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# Liquid crystal reflection cell with improved response times

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In recent papers[1,2] the authors described a liquid crystal (LC) device, operated in the transmission mode, that had response times of the order of 0.2–0.4 msec and contrasts of ~6%. These response times are considerably faster than the 20–50 msec normally associated with cells using the twisted nematic configuration. The improvement in response time results from (1) the addition of a small amount of a cholesteric to a binary nematic, and (2) operation of the cell with the signal voltage superimposed on a square-wave pedestal voltage whose polarity is reversed at a 20-Hz rate.[1] With an aim toward incorporating these features into a light valve of the type described by Beard *et al.*,[3] which uses a photoconductor-LC sandwich configuration, we have carried out experiments similar to those described earlier[2] but on a cell in the reflection mode.

The reflection cell consisted of a front electrode of 2.5 × 2.5-cm NESA glass obtained from Industrial Optics. The rear electrode was a deposited thick film of amorphous silicon that had an aluminum backing film that served as an electrical contact. Mylar spacers were placed between the front glass electrode and the silicon to form a cavity to hold

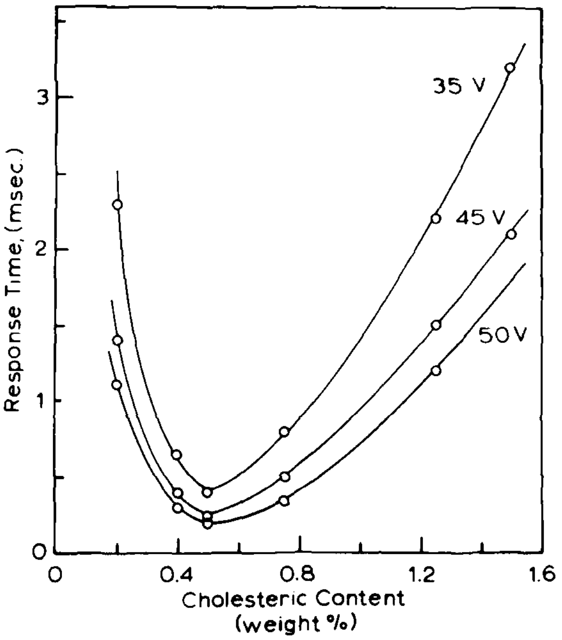

Fig. 1. Response times as a function of cholesteric content for a reflection cell containing a mixture of cholesteryl nonanoate, *p*-cyanophenyl *p*-butylbenzoate, and *p*-cyanophenyl *p*-heptylbenzoate in the weight ratio $x$:100:230, respectively.

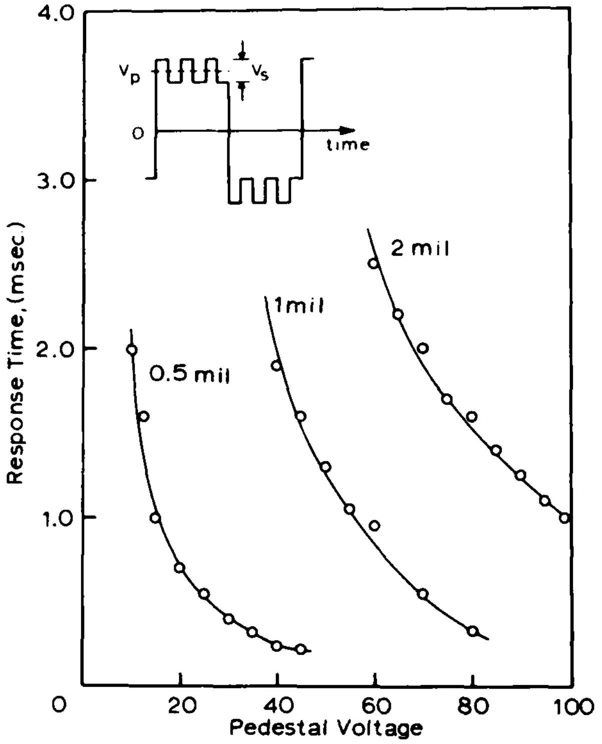

Fig. 2. Response times (turn-on times) for a LC reflection cell with 0.5% weight of cholesteryl nonanoate as a function of pedestal voltage and cell thickness. Inset shows the waveform of the cell drive voltage indicating the signal voltage superimposed on the pedestal voltage.

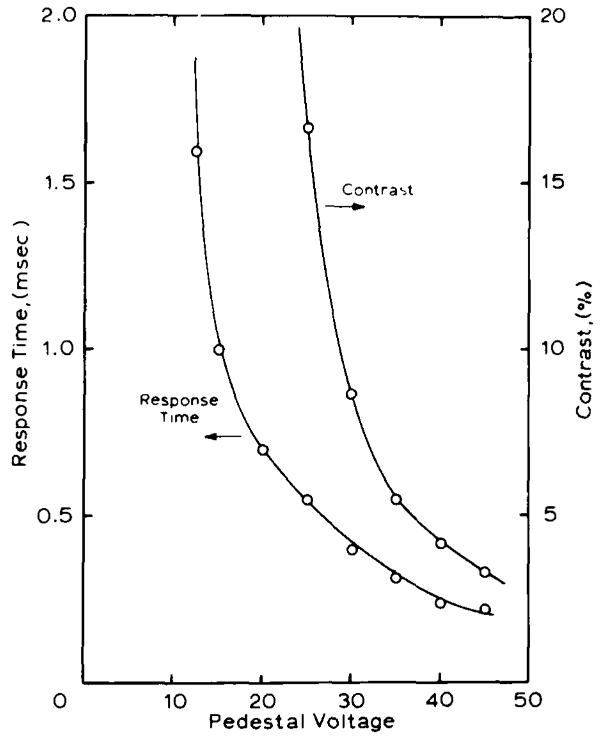

Fig. 3. Response time and contrast for a 1/2-mil thick reflection cell containing 0.5% cholesteryl nonanoate as a function of pedestal voltage.

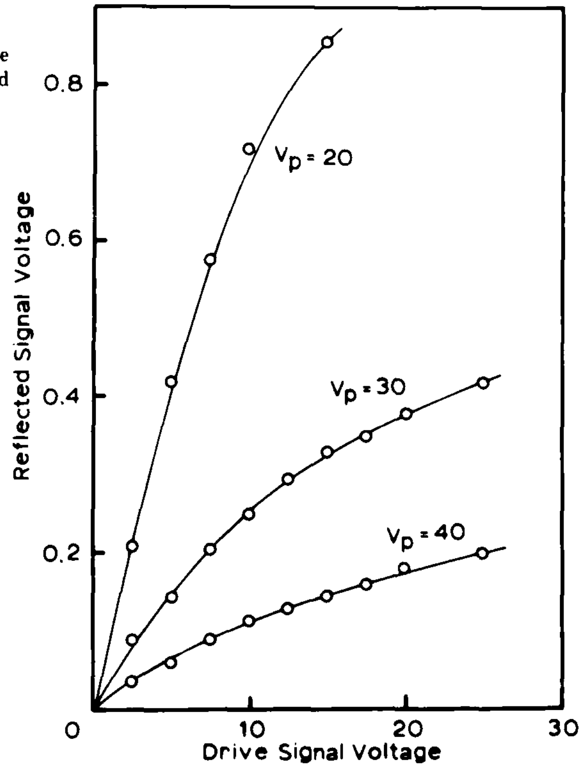

Fig. 4. Reflection cell output voltage as a function of square-wave signal drive voltage with pedestal voltage as a parameter. Liquid crystal was a 0.5% cholesteric with a thickness of 1/2 mil.

the LC material. The silicon acted as a reflecting mirror and had sufficient electrical conductivity so that essentially all of the cell operating voltage appeared across the LC. The LC was a positive cholesteric formed from a mixture of cholesteryl nonanoate, *p*-cyanophenyl *p*-butylbenzoate, and *p*-cyanophenyl *p*-heptylbenzoate in the weight ratio $x$:100:230, respectively. Various values of $x$ were investigated to optimize the response time and to corroborate our earlier work.[2] The response times are shown in Fig. 1, which led us to choose the 0.5% composition as optimum for the reflection cell, which is only slightly less than the 0.75% chosen for the earlier experiments on the transmission cell.

The experimental set-up consisted of a linearly polarized He-Ne laser (CW Radiation Model LS4P) whose beam was incident at approximately 22° with respect to the normal of the front glass electrode. The reflected beam was measured with a *P-I-N* diode, dc amplifier, and a Tektronix model 5103N oscilloscope. In preparing the cells we followed the cleaning procedure outlined previously.[2] Prior to assembly the front glass electrode was rubbed with a tissue in a unidirectional manner to tilt the LC director slightly away from the electrode surface. Experiments showed that the fastest response times occurred when the rubbed direction was parallel to the polarization axis of the laser beam. The response times (i.e. turn-on times) as a function of pedestal voltage are shown in Fig. 2. As noted earlier for the transmission cells, the turn-off times always exceeded the turn-on times, but these values approached each other as the pedestal voltage was increased.

Measurements of the contrast (or modulation depth) for the 1/2-mil cell are shown in Fig. 3, along with an expanded scale plot of the response time for a particular cell. For these measurements a polarizer/analyzer was not used, thus a different definition of contrast was necessary from that employed in our previous work.[2] In this case it was defined as the ratio of the peak-to-peak reflected signal amplitude to the reflected light intensity with the cell drive signal voltage removed but with the pedestal voltage intact. With this definition the contrast thus depends on the cell drive voltage so that we chose to refer the data to a value of 10-V peak-to-peak. Higher contrast values can be obtained with larger drive voltages since, as shown in Fig. 4, the reflected signal voltage is proportional to (but not quite linearly) to the drive voltage. Further, these data show that a gray scale exists for the device, which may be an important feature for its later application as a data processing element.

In these experiments the silicon film acted primarily as a reflection mirror and interface electrode to the LC. Eventually, the parameters of the silicon will be tailored to form a photodiode and be incorporated into a light valve of the type developed by workers at the Hughes Research Laboratories,[3,4] but one that has response times in the submillisecond range. Finally, it is important to note that the devices are compatible with the voltage levels of IC circuitry, especially for those using the thin LC layers (i.e., 1/2 mil), and requires minimal electrical power.

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