane. In the measurements, the angle θ ranged from 0 to 15°, and the angle φ assumed two discrete values, 0 and $\pi/2$. The electric vector $\mathbf{E}$ of the light incident on the layer in the direction of the axis oscillated along the x axis. We considered layers with initial orientation of the long axes of the molecules (of the director $\mathbf{n}$) along the x or y axis.

RESULTS OF INVESTIGATIONS AND DISCUSSION

A layer with homogeneous orientation is similar in its optical properties to a uniaxial-crystal plate cut parallel to the optical axis. The action of acoustic oscillations changes the structure of the layer, a fact manifest in the texture. The observations have shown that a change in the texture takes place only when the acoustic intensity exceeds a certain minimum value J', and manifests itself in the formation of a system of domains. At higher intensities, the picture remains on the whole the same, but becomes more dynamic. The motion of the medium observed at $J > J''$ leads first to violation of the regularity, and then to a complete destruction of the domains. Photographs of the texture in polarized light ($\mathbf{n} \perp \mathbf{E}$), shown in Figs. 2a–2h, illustrate successive stages of formation and destruction of domains in a layer 40 μ thick as the acoustic intensity is increased (66, 90, 135, 176, 230, 290, 360 and 800 mW/cm^2). This system of domains is close to linear, and the lines of the boundary are at right angles to the "director," which is oriented in the same direction as the lines seen on the photographs and produced when the surface of the film is treated with micropowder. At the indicated layer thickness, the values of J' and J'' were 44 and 120 mW/cm^2, respectively. When the domains are produced, the orientation in the layer is no longer uniformly homogeneous, and this leads to a change in the conditions under which the light passes through it, as is manifest in a change in the polarization of the light and its scattering.

It was established that, just as in the case of a layer with homotropic arrangement of the molecules,[3] at a certain acoustic intensity J_1, the light flux passing through the layer acquired a component with a polarization opposite to the initial one, and the intensity of the component with the initial polarization decreases. This is confirmed by the polarization characteristics of a layer of thickness 40 μ, corresponding to the case $\mathbf{n} \perp \mathbf{E}$, shown in Fig. 3. Curves 1 and 2 represent respectively the change of the relative intensity of the component with initial (along the x axis) polarization ($I_\parallel/I_0$) and with opposite polarization ($I_\perp/I_0$) with increasing acoustic intensity; I_0 is the intensity of the light flux passing through the system in the absence of sound when the polaroids are parallel. The choice of one or another component in the measurements is determined by the position of the analyzer polaroid. It is seen that the relative intensity of the component with a polarization opposite to the initial one is small and with increasing acoustic intensity the quantity $I_\perp/I_0$ passes through a maximum. The character of the behavior of the polarization characteristics at $\mathbf{n} \parallel \mathbf{E}$ is analogous to those given above, the only difference being that in this case the relative intensity $I_\perp/I_0$ is somewhat larger.

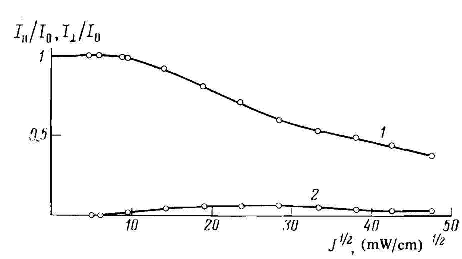

FIG. 3. Plots of $I_\parallel/I_0$ and $I_\perp/I_0$ against the acoustic intensity at $\mathbf{n} \perp \mathbf{E}$. Frequency f=3.2 MHz; layer thickness 40 μ.

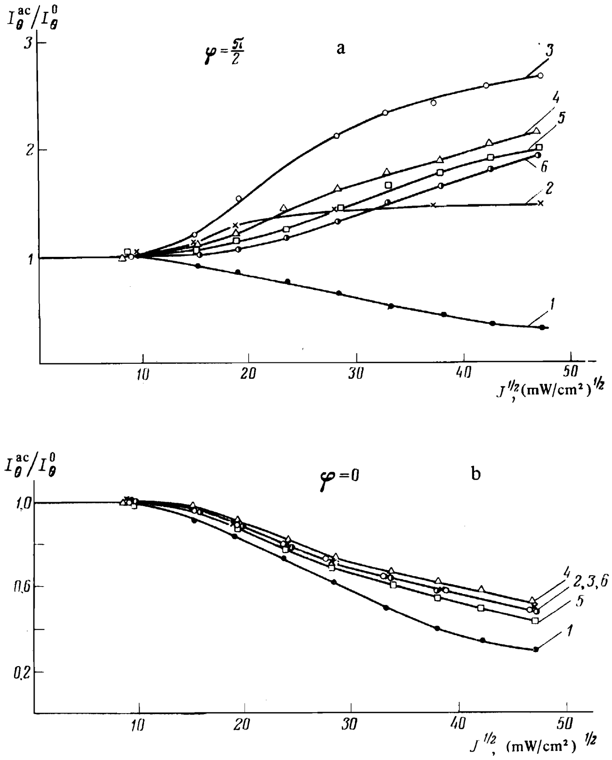

FIG. 4. Plot of $I_\theta^{ac}/I_\theta^0(J)$ at $\mathbf{n}\perp\mathbf{E}$ for $\varphi=\pi/2$ (Fig. a) and $\varphi=0$ (Fig. b). Frequency $f=3.2$ MHz, layer thickness 40 μ.

Just as in the case of a layer with a homotropic orientation,[3] in the case of homogeneous arrangement of the molecules, at a certain acoustic intensity, the light flux incident in the direction normal to the surface of the layer ($\theta=0$) is scattered. Typical characteristics of the scattering of a layer of thickness 40 μ for the case $\mathbf{n}\perp\mathbf{E}$ are shown in Figs. 4a and 4b respectively at $\varphi=\pi/2$ and $\varphi=0$. Curves 1–6 correspond to the following values of θ: 0, 3, 6, 9, 12, and 15°. Here I_θ^{ac} and I_θ^0 are the light intensities at an angle θ in the acoustic field and without sound. In these measurements there was no analyzer polaroid in the receiving system. As seen from the figures, when a certain acoustic intensity J_2 is exceeded, the light intensity passing through the layer in the direction $\theta=0$ decreases for both values of φ. At $\varphi=\pi/2$, this attenuation of the direct beam is accompanied by an increase in the relative intensity of the lateral radiation, and the largest effect in the considered interval of the angles θ corresponded to $\theta=6°$. In the case $\varphi=0$, the lateral radiation becomes weaker, as does also the direct beam.

The observed ambiguity in the variation of the relative intensity of the scattered light is clearly pronounced in the behavior of the scattering patterns corresponding to $\varphi=0$ and $\varphi=\pi/2$, which are shown in Fig. 5 for $\mathbf{n}\perp\mathbf{E}$. Here I_θ and I^0 are the intensities of the light scattered at an angle θ and incident on the layer, respectively. Curves 1 and 2 were obtained in the absence of sound and in a sound field at an intensity 2.2 W/cm². As follows from this figure, the acoustic oscillations cause a redistribution of the radiation toward larger angles θ in the yz plane ($\varphi=\pi/2$) that contains the director $\mathbf{n}$ and the normal to the layer. The character of the behavior of the scattering patterns at $\mathbf{n}\parallel\mathbf{E}$ are analogous to that described above, so that in this case the lateral radiation becomes more intense in the plane xz ($\varphi=0$).

Let us compare the behavior of the polarization characteristics and the scattering characteristics with changing texture, noting that changes of the polarization of the light and of the distribution of the scattered radiation occur at acoustic intensities $J_1=36$ and $J_2=100$ mW/cm², respectively.

As shown by the observations, the system of domains in the layer sets in at an intensity $J\approx 44$ mW/cm². This value of J practically coincides with the cited value J_1 at which the polarization of the light flux changes; this seems to indicate that these two phenomena are connected. The destruction of the domains, initiated by the motion of the medium, was observed at an intensity ~ 120 mW/cm², which is quite close to the value J_2. This agreement suggests that, just as in the case of the homotropic arrangement of the molecules, the change of the angular distribution of the intensity of the scattered radiation in an acoustic field is produced in a layer with homogeneous orientation by the motion of the anisotropic medium.

USE OF LAYERS WITH HOMOGENEOUS ORIENTATION IN DEVICES FOR THE DISPLAY OF ACOUSTIC INFORMATION

Our investigations have shown that by using acoustic oscillations it is possible to control the optical properties of a layer of a nematic crystal with homogeneous molecule orientation. Since the change of one or another optical characteristic of the layer with homogeneous arrangement of the molecules is determined by the acoustic intensity, it is possible to develop on this basis a device for the conversion of acoustic information into equivalent optical information, and in particular for the visualization of acoustic patterns.

As can be judged from the characteristics presented

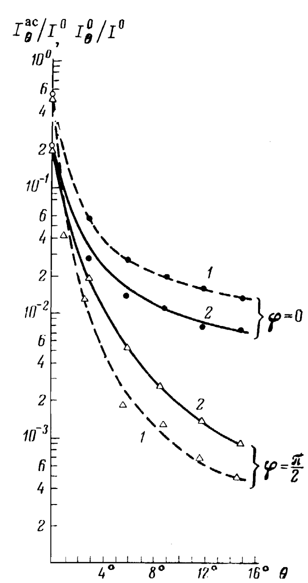

FIG. 5. Scattering diagrams without sound and in a sound field (dashed and solid lines) at $\varphi=\pi/2$ and $\varphi=0$. Frequency $f=3.2$ MHz; intensity 2.2 W/cm²; layer thickness 40 μ.

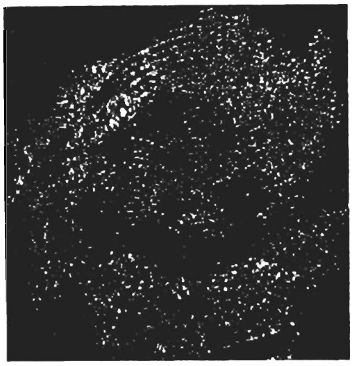

FIG. 6. Field of acoustic radiator (disk 0.5 mm thick and 38 mm in diameter) at a frequency 3.2 MHz (×2). Layer thickness 40 μ.

FIG. 7. Acoustic image of object. Frequency 3.2 MHz, layer thickness 40 μ (×6).

above, the change of the polarization of the light flux on passing through the layer is quite negligible, so that it is more advantageous to use for the indicated devices the effect of light scattering.

The design of the corresponding liquid-crystal cell is governed mainly by whether it is to operate in transmitted or reflected light. The latter method was used in the installation illustrated in Fig. 1. This installation yields the image of the field of an acoustic radiator (Fig. 6) or makes it possible to visualize an acoustic image of the object. To this end, the object is placed on the axis of a sound beam near the cell. Because an acoustic shadow is produced on the surface of the layer, sections of the layer experience different acoustic action and scatter the light differentially. The optical picture on

FIG. 8. Acoustic image of object used to estimate the resolving power of the system. Layer thickness 40 μ (×6).

the surface of the layer duplicates the distribution of the acoustic intensity, which in turn is determined by the shape of the object and by its structure. By way of example, Fig. 7 shows the image of an object in the form of a hollow cruciform box.

The resolving power of the setup was estimated with the aid of an object in the form of a wire grid of brass of 0.25 mm diameter (this is half the wavelength of the ultrasound at the frequency 3.2 MHz in water) with a mesh 0.5×0.5 mm. The satisfactory agreement of the obtained image (Fig. 8) demonstrates that the proposed device has a resolution adequate for the given sound frequency.

CONCLUSION

The reported investigation demonstrated the feasibility of developing a device for displaying acoustic information, operating in real time, with an active element in the form of a layer of a nematic crystal with homogeneous orientation of the molecules, based on the light-scattering effect. One of its main advantages is that the dimensions of the active element exceed by several hundred times the wavelength of the ultrasound, a most important factor when such a device is used to record acoustic holograms. It should also be noted that this device can be used to investigate various vibrating and radiating acoustic systems.

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