Memory effects in polymer-encapsulated cholesteric liquid crystals

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Optical memory effects have been studied in films of polymer-encapsulated cholesteric liquid crystals. Information is recorded in forward and reverse regimes by a thermal-contact or thermooptic method. The information can be erased by changing the strength of an electric field.

1. Optical memory effects in liquid-crystal media are attracting much research interest, as is the effort to develop corresponding devices for writing, storing, and displaying information.[1,2] Promising materials here are polymer-encapsulated cholesteric liquid crystals, whose contrast–voltage characteristics, like the corresponding characteristics of pure layers of cholesteric liquid crystals,[5,6] have a substantial hysteresis.[3,4]

2. The cholesteric-liquid-crystal composition used in these experiments was a mixture of nematic liquid crystals with $\Delta\epsilon > 0$ and the cholesteric liquid crystal Kh3, as a chiral additive.[4] After preparation, the mixture was encapsulated in polyvinyl butyral from the melt. The average size of the droplets of the cholesteric liquid crystal was 1–3 μm at an encapsulated-film thickness of about 15 μm. The temperature of the transition of the cholesteric droplet to an isotropic state was $T_c = 33.2\,^\circ\mathrm{C}$. Choosing the appropriate refractive indices for the polymer and the cholesteric, we achieved a transparent state of the composite film as it was oriented by an electric field.

To measure the contrast–voltage characteristics of the test samples and the temperature dependence of the optical transmission, we used a helium–neon laser. The laser beam passed through a cell made of two glass plates with transparent electrodes sandwiching the encapsulated film. The cell was inside a cell for heating and cooling. The laser beam was stopped down and directed to a KD-263 photodiode. The output signal from this diode was analyzed with the help of a S9-8 digital storage oscilloscope or a Endim 622 x, y chart recorder. The sample was reoriented by a sinusoidal signal with a voltage up to 300 V at a frequency of 1 kHz. The temperature was measured within 0.1 °C by a copper–constantan thermocouple.

3. Figure 1 shows contrast–voltage characteristics of the encapsulated film at various temperatures. The results were recorded on the chart recorder by increasing the control voltage to a maximum over 0.5 min and then reducing this voltage to zero at the same rate. The arrows show the forward branch of the hysteresis loop, which corresponds to an increasing voltage, and the reverse branch, which corresponds to a decreasing voltage. There are substantial changes in all parameters of the contrast–voltage characteristics of the material during the heating: the threshold fields $U_{0.1}\uparrow$ and $U_{0.1}\downarrow$ on the forward and reverse branches of the hysteresis loop, respectively, the

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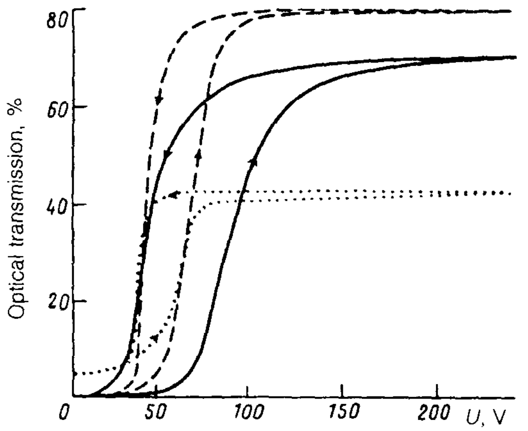

FIG. 1. Contrast–voltage characteristics of a film of a polymer-encapsulated cholesteric liquid crystal corresponding to relative temperatures $\Delta T = T - T_c = 10.9\,^\circ\mathrm{C}$ (the solid curve), $\Delta T = 1.8\,^\circ\mathrm{C}$ (the dashed curve), and $\Delta T = 0.4\,^\circ\mathrm{C}$ (the dotted curve).

saturation fields $-U_{0.9}\uparrow$ and $U_{0.9}\downarrow$, the steepness of the characteristic, the magnitude of the hysteresis, and the contrast.

The forward regime of information recording can be achieved in these encapsulated films because the threshold field $U_{0.1}\uparrow$ at room temperature is higher than the saturation field ($U_{0.9}\uparrow$) corresponding to a temperature near T_c. A voltage close to $U_{0.1}\uparrow$ is applied to the encapsulated film sample at room temperature. Part of the sample is heated to the phase-transition temperature by a thermooptic or thermal-contact method. The transformation of the forward branch of the hysteresis loop corresponding to the heating results in a local bleaching of the encapsulated film, since the applied voltage is sufficient to completely orient the heated droplets of cholesteric liquid crystal. During a subsequent cooling, the transparent state of this part of the sample "is remembered," in accordance with the upper level of the reverse branch of the hysteresis loop.

The memory effect is illustrated in Fig. 2, which is a plot of the temperature dependence of the optical transmission of an encapsulated film at various values of the orienting field. The heating and cooling rates were about 5 deg/h. In the case of cooling immediately after the transition to the liquid-crystal phase, the curve of the optical transmission for a voltage of 60 V runs above the corresponding curve during heating. By varying the maximum temperature reached in the heating in the thermal addressing, one can vary the gradations of gray. The magnitude of the contrast depends on the applied voltage and on the recording temperature, reaching and exceeding 100:1. The written image can be erased by turning off the electric field.

To realize a reversible regime of information recording, the film is first oriented to saturation by an electric field. The field is then reduced to $U_{0.3}\downarrow$, which corresponds to an optical transmission of 30% of the maximum level. Heating the sample increases the threshold field for the reverse branch of the hysteresis loop (Fig. 1) and thus leads to a relaxation of the semitransparent metastable state of the sample to a light-scattering state. The encapsulated film does not have to be heated into the isotropic phase. Figure 3 illustrates the process of information recording by means of this mechanism. Contrast values up to 60:1 were achieved. The written image can be

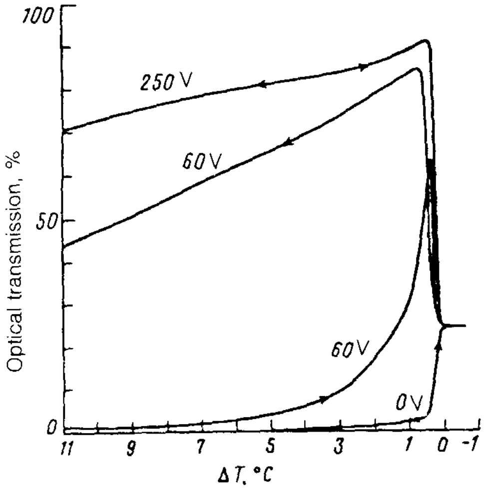

FIG. 2. Forward regime of information recording. At $U=60$ V a memory effect occurs; at $U=0$ and 250 V, there is no memory effect.

erased by increasing the field to the point at which the entire sample becomes transparent. To increase the sensitivity of the polymer-encapsulated cholesteric-liquid crystal material in thermooptic addressing, the cholesteric-liquid-crystal composition can be doped with a dye with a narrow absorption band at the wavelength of the writing light.

4. In summary, we have proposed and implemented two different methods for recording optical information in polymer-encapsulated cholesteric-liquid-crystal films, through thermal addressing and a rapid erasure of this information (in 10^{-2}–10^{-3} s) by an electric field.

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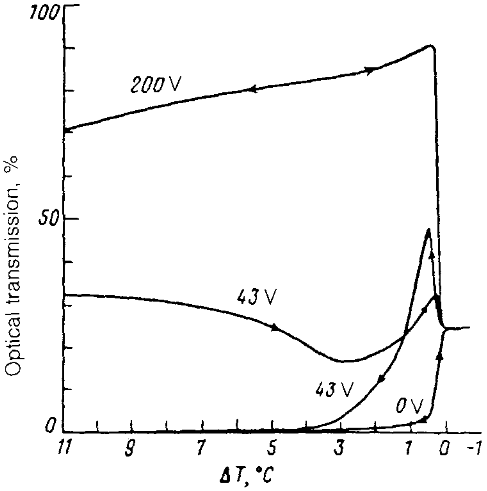

FIG. 3. Reverse regime of information storage. At $U=43$ V, there is a memory effect; at $U=0$ and 200 V there is no memory effect.

[1] L. M. Blinov, *Electro-Optical and Magneto-Optical Properties of Liquid Crystals* (Wiley, New York, 1983).

[2] A. S. Sonin, *Introduction to the Physics of Liquid Crystals* [in Russian] (Nauka, Moscow, 1983).

[3] D.-K. Yang *et al., IV Int. Top. Meet. on Optics of Liq. Cryst., Abstracts* (Florida, 1991), p. 36.

[4] S. L. Smorgon *et al.*, Preprint 780-F, Institute of Physics, Siberian Branch of the Russian Academy of Sciences, 1993.

[5] W. Greubel, Appl. Phys. Lett. **25**, 5 (1974).

[6] S. A. Tager and V. M. Shoshin, Mikroelektronika **12**, 157 (1983).

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