Optimization of the contrast, brightness, and modulation amplitude of light in electrooptic devices based on polymer-encapsulated ferroelectric liquid crystals

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An analysis is made of the relations connecting the maximum optical transmittance, the light modulation amplitude, and the contrast in a polymer-encapsulated ferroelectric liquid-crystal device to the geometry of device and the tilt angle θ of the director. The correctness of the calculations is confirmed by their agreement with experimental measurements.
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Planar-oriented films of polymer-encapsulated ferroelectric liquid crystals (PEFELCs)[1,2] can be used for modulation of plane-polarized light[3–5] through the electric-field-controlled light-scattering effect. The material is prepared in such a way[1–5] that the directors of the LCs in all the droplets are oriented in the same direction in the plane of the film. Such a film is semitransparent for light polarized perpendicular to the director if the refractive index of the polymer matrix is equal to the ordinary (in the optically uniaxial approximation) refractive index of the FELC. At the same time, light polarized parallel to the director is strongly scattered. The application of an alternating electric field leads to modulation of the director orientation in the plane of the film with an amplitude of 2θ, where θ is the tilt angle of the FELC molecules with respect to the plane of the smectic layers.

The amplitude of the change in the transmittance upon modulation of plane-polarized light transmitted through a PEFELC film is determined by the relations:[3–5]

$$\Delta T=(T_{\perp}-T_{\parallel})\sin 2\alpha \sin 2\theta, \quad (1)$$

where $T_{\perp}=I_{\perp}/I_0$ and $T_{\parallel}=I_{\parallel}/I_0$ are the optical transmittances for light polarized perpendicular and parallel to the director of the FELC, I_0 the intensity of the components of the incident light, $I_{\perp}$ and $I_{\parallel}$ are the intensities of the corresponding components of the transmitted light, and α is the average over the ensemble of droplets of the angle between the normal to the smectic layers and the plane of polarization of the incident light (see the inset in Fig. 1).

In a number of cases, especially in display devices, one is more interested in such optical characteristics as the contrast and brightness than in the transmittance modulation amplitude ΔT. The goal of this paper is to analyze the possibility of optimizing these characteristics of PEFELC devices in a single-polarizer geometry.[1–5]

The PEFELC film samples were made from the ferroelectric liquid crystal ZhKS-285 (FIRAN) with phase transition temperatures Cr–(−2°C)–SmC*–57°C–SmA–112°C– Is, which was mixed with polyvinylbutyral in a proportion of 4 : 6. The tilt angle θ of the molecules for ZhKS-285 at room temperature is 27°. The thickness of the film is approximately 5 μm. The planar-oriented state of the film is achieved by a shear deformation. The components of the transmittance ($\lambda=0.633$ μm) were $T_{\perp}=0.53$; $T_{\parallel}=0.008$. Electrooptic measurements were made with a sinusoidal electric signal having a frequency of 1 kHz.

We restrict discussion to the range of angles $\alpha=0$–90° (see the inset in Fig. 1). The maximum optical transmittance achievable with modulation of the optical signal determines the maximum brightness of the device and can be calculated from the formula

$$T_{\max}=T_{\perp}\sin^2(\alpha+\theta)+T_{\parallel}\cos^2(\alpha+\theta)$$
$$=T_{\parallel}+(T_{\perp}-T_{\parallel})\sin^2(\alpha+\theta). \quad (2)$$

In our case $T_{\max}$ reaches its maximum value, equal to $T_{\perp}$, at $\alpha+\theta=90°$, i.e., at $\alpha=90°-\theta=63°$ (Fig. 1).

It follows from Eq. (1) that the maximum light modulation amplitude (the modulation amplitude ΔT of the transmittance) at any value of the angle θ will correspond to an angle $\alpha=45°$ (Fig. 1).

The dependence of the contrast on the angle α is given by the formula

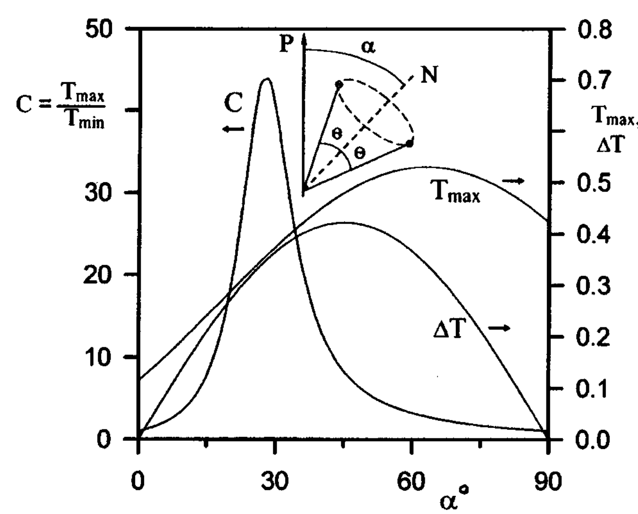

FIG. 1. The contrast C, the maximum transmittance $T_{\max}$, and the transmittance modulation amplitude ΔT as functions of the angle α, as calculated using Eqs. (1)–(3). The inset shows the relative orientation of the polarizer P, the normal N to the smectic layers, and the director of the FELC.

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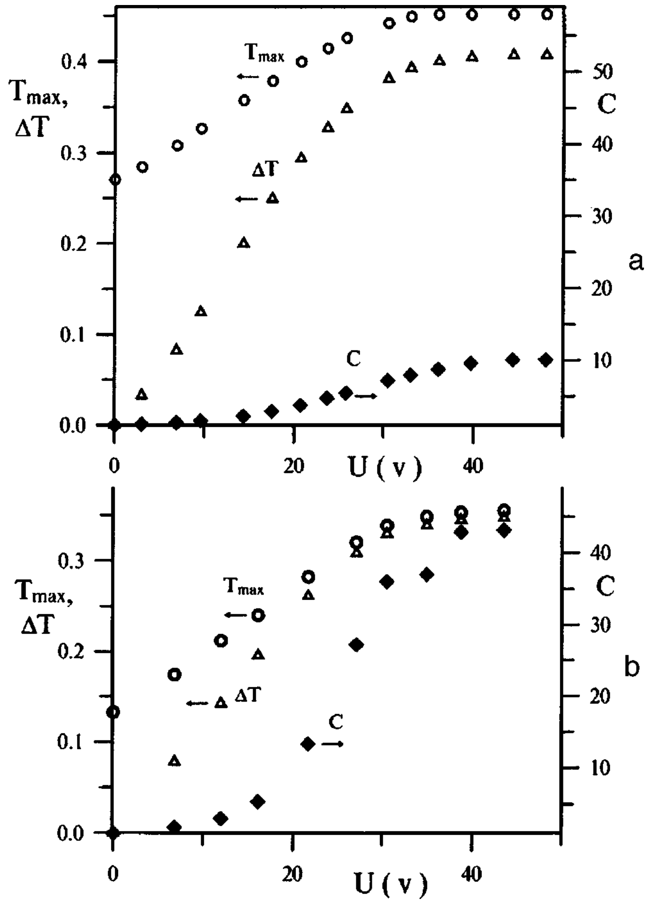

FIG. 2. The contrast C, the maximum transmittance $T_{\max}$, and the transmittance modulation amplitude ΔT as functions of the applied voltage, measured for $\alpha=45°$ (a) and $\alpha=27°$ (b).

$$C=\frac{T_{\max}}{T_{\min}}=\frac{T_{\perp}\sin^2(\alpha+\theta)+T_{\parallel}\cos^2(\alpha+\theta)}{T_{\perp}\sin^2(\alpha-\theta)+T_{\parallel}\cos^2(\alpha-\theta)}, \qquad (3)$$

from which it follows that C reaches a maximum for

$$\alpha=0.5\cos^{-1}\left(\frac{T_{\perp}-T_{\parallel}}{T_{\perp}+T_{\parallel}}\cos 2\theta\right). \qquad (4)$$

It should be noted that the angle α in Eq. (4) depends not only on the tilt angle θ of the molecules but also on the anisotropy of the transmittance of the sample. However, if the ratio $T_{\parallel}/T_{\perp}$ is small, then the angle $\alpha\simeq\theta$. In our case $\alpha\simeq 27.6°$. It follows from Eq. (3) that for such samples the maximum contract of the PEFELC device can be estimated using the approximate relation

$$C_{\max}\simeq 1+(T_{\perp}/T_{\parallel}-1)\sin^2 2\theta\simeq T_{\perp}/T_{\parallel}\sin^2 2\theta. \qquad (5)$$

We see that the aforementioned characteristics of PEFELC devices in general reach their maximum values at different values of the angle α, and the positions of the maxima of the contrast and maximum transmittance depend on the angle θ. The positions of the maxima draw closer together as the angle θ is increased, becoming equal for $\theta=45°$. However, FELCs with a molecular tilt angle $\theta=45°$ are exotic materials. Most of the commercially available FELCs have tilt angles θ in the range 0–30°; in the FELCs specially prepared for Clark–Lagerwall cells[6] the angle $\theta\simeq 22.5°$. By analyzing relations (1)–(5) one can estimate the range of variation of the values of the parameters and the possibility of optimizing them by changing the relative orientation of the polarizer and the PEFELC film.

As an illustration, Fig. 2a and 2b shows the modulation amplitude of the transmittance, contrast, and maximum transmittance as functions of the applied voltage for angles $\alpha=45°$ (Fig. 2a) and $\alpha=27°$ (Fig. 2b). For $\alpha=45°$ the contrast barely reaches a value of 10. When the polarizer is rotated to $\alpha=27°$ the contrast increases to 43, while at the same time the maximum transmittance decreases by approximately 20% and the modulation amplitude by 10%. We see that the good agreement is observed between the measured characteristics in the saturation region (Fig. 2a and 2b) and the results of the calculation (Fig. 1).

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