Optical hysteresis in liquid crystals with helicoidal distributed feedback

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An optical hysteresis has been achieved for the first time in an impurity cholesteric liquid crystal with a helicoidal distributed feedback at comparatively low light intensities (the power of the laser pump is on the order of a few kilowatts) with a short time constant (the pulse length is $\tau \cong 8$ ns).

An important condition for achieving optical hysteresis is the presence of a feedback, which is usually arranged by means of cavities or a hybrid circuit.[1,2] A cavity-free optical hysteresis with an artificial distributed feedback in a phase-conjugation arrangement was first observed experimentally in CdS (the light power density was $P = 100$ MW/cm^2, with $\tau \cong 50$ ns).[3] In periodic structures, on the other hand, a distributed feedback can be arranged by means of Bragg diffraction of light.[4,5]

In the present letter we report a new principle for achieving optical hysteresis and optical bistability, on the basis of the resonant absorption of light by an impurity in a cholesteric liquid crystal, which has a natural helicoidal distributed feedback. The resonant absorption in this system leads to an optical hysteresis at comparatively low light intensities, with a short response time and a simultaneous polarization of the light.

According to the theory of Ref. 6, the equation for the dimensionless intensity ($\bar{\rho}$) of the reflected wave, normalized by dividing by the saturation intensity (under the condition that the saturation of the resonant transitions is slight), is

$$\frac{d\bar{\rho}}{dz} = \sqrt{A\bar{\rho}^{\,2} + B\bar{\rho} + I}, \tag{1}$$

where $A = 2\Gamma(\Delta + \Gamma)$; $B = 1 - (\Delta - \Gamma)^2 + 2\Gamma I(\Delta + \Gamma)$; $I = \bar{\rho} - \sigma -$ const; σ is the dimensionless intensity of the passing wave; $\Delta = 4(\omega - \omega_B)/\omega\delta\epsilon_r$ is the relative deviation of the laser frequency ω from the "Bragg" frequency ω_B of the selective reflection; $\delta\epsilon_r$ is the amplitude of the helicoidal modulation of the dielectric constant; $\Gamma = (8\pi/3)(N\chi_r/\delta\epsilon_r)$, χ_r is the real part of the resonant susceptibility; N is the population difference of the resonant transitions of the impurity; and z is the thickness of the sample. Solving Eq. (1), we can find the necessary conditions for observing an optical hysteresis, and we can calculate the behavior for various parameters. Estimates of the threshold intensity for optical hysteresis yield values on the order of 1 kW/cm^2 (at $z = 10^{-3}$ cm). This threshold intensity of the incident light is required in order to change (Δn) the refractive index of the medium sufficiently to cause a phase shift $\Delta n(\omega/c)z = \pi$ of the light wave[6] and a deviation from Bragg reflection conditions.

The impurity in the cholesteric liquid crystal is pumped by an LGI-21 pulsed nitrogen laser, with an output wavelength of 337.1 nm. After passing through a Nicol prism, the linearly polarized light strikes a quartz cell holding the liquid crystal. The

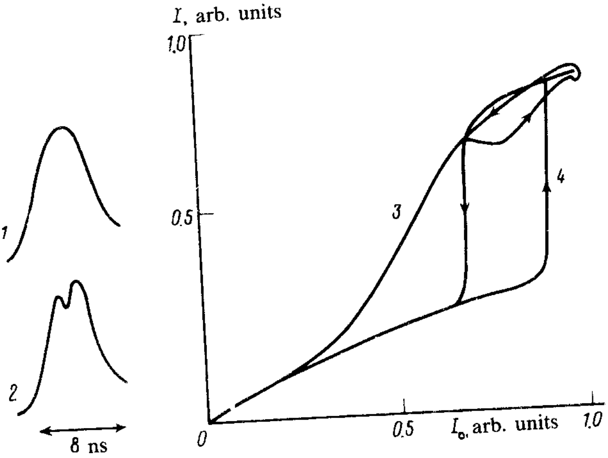

FIG. 1. Oscilloscope traces of the intensity distribution in the pulses of (1) the incident light and (2) that transmitted through the impure cholesteric liquid crystal. 3—Optical hysteresis in the impure cholesteric liquid crystal (I_0 and I are the intensity of the incident light and that of the light transmitted through the liquid crystal, according to oscilloscope traces 1 and 2); 4—theoretical prediction of the optical hysteresis.

cell is in a temperature-regulated furnace; the temperature of the mesophase is held constant (155 °C) within 0.01 °C. The thickness of the liquid-crystal layer in the cell is 10–20 μm. The incident light beam propagates along the axis of the helix of the cholesteric liquid crystal. The intensity of the light transmitted through the liquid crystal is measured with an FK-2 photodetector and an S1-70 stroboscopic oscilloscope; the results are recorded on an x, y recorder.

Figure 1 shows the changes in the shape of the laser pulse transmitted through a

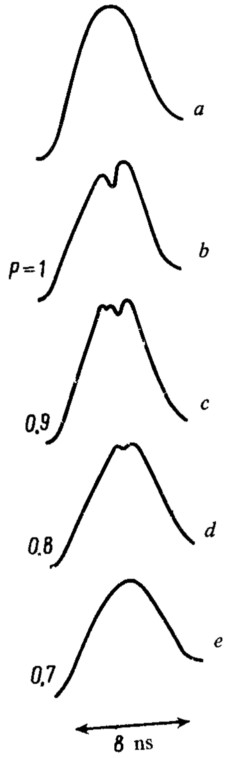

FIG. 2. Oscilloscope traces of the pulses of the incident light (a) and of the light transmitted through the cholesteric liquid crystal (b, c, d, e) versus the power of the incident light ($P = 1$ corresponds to a power density of 10 kW/cm^2).

specific cholesteric liquid crystal (cholesterol benzoate with an impurity of 3% by weight) and the optical hysteresis found from the experimental data and predicted theoretically. Figure 2 shows the experimental dependence of the effect on the power of the incident light. The changes in the pulse shape are greatest at $P = 10$ kW/cm^2; the curve of the intensity distribution in the pulse of the transmitted light becomes progressively smoother as the power density of the incident light is reduced. The threshold intensity required for observation of the optical hysteresis is 5–7 kW/cm^2, varying with the thickness of the liquid-crystal layer.

A close relationship has been established between the observed optical bistability and the diffractive suppression of optical absorption in a cholesteric liquid crystal. For example, a maximum optical hysteresis is found in those intervals of the concentration, the temperature, and the thickness in which the suppression of absorption is at a maximum.[7]

The cavity-free optical hysteresis that has been achieved in a cholesteric liquid crystal in these experiments has a record low threshold energy ($\Delta E = P\tau \leqslant 10^{-5}$ J) and a short response time ($\tau \sim 10^{-8}$ s). This hysteresis may find applications in optical information processing.

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