Molecular Crystals and Liquid Crystals

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

Transient Surface Temperature Response of Liquid Crystal Films

Robert Parker [a]

[a] Lawrence Livermore Laboratory, University of California, Livermore, California, 94550

To cite this article: Robert Parker (1973): Transient Surface Temperature Response of Liquid Crystal Films, Molecular Crystals and Liquid Crystals, 20:2, 99-106

To link to this article: http://dx.doi.org/10.1080/15421407308083305

Molecular Crystals and Liquid Crystals. 1973. Vol. 20, pp. 99–106

Printed in Great Britain

Transient Surface Temperature Response of Liquid Crystal Films†‡

ROBERT PARKER

Lawrence Livermore Laboratory
University of California
Livermore, California 94550

Received January 28, 1972; *in revised form May* 15, 1972

Abstract—Various commercially available microencapsulated cholesteric liquid crystal films and coatings were tested to determine their response to rapid heating. The rapid response data are required for the diagnostic devices to be used to measure the spatial energy distribution in lasers and electron beams. These films, which reversibly change color at discrete temperatures, were placed on tapered stainless steel strips that were pulse heated to a predetermined level in 30 μsec by discharging through the steel strip the stored charge from a high-voltage low-inductance capacitor bank. The taper introduced a temperature gradient along the length of the strip with the higher temperature at the narrow end. A high-speed movie camera and time fiducial system recorded the color change movement along the length of the bar as a function of time.

The response time is the time required for the material to achieve its event temperature when the ratio of event temperature less initial temperature to substrate temperature rise is 0.9. These data are reported in tabular form for each material tested. In general, the response is inversely proportional to the film thickness squared since this is one of the limiting factors for heat diffusion.

Various techniques to reduce film and coating thickness and enhance response were demonstrated and are discussed in the paper.

1. Introduction

The recent introduction of microencapsulated, cholesteric liquid crystal films and sprays to the commercial market by several manufacturers has encouraged many new applications for these reversible temperature indicators. One potential application of interest is the use of these sensors to quantitatively map the spatial energy

---

† This work was performed under the auspices of the U.S. Atomic Energy Commission.

‡ Presented at the Fourth International Liquid Crystal Conference at Kent State University, August 21–25, 1972.

distribution in laser and electron beams. However, before prototype diagnostic devices could be built, the response time of these films on metallic substrates subjected to rapid heating conditions had to be determined.

Cholesteric liquid crystals will reversibly change color at a particular temperature. A detailed description of the mechanism involved appears in the literature.(1,2,3) The materials tested were either in a thin film form that could be placed directly on the surface or microencapsulated as a slurry sprayed on the test sample. Only one sample of unencapsulated material was tested, because without encapsulation the material degrades with exposure to ultraviolet radiation, dust, and air-borne vapors.

2. Experimental Method

A tapered strip of stainless steel, as shown in Fig. 1, with a thin liquid crystal coating on the surface, was rapidly heated by discharg-

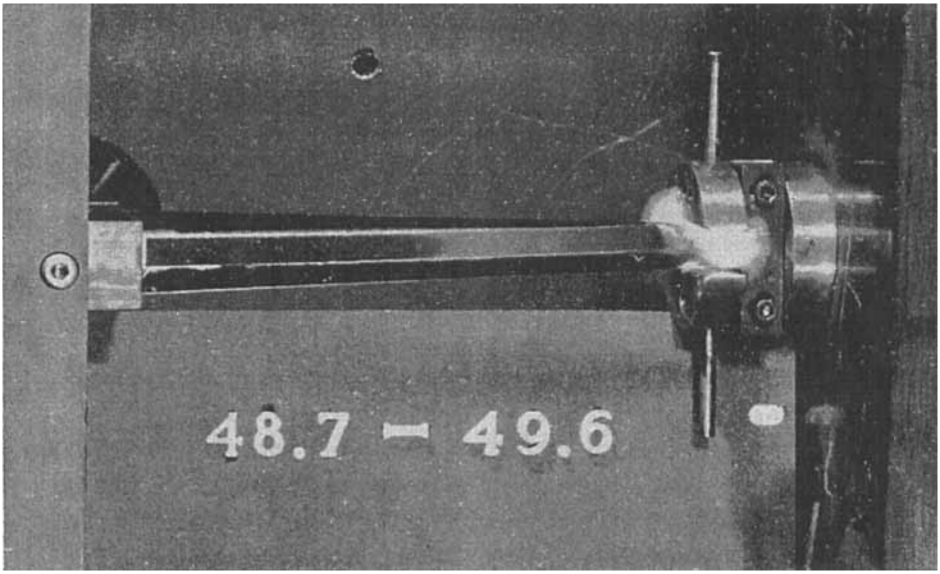

Figure 1. Formation of color band on liquid crystal tape bonded to stainless steel specimen during pulse heating.

ing the stored energy in a low-inductance capacitor bank through it in approximately 30 μsec. Thermocouples spot welded to the rear of the strip were used to record the temperature rise. A high-speed camera with a framing rate of 200 frames/sec photographed the liquid-crystal surface. A flash lamp was triggered by the discharge of the capacitor bank to provide a zero-time mark for the movie record.

The discharge from the capacitor provides a convenient repeatable method for pulse heating the stainless steel strip very rapidly ($\simeq 30\ \mu$sec). An analysis and description of the heating time is presented in Ref. 4. The tapered strip geometry provides a temperature gradient along the length of the strip, depending on the length and width ratio. The variation in temperature rise as a function of

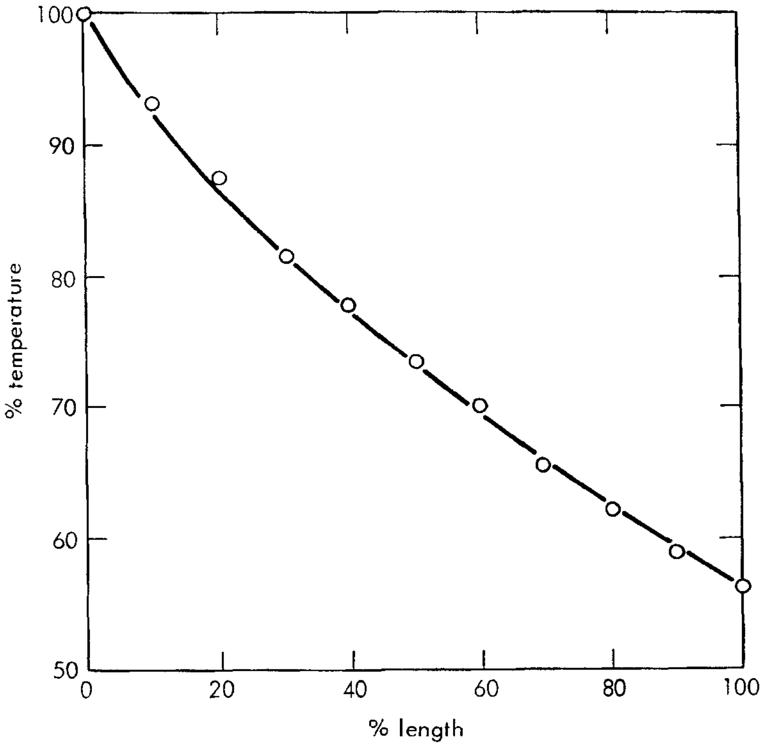

Figure 2. Computed percent temperature vs. percent length on tapered pulse-heated strip.

length in the bar is given by Eq. (1). (See Ref. 5 for a complete derivation.)

$$\Delta T = \frac{0.239\rho}{dc_p h^2 (a+Kx)^2} \int i^2 \mathrm{d}t, \tag{1}$$

where ρ = resistivity, Ω-cm (assumed constant with temperature); d = density, g/cc; h = strip thickness, cm; c_p = specific heat, cal/g/°C; a = narrow width; K = taper constant; i = current, amp; t = time, sec; x = distance along the tapered strip, cm. Rewriting we may say:

$$\Delta T_x = \frac{K_2}{(a+Kx)^2}. \tag{2}$$

A normalized plot of ΔTx vs. x is shown in Fig. 2.

3. Experimental Analysis

The thin film and substrate combination is shown in Fig. 3. The thin film is assumed to be in intimate contact with the metal substrate at one boundary and perfectly insulated at the other boundary.

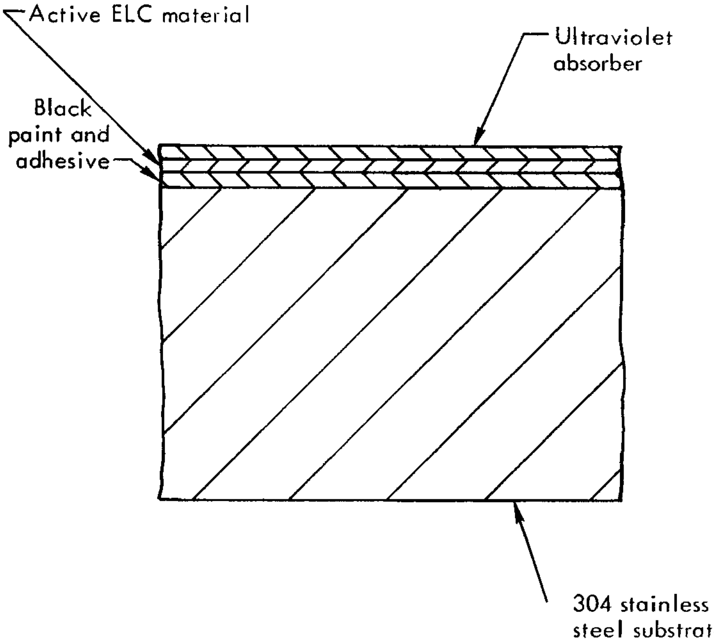

Figure 3. Cross section of some typical ELC films on a stainless steel substrate.

Because of its much larger mass, the metal substrate is assumed to remain at T_0 for many seconds, much longer than the response of the liquid-crystal film. (This was verified experimentally.)

It is not apparent at which fraction of the total thickness of the various liquid crystal coatings a noticeable color change will occur. However, as an upper limit, the total thickness was used.

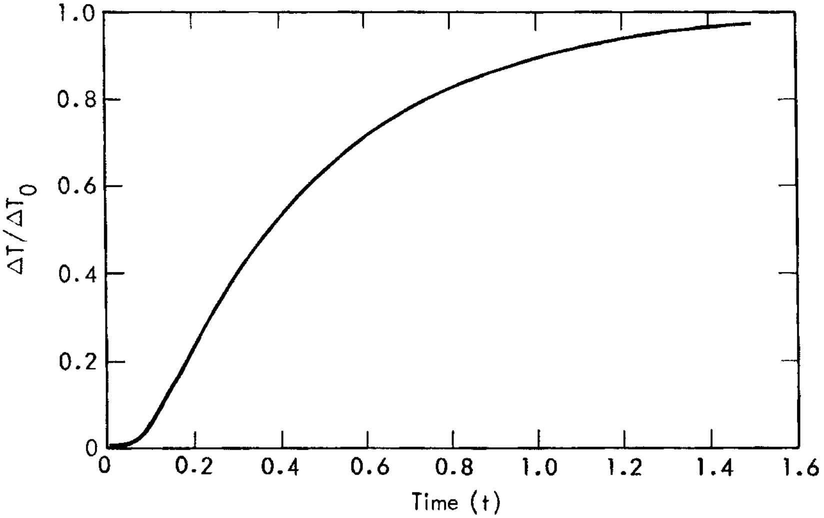

Figure 4. Normalized temperature vs. dimensionless time for outer boundary of a material. Inner boundary maintained at a constant temperature T_0; outer boundary perfectly insulated.

A plot of the normalized temperature ($\Delta T/\Delta T_0$) vs. time on the outer boundary is shown in Fig. 4 ($\Delta T_0 = T_0 - T_i \Delta T = T - T_i$). The liquid crystal material responds at a particular temperature T_r; the time required for this response depends on several factors including the ratio in the equation

$$\frac{T_r - T_i}{T_0 - T_i} = \theta, \tag{3}$$

where T_i = the initial temperature of the system and T_0 = the substrate temperature. Hence, from an examination of Figs 4 and 2, we may expect that a color band will be formed at the lower, or warmest, part of the specimen. This band will travel up the bar as heat diffuses through the encapsulated liquid crystal (ELC) thickness. The travel of the color indication of the liquid crystal element along the bar vs. time will be exponential and will reach an equilibrium position along the bar. Hence, to best represent the temperature response, the point where $\theta = 0.9$ was selected for comparison between the various films.

4. Experimental Results

The equations and curves used in the preceding discussion do, in fact, qualitatively describe the physical response of the films. A color band does seem to travel up the tapered bar. By viewing this travel and counting the number of frames in the high-speed film, the response time was measured and noted in Table 1.

TABLE 1 Response Time of Various Liquid Crystal Films Response

Product Name and Description	Thickness (in.)	Time (msec)	Comments
Vari-Light Corp. Permacoat ELC	0.0035	230	Considerable thickness of material required to visualize color change.
Hoffmann Laroche, Inc. Rochrome Tape black backing removed	0.003	170	Active ELC thickness probably less (protective layer 0.001 in.)
Hoffmann Laroche Inc. Rochrome Tape with backing	0.005	450	
Westinghouse Electric Corp. Spectratherm unencapsulated	0.0015	75–80	Difficult to achieve a uniform thickness.
NCR (ELC)	0.001	36	

The data from Table 1 are plotted in Fig. 5 as response time vs thickness squared. It should be noted that the thickness of the Rochrome tape included a 1-mil inactive ultraviolet protective coating over the ELC material. This thickness was subtracted from the total thickness for the plot. It was difficult to determine precisely the response time because the color band has some finite width along the taper, depending on the temperature range. Narrow range materials were somewhat easier to interpret. It was difficult to determine accurately the thickness. In general, the data reported in

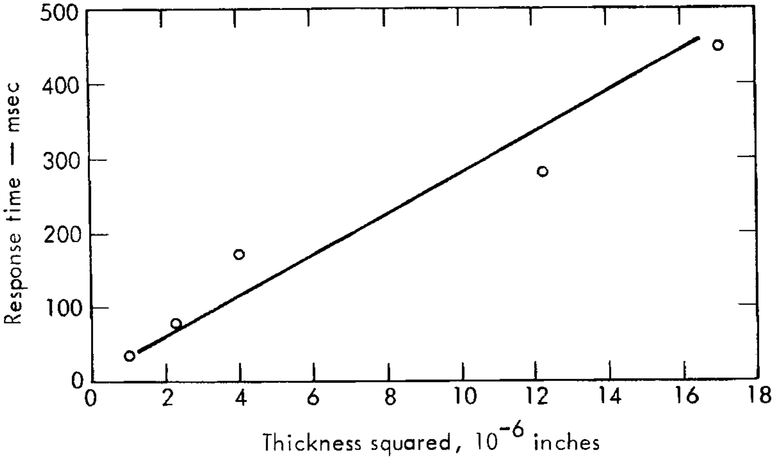

Figure 5. Response time vs. thickness squared for the various films tested.

Table 1 have an error band of at least ± 25 %. The response time is strongly governed by the heat diffusion through the ELC thickness.

5. Conclusions

The commercially available films have several features in common. They are usually composed of three or more layers of material, as shown in Fig. 3. The substrate is shown next to the films, which are composed of a light absorber (black plastic or india ink), the microencapsulated liquid crystal film, and some protective layer of plastic to act as an ultraviolet absorber. In addition, there is an adhesive layer between the substrate and the film. It is also apparent that the thickness should be uniform to obtain a uniform response time.

The ultraviolet absorbing layer may be physically some distance from the film. This does not constitute any major difficulty. The absorbing black plastic layer was no longer required because the metal substrate was chemically blackened. This was easily accomplished with stainless steel, aluminum foils and sheets. These modifications greatly enhanced the response of the liquid crystal materials, as shown in Table 1, because of the reduced thickness. The chemically blackened substrates did not degrade the color contrast of the materials.

The development of thin ELC films is significant because these films on metal foil can be used as calorimeters to visually map incident radiation from lasers or electron beams and, hence, map spatial energy distributions. The resolution of a system of this type is strongly dependent on the time required for the system to reach thermal equilibrium throughout the thickness, because during this time there can be radial flow that would degrade resolution. Hence, in general, it is desirable to obtain thin coatings of liquid crystals.

Acknowledgements

I would like to thank Jim Caywood, who so ably photographed our experiments, and Robert Coleman, who fabricated our samples and made many helpful suggestions.

REFERENCES

1. Fergason, J. L., *Sci. Am.* **210**, 77 (1964).
2. Brown, G. H. and Shaw, W. G., *Chem. Rev.* **57**, 1049 (1957).
3. Chistyakov, I. G., *Soviet Phys.—Crystallogr.* **5**, 917 (1961).
4. Parker, R. and Henning, C. D., *ASME J. Heat Trans.*, 146 (1967).
5. Parker, R., "A Passive Technique for Measuring High Transient Currents," presented at ISA Conference, 1970.