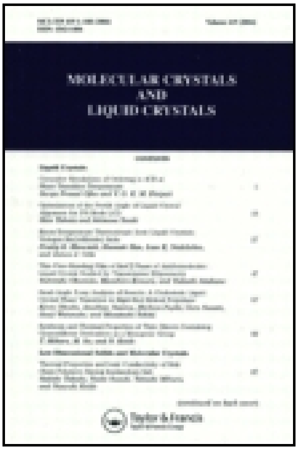

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

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Version of record first published: 17 Oct 2011.

To cite this article: W. Hamidzada & S. V. Letcher (1985): Sensitivity to Ultrasound of a Boyd-Cheng Cell, Molecular Crystals and Liquid Crystals, 122:1, 89-96

To link to this article: http://dx.doi.org/10.1080/00268948508074744

Mol. Cryst. Liq. Cryst., 1985, Vol. 122, pp. 89–96
0026-8941/85/1224–0089/$15.00/0

Sensitivity to Ultrasound of a Boyd–Cheng Cell

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(*Received August 2, 1984*)

The nematic bistable cell of the Boyd–Cheng type is shown to be quite sensitive to ultrasonic tone bursts of about 50 msec duration. It is considerably more sensitive to this excitation than either a homeotropic nematic or a Berreman–Heffner cholesteric cell. It is also possible for the ultrasound to switch the cell from one stable state to the other, but this is not as effective as the ultrasonic switching of the Berreman–Heffner cell.

INTRODUCTION

The need for a low-cost ultrasonic mapping or imaging device has led to a rather wide study of the interaction of ultrasound with liquid crystals.[1–6] Recently it has been shown that ultrasound can cause switching between bistable states of a weakly cholesteric liquid crystal cell, providing the possibility of an ultrasonic detector with storage.[7]

A nematic liquid crystal cell, exhibiting interesting bistabilities, developed by Boyd, Cheng and Ngo,[8] has been studied intensively lately[9–15] because of its potential application in electro-optic storage displays. This Boyd–Cheng cell is a thin layer of nematic material with an oblique attachment angle at the confining surfaces.[8] It has two topologically inequivalent stable states: *H*, in which the director at the midplane is horizontal, or parallel to the surfaces; and *V*, in which the midplane director is vertical. In an aligning field, an additional bistability arises as the *H* state becomes asymmetric, with the plane of the horizontal director moving towards the top or bottom surface.[9, 10] We report here on the ultrasonic sensitivity and switchability of this type of cell.

EXPERIMENT

Our cell is composed of thin (0.13 mm) glass plates sandwiching a 50 μm layer of liquid crystal. The glass surfaces are treated with indium-tinoxide for transparent electrodes and with silicon monoxide for a molecular attachment angle of ~55° from the surface normal. The material used is either 5CB or the two-frequency nematic called TX2A. The cell is sealed and placed between crossed polarizers in a water tank (see Fig. 1). The cell is in the near field of a ceramic piezoelectric transducer that emits tone bursts of 4.1 MHz ultrasound.

Figure 2 shows the time dependence of the light transmitted through the cell in the V state when subjected to ultrasonic pulses of varying amplitudes. The polarizer is set at 45° with respect to the component of the director in the plane of the wavefront. In general, then, the light emitted from the cell in the absence of ultrasound is elliptically polarized and some intensity, J_0, passes through the

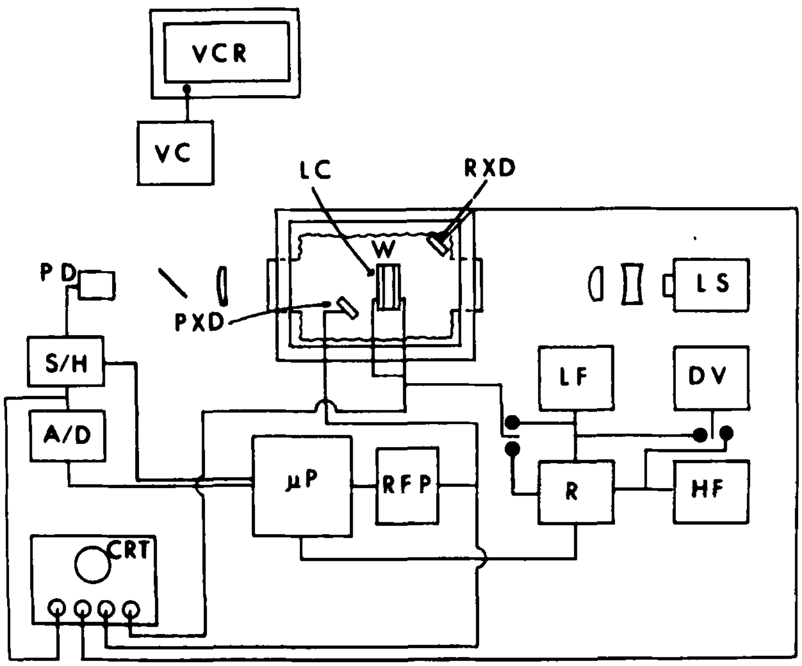
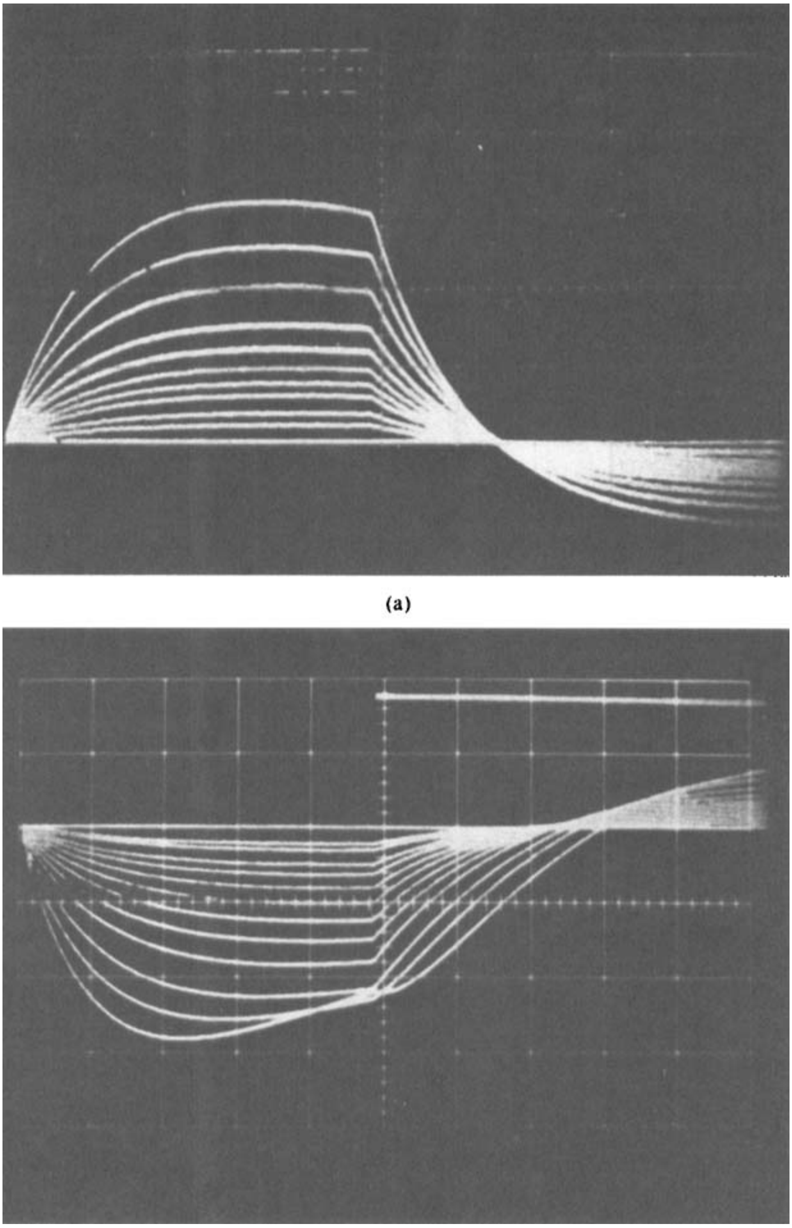


FIGURE 1 Experimental configuration. The signal to the transducer (PXD) comes from the rf pulse forming electronics (RFP) that are controlled by a computer (μP). The holding voltage to the cell (LC) can be switched via a relay (R) from a low (LF) to a high frequency (HF) audio signal. Light passing through the cell from the source (LS) is focused on either a photodiode (PD) or a video camera (VC).



(a)

(b)

FIGURE 2 Optical signal generated by a 50 msec ultrasonic pulse of varying amplitudes. The cell is in the V-state with a holding voltage of 2.8 V. (a) Sound in the SNM direction, (b) sound in the SAM direction.

crossed analyzer. What is shown in Fig. 2 is the change in light intensity, $J - J_0$, caused by the sound. The change may be positive or negative, as is seen. The only difference between Figs. 2a and 2b is the direction of the incident sound beam. In each case the angle of incidence is 33° from the cell normal; in the former case the sound is roughly normal to the nematic director at the incident surface (called the SNM direction), in the latter, roughly parallel (SAM).

A plot of the optical signal as a function of the voltage applied to the transducer is shown in Fig. 3. The points represent the optical signal at the end of the 50 msec pulse; for low acoustic intensities this is the maximum signal, but for high intensities it may be less than the

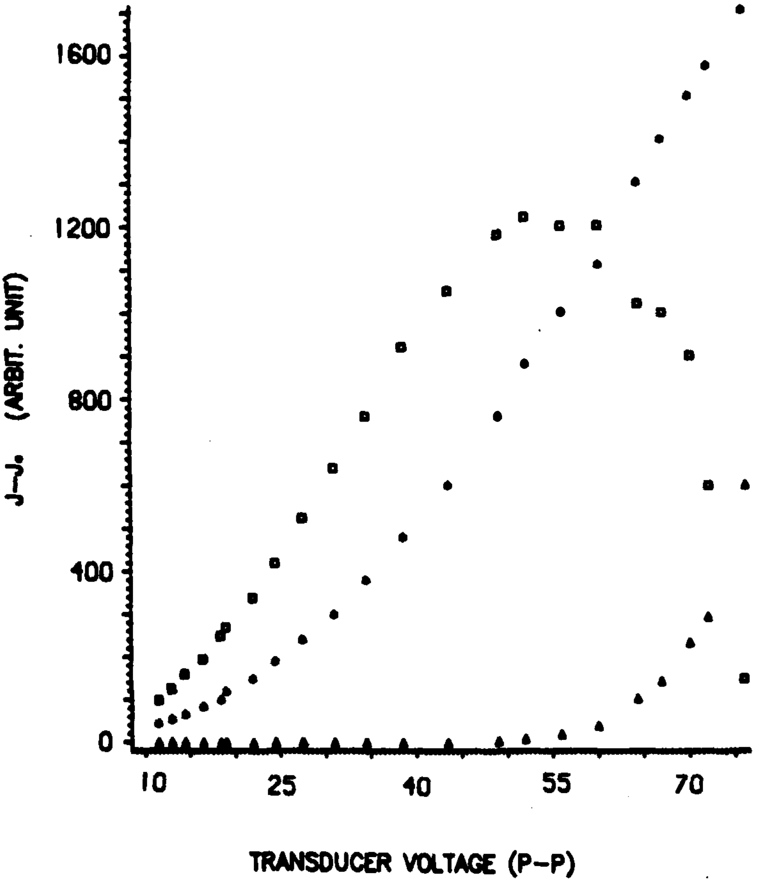


FIGURE 3 Optical signal at the end of a 50 msec pulse vs. voltage applied to the transducer. Fifty volts correspond to an acoustic intensity of 27 mW/cm^2.

maximum (see Fig. 2b). For modest acoustic intensities, the cell is more sensitive for sound incident in the SAM direction than in the SNM direction. For both directions the Boyd–Cheng cell is two orders of magnitude more sensitive than a homeotropic cell that is otherwise exactly equivalent, shown at the bottom of the figure. The sensitivity of the horizontal state (not shown) falls between that of the vertical state and that of the homeotropic cell. The optical signal as a function of the angle of incidence of the acoustic beam is shown in Fig. 4. The incidence angle is varied on both sides of the surface normal. The SAM direction is again seen to be more sensitive than the SNM direction. This may well restrict the usefulness of this type

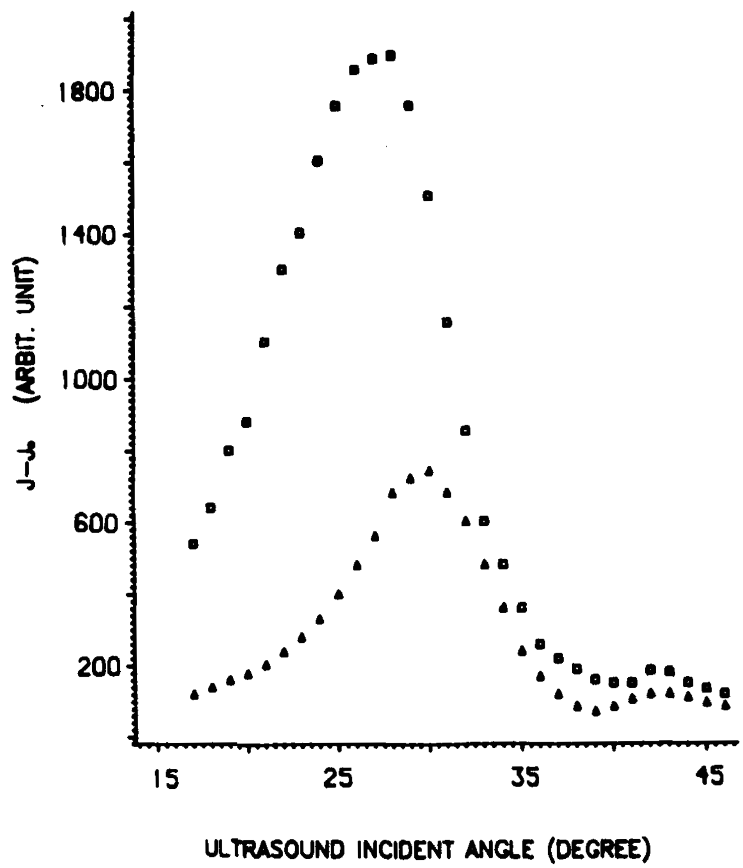


FIGURE 4 Optical signal as a function of angle of incidence of the sound beam. The incidence angle is measured from the normal to the cell surface. The top set of points is for the SAM direction and the lower set for the SNM direction.

of cell for acoustic imaging. On the other hand, the peaked nature of the response is not of as much concern since it can be broadened by making a cell with multilayer structure.

ULTRASONIC SWITCHING

The lively recent interest in this cell was stimulated by the discovery that a dc pulse can cause switching from one asymmetrical horizontal state to the other.[12] The two states are made optically distinguishable by rotating one glass plate 45° with respect to the other.

Although we used a cell whose thickness (50 μm) is much larger than ideal for switching[13] and a material (TX2A) that was not very amenable, we have demonstrated that an ultrasonic pulse, in conjunction with a dc voltage pulse, can cause switching. This can lead to an ultrasound detector with memory. The cell starts in the symmetric horizontal state that is achieved during an idling time without acoustic or electric fields. If a holding voltage were applied at this point, the asymmetry would always develop in the same way; this built-in asymmetry is called the Favored state. We now apply to the symmetric cell a combination of a dc voltage pulse and an ultrasonic pulse, each of which pushes the cell toward the Unfavored state (cusp moving toward the opposite surface). At the end of these biasing signals, a holding voltage is applied. In the regions where the sound has hit the cell, the *U* state is held; in the regions exposed only to the dc pulse, the cell returns to the *F* state. After a few seconds the holding voltage is removed and the cell is recycled by allowing it to return to the symmetric state. For our cell made with TX2A, a two-frequency nematic, a high-frequency erasing voltage speeds up the recycling process. Unfortunately, TX2A also has a rather small dielectric anisotropy. As a result our holding voltage puts us just into the region where the asymmetry starts to develop. Although the initial contrast was quite good and the response was distinctly different from the transient effects described above, the signal faded after a few seconds. Being in, or at least closer to, the boundary layer regime[9] is expected to enhance the performance.

A larger or longer dc pulse can switch the entire cell without benefit of the ultrasound. We have chosen the dc pulse characteristics somewhat below this threshold. Presumably an ultrasonic pulse by itself can also cause switching, but we have not observed it with this cell. The most effective switching occurs when the sound is incident from the SNM direction. From the other direction (SAM), a longer or stronger acoustic signal is needed. When the sound is incident from the other side of the cell, no switching is observed, presumably because the acoustic biasing is towards the F state.

DISCUSSION

We have shown that the nematic cell of the Boyd–Cheng type is sensitive to ultrasound and that the response is strongly dependent on the state the cell is in and on the direction of incidence of the sound beam. In the range of acoustic intensities we have used (up to about 50 mW/cm^2), this cell is two orders of magnitude more sensitive than a homeotropic nematic cell. It is also an order of magnitude more sensitive than the bistable cholesteric cell of the Berraman–Heffner type.[7–16] On the other hand, acoustic switching from one bistable state to the other is much more easily accomplished with the Berreman–Heffner cell and without the need for an assisting biasing pulse. In our measurements with TX2A cells, an acoustic pulse must contain about eight times more energy to switch a Boyd–Cheng cell.

Our results for the Boyd–Cheng cell, particularly the dependence of the optical transmission on the acoustic incidence direction, are qualitatively consistent with the acoustic streaming model of Candau *et al.*[17] and are not consistent with the minimum-entropy-production model of Dion.[3] In the streaming model, the nonlinear ultrasonic wave generates lateral flow of the liquid crystal between the glass plates. Onset of flow alignment produces the optical signal. For a cell in the V state, for example, we would expect the flow to be generated more easily by sound from the SAM direction than from the SNM direction. Our calculations of the light transmission due to the Dion mechanism, however, predict a difference of less than 1% between SAM and SNM.

Acknowledgements

We are grateful to W. R. Heffner for helpful suggestions.

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