Observation of domain patterns induced by ultrasound pulses in a nematic liquid-crystal film

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The homeotropically aligned nematic liquid-crystal layer with a free circular edge is studied. Domain patterns induced by high-frequency ultrasound pulses are observed for the first time to our knowledge. The pattern changes for different incident angles of the ultrasound and can be enhanced by a quasi-static electric field.

Previous attempts have been made to explain the phenomenon of acousto-optical effects according to several proposed mechanisms by both theoretical and experimental approaches. The molecular reorientation under periodic compression is interpreted as a threshold effect caused by nonlinear stresses.[1-3] Static deformation, resulting from a torque associated with the anisotropy of acoustic attenuation, has also been reported.[4,5] However, most recent experiments[4-6] performed on homogeneously deformed nematic liquid crystals have revealed no characteristic thresholds other than the apparent thresholds caused by the sensitivity limit of the measuring instruments.[4,5] On the other hand, there is considerable experimental evidence supporting the acoustic streaming arising from the gradients of the acoustic pressure within the nematic mesophase.[7-12] Nevertheless, the phenomenon of acousto-optical effects crucially depends on acoustic excitation and the experimental geometry. Further study of special acoustic excitation and sample geometry, e.g., different boundary conditions, is needed to understand this phenomenon.

In this Letter we have investigate the induced domain patterns of a free-circular-edged homeotropically aligned nematic liquid-crystal film by application of high-frequency (of the order of a megahertz) ultrasound pulses alone at various incident angles (β) or together with a quasi-static electric field. To our knowledge this is the first observation of acousto-optical effects induced by ultrasound pulses instead of a continuous acoustic wave in the high-frequency range.

The liquid-crystal cell is composed of a free-circular-edged layer of *N*-(*p*-methoxybenzylindene)-*p*-butylaniline (MBBA) sandwiched between two 150-μm-thick cover glasses or between two pieces of 1-mm-thick slide glass coated with indium tin oxide as transparent electrodes with an aluminum-coated surface superimposed onto one of them. The sample had a round shape, with a diameter of 5 mm and a thickness of 200 μm as determined by a Mylar spacer. The homeotropic alignment was achieved by coating[13] the glass surfaces with dimethyl octadecyl aminopropyl trimethorysilyl chloride, and the cell was examined by conoscopy.

The ultrasound was generated from a pulse generator obtained from Matec. The ultrasound frequency was 2 MHz, and the maximum peak-to-peak pulse voltage was 460 V. The pulse width was 2.5 μsec, with a repetition rate ranging from 50 to 500 Hz. The liquid-crystal cell was immersed in a water bath with a temperature between 23.2 and 24.2°C and was 5 cm from the transducer. The ultrasound from the transducer (diameter of 2.5 cm) could cover the whole liquid-crystal sample at all incident angles in our experiment (see Table 1).

A He–Ne laser was expanded by a lens, which result-

Table 1. Displacements of the Center of Curvature and the Average Periods of the Fringes

	Reflection Mode with Thin Glass Substrates (Electric Field Enhanced)			Transmission Mode with Thick Glass Substrates								
Incident angle β (°)	0	10	20	20	25	30	35	40	45	50	55	60
Average period of the fringe (mm)	0.36	0.56	1.43	1.31	1.33	1.42	1.42	1.92	1.77	1.85	2.5	2
Displacement of the center of curvature of the fringe (mm)	0	0.42	0.57	0.54	0.96	1.13	1.75					

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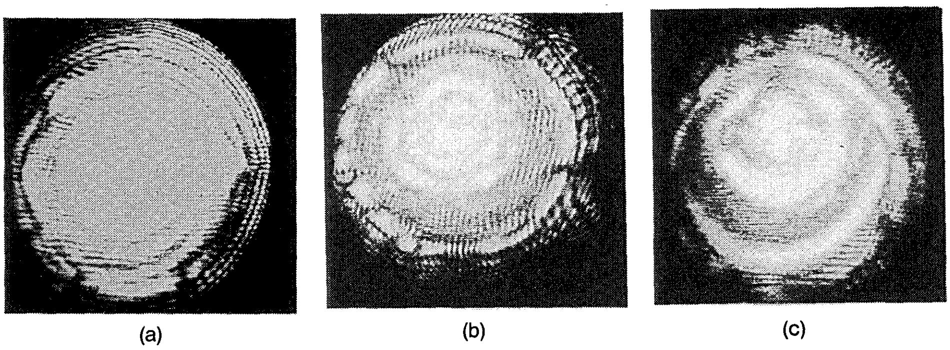

Fig. 1. Birefringence patterns of the reflection mode with thick slide glass substrates enhanced by a voltage of 3.5 V. (a) $\beta = 0°$, (b) $\beta = 10°$, and (c) $\beta = 20°$.

ed in an extended beam of ±0.9° before it was normally incident upon the liquid-crystal film. For large incident angles of ultrasound the birefringence patterns of the transmission mode were observed. However, for small incident angles the transducer will block the transmission light. The sample with the aluminum-coated slide glass as one of its substrates was used in order to achieve the reflection mode of the birefringence patterns. For these samples we could not attain clear patterns in the power range of our ultrasound pulse generator. The patterns were observed by applying an additional electric field at 1 kHz with a voltage of 3.5 V.

In the absence of the acoustic excitation, the view of the homeotropic nematic MBBA film through two crossed polarizers was dark. As the ultrasound pulses were applied, a circular or arched domain pattern appeared owing to the molecular reorientation. It was verified that the molecules were tilted in a direction perpendicular to the arched fringe. However, we

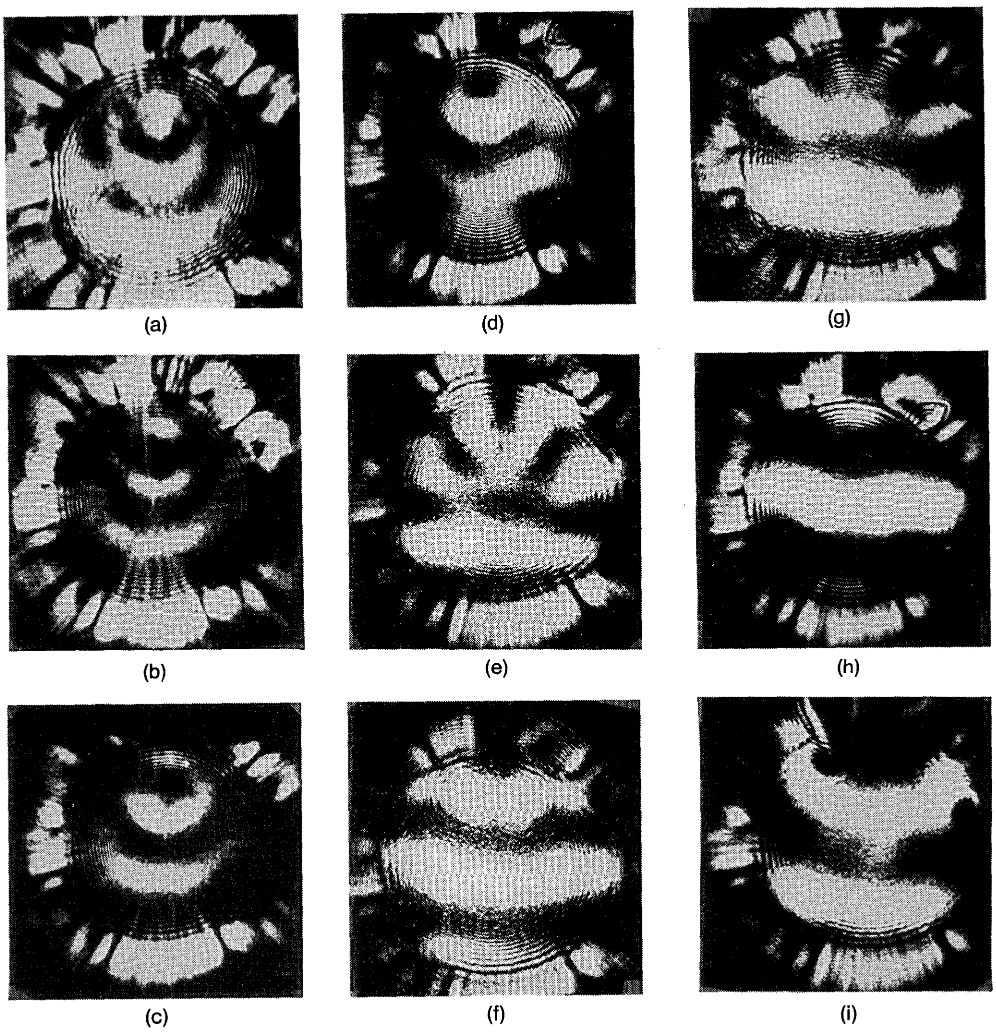

Fig. 2. Birefringence patterns of the transmission mode with thin cover glass substrates. (a) $\beta = 20°$, (b) $\beta = 25°$, (c) $\beta = 30°$, (d) $\beta = 35°$, (e) $\beta = 40°$, (f) $\beta = 45°$, (g) $\beta = 50°$, (h) $\beta = 55°$, and (i) $\beta = 60°$.

could not attain clear patterns with $\beta < 20°$ and $\beta > 35°$ for the samples with thin and thick glass substrates, respectively, in the power range of our ultrasound generator.

The birefringence patterns of the reflection mode are shown in Figs. 1(a)–1(c) for $\beta = 0°$, $10°$, and $20°$, respectively, with the figures showing the whole area of the 5-mm-diameter sample. The sample film was prepared with slide glass. Some circular domain patterns were obtained by an additional electric voltage of 3.5 V, which is below the Freedericksz threshold (−3.7 V) of MBBA. It is clear, from Fig. 1, that the electric field can enhance the acousto-optical effect since we could not get clear patterns for these incident angles by using our ultrasound pulses alone.

The birefringence patterns of the transmission mode are shown in Fig. 2 for β values of 20° to 60°. It can be clearly seen that there are three patterns in these figures. The first pattern is the closely spaced thin rings, which are also present in Fig. 1. We believe that these are due to some interference effect from our optical setup and are not related to the orientation of the liquid-crystal molecules. The second pattern is located outside the rings, close to the edge of the sample, and is more likely due to the edge effect. The third pattern has arched fringes instead of the thick circular rings observed in Fig. 1. As one can see from the figures, these fringes shift as β changes, indicating that they are indeed induced by the obliquely incident ultrasound. In Fig. 1(a) the center of curvature of the circular patterns coincides with that of the liquid-crystal film. However, it shifts to the right-hand side as the ultrasound is incident from the left-hand side, and vice versa. The displacements of the center of curvature increase, as shown in Figs. 1(b), 1(c), and 2 for $\beta < 35°$.

In conclusion, we have used the ultrasound pulses instead of the continuous acoustic wave in the high-frequency range for the first time to our knowledge to excite the acousto-optical effect in a free-circular-edged liquid-crystal film. Circular and arched fringe patterns for small and large incident angles of the acoustic wave, respectively, are obtained. The center of curvature of the circular fringe coincides with that of the liquid-crystal film for a normal incident acoustic wave. It shifts to the right-hand side as the incident angles shifts to the left-hand side of the liquid-crystal film center and vice versa. The displacement of the center of curvature and the period of the fringe increase as β increases for a small β in the reflection mode and transmission mode. The acousto-optical effect can be enhanced by a quasi-static electric field (−1 kHz).

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