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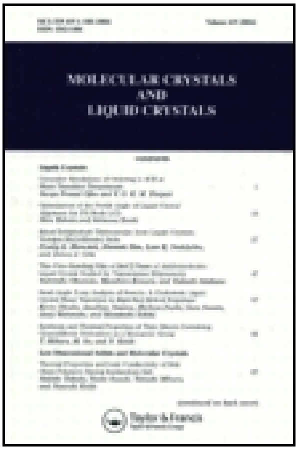

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Controlled Passive Liquid Crystal Shutters—A New Class of Solid-State Laser Q-Switches

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CONTROLLED PASSIVE LIQUID CRYSTAL SHUTTERS - A NEW CLASS OF SOLID-STATE LASER Q-SWITCHES

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Abstract Different types of liquid crystal (LC) Q-switches and means for controlling radiation parameters of solid-state lasers by using the Q-switches are discussed.

INTRODUCTION

The use of phototropic LC media as passive shutters (PS) in solid-state lasers makes it possible to control radiation parameters [1]. Diversity of optical effects in LC allows realization of different PS types [2-5].

BLEACHABLE SHUTTERS BASED ON DYES IN LC

Studies concerned with bleaching of a number of dyes, such as phtalocyanine, indolenine and bisantene, in various nematics [2] provided a set of phototropic LC media for ruby lasers. The most promising are bisantene dyes dissolved in cyanobiphenyls. They are characterized by a strong absorption dichroism [5] reaching 0.7, maximum absorption at radiation wavelength, a comparatively high photoresistance and bleaching efficiency [2].

Figs. 1 and 2 give the generation parameters of a ruby laser with bleachable filter based on diphenylbisantene dissolved in five-component cyanobiphenyl mixture (CBM) whose temperature of the nematic - isoptropic transition is $T_{NI} = 56^{\circ}C$. By changing the initial filter absorption coefficient K_0, we were able to control the

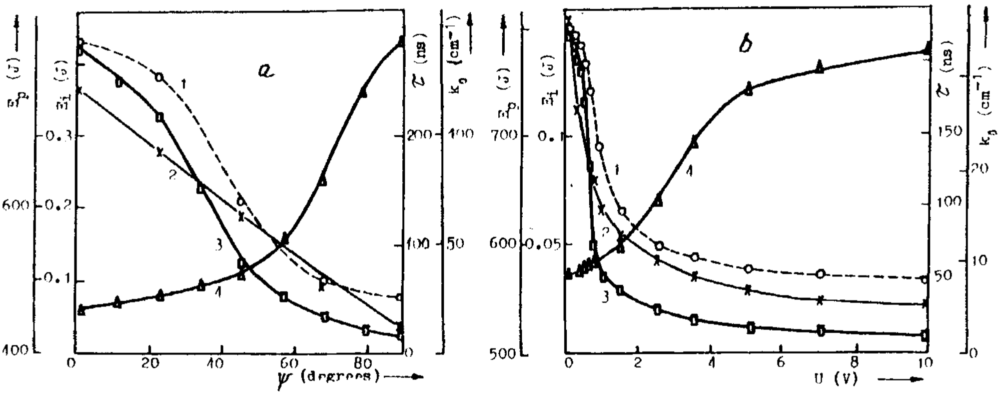

FIGURE 1 Initial absorption coefficient of the filter K_0(1), threshold pumping energy E_P (2), pulse energy E_i (3) and duration τ (4) as function of the angle ψ (a) and control voltage U (b) applied to the LC cell. A planar cell of thickness d=60 μm was used. The mixture concentration is 10^{-3} M.

lasing mode in a wide range - from the mode close to the freespike lasing to the high-power single pulse mode. The control is based on changing the director orientation **L** relative to the radiation polarization vector **E** both in the azimuthal plane (by rotating the cell through a certain angle (Fig. 1a) and in the wave polarization plane (in electric field (Fig.1b)), and, also, on a change of the parameter S with increasing LC temperature (Fig. 1d).

It is obvious from the figures that the energy dependences $E_i(\psi)$, $E_i(U)$ and $E_i(T)$ in mesophase region (25 to 50 °C) change in accordance with analogous dependences for absorption coefficients, which is typical of lasers with PS. Near the nematic-isotropic transition ($\Delta T = T_{NI}-T = 0.5-1$°C) the changes in the pulse energy and duration are no longer monotonous and an abrupt increase in energy (2-3 times) and a less marked decrease in the pulse duration are observed. Physical interpretation of the anomalous radiation behaviour includes, in our opinion, two factors [6]. It is known that induced losses caused by a nonuniform heating of the PS based on the dye solutions may reduce the laser output energy by an order of magnitude. Taking into account a considerable increase in LC heat

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capacity in the transition region and assuming that amount of heat released by the filter is constant regardless of the initial temperature, it is natural to expect a significant decrease of the heating degree of the medium, and, hence, of the induced thermal losses of radiation because of temperature gradients in the PS [7]. Of importance is also such factor as a change of the layer scattering coefficient when passing from the mesophase to isotropic state. The radiation density necessary for the transition to this state is 0.1 - 0.2 J/cm^2 for the absorption coefficient of about 100 cm^{-1}. Since at the lasing onset the energy density in the cavity is much lower, the pulse starts its development as a result of bleaching of the dye in the LC. Then, a rise in the energy density stimulates the phase transition which promotes increasing transparency of the layer and, hence, the cavity loss differential.

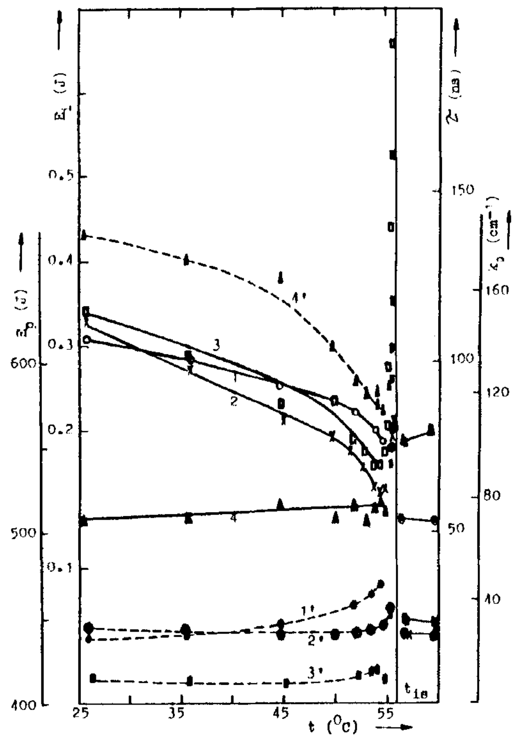

FIGURE 2 Temperature dependences K_0 (1,1'), E_P (2,2'), E_i (3,3') and τ(4,4') for parallel (1-4) and perpendicular (1'-4') orientations of **L** and **E**.

PS BASED ON THERMOOPTICAL EFFECTS IN NEMATICS

Owing to high values of LC thermal nonlinearity parameters (which exceed analogous values for isotropic media by 2-3 orders of magnitude [4]) and short development periods of thermal processes in LC activated by absorbing additives (about 10^{-8}s) [2], effective Q-switching of the laser can be carried out by using various

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thermooptical effects in LC. We realized experimentally three methods of the Q-switching control.

The first one is based on PS transmission changes as a result of phase modulation of the laser beam caused by a decrease of the layer optical anisotropy Δn under laser heating [5]. The Q-switch comprised a cell filled with a CBM planar layer (d = 20 μm), activated with anthraquinone dye (K_0 = 50 cm^{-1}), and a Glan prism used as an analyzer. When the initial layer temperature changes from 48 to 47°C, the pulse energy changes from 0.05 to 0.27 J, and its duration changes from 150 to 50 ns.

In the second method we used the peculiarities of the optical transmission changes of a Q-switch, which consisted of a twist-cell and a Glan prism, near the phase transition ΔT = 0.1 - 0.2°C [4]. A decrease of Δn under the action of laser radiation results in increasing transmission of such a Q- switch in the cavity initially caused by disturbance of the Mogen regime and, then, by the phase transition stimulated by the developing pulse. For a five-component CBM layer 5 μm thick, the anthraquinone dye absorption coefficient of 50 cm^{-1} and ΔT = 0.2°C, we obtained E_i = 0.4 J and τ = 90 ns.

The third method of Q-switching is based on change of the coefficient of reflection from anisotropic LC layer near the TIR angle α_0 as a result of decreasing n_o and n_e under laser radiation [4]. The PS consisted of two glass prisms between which a layer of CBM with an addition of anthraquinone dye was disposed. The prism' bases were coated with transparent conducting and orienting layer. The lasing parameters of the laser equipped with such a PS are significantly dependent on the layer parameters n_o, n_e, K_0, d/λ , the parameter of the interfacial medium n_1 as well as on the angle of incidence α of the laser beam on the layer. By changing α for given layer parameters or changing n_o and n_e in thermal or electric field for given orientation of the PS, we could control the radiation parameters (Fig. 3).

As can be seen from Fig.3, both thin ($d \approx \lambda$) and thick ($d \gg \lambda$)

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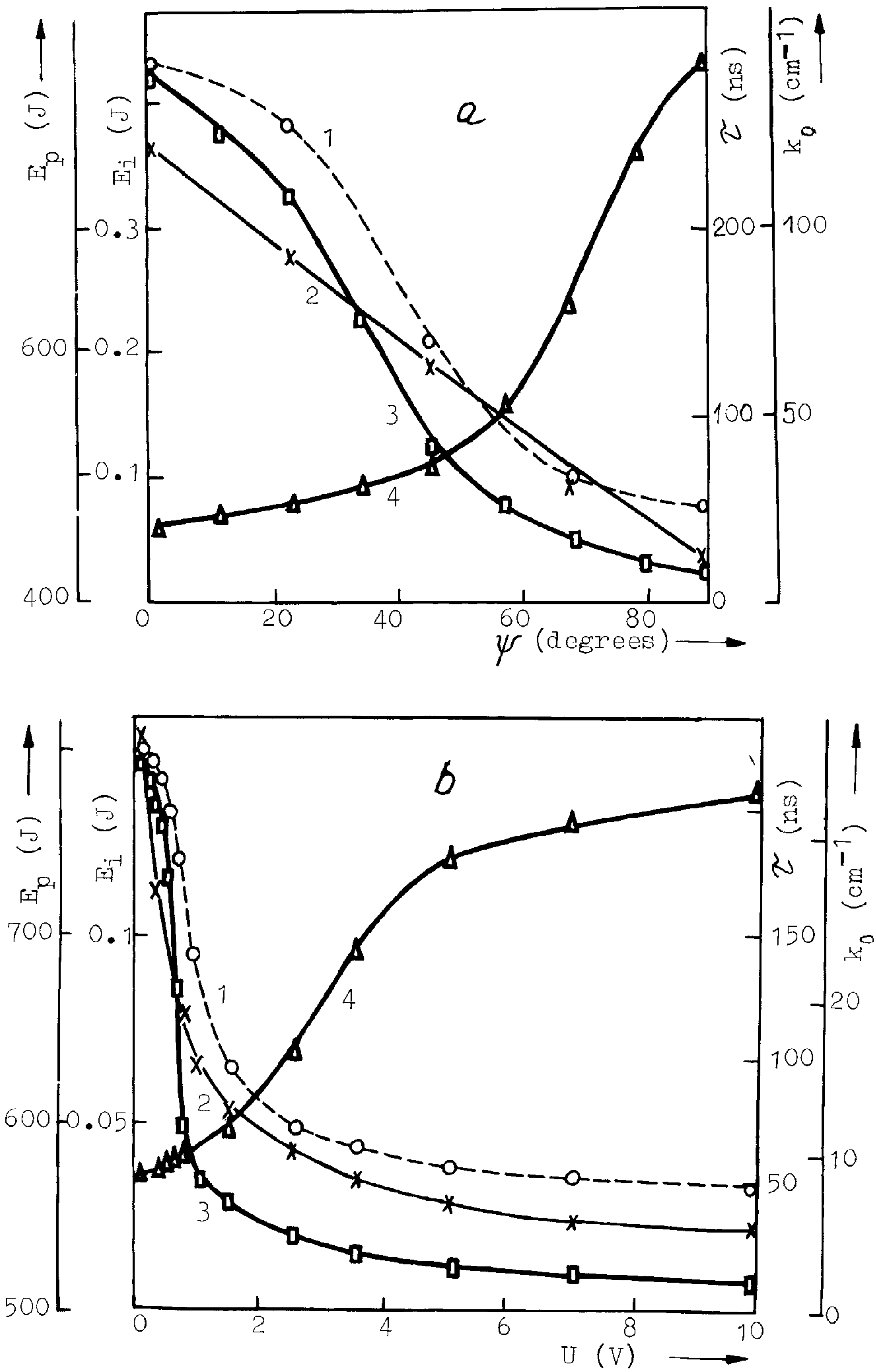

Fig. 1

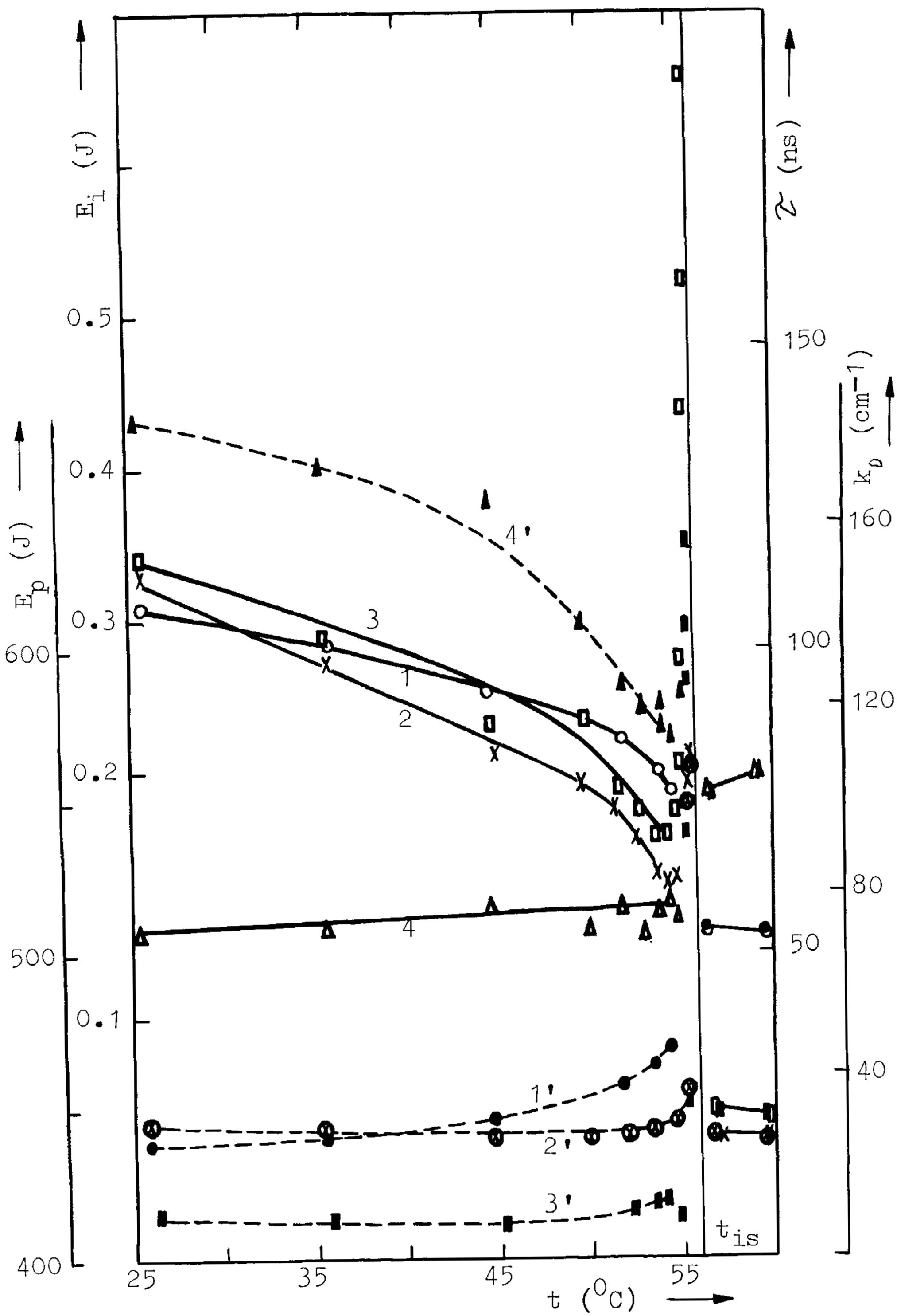

FIG. 2

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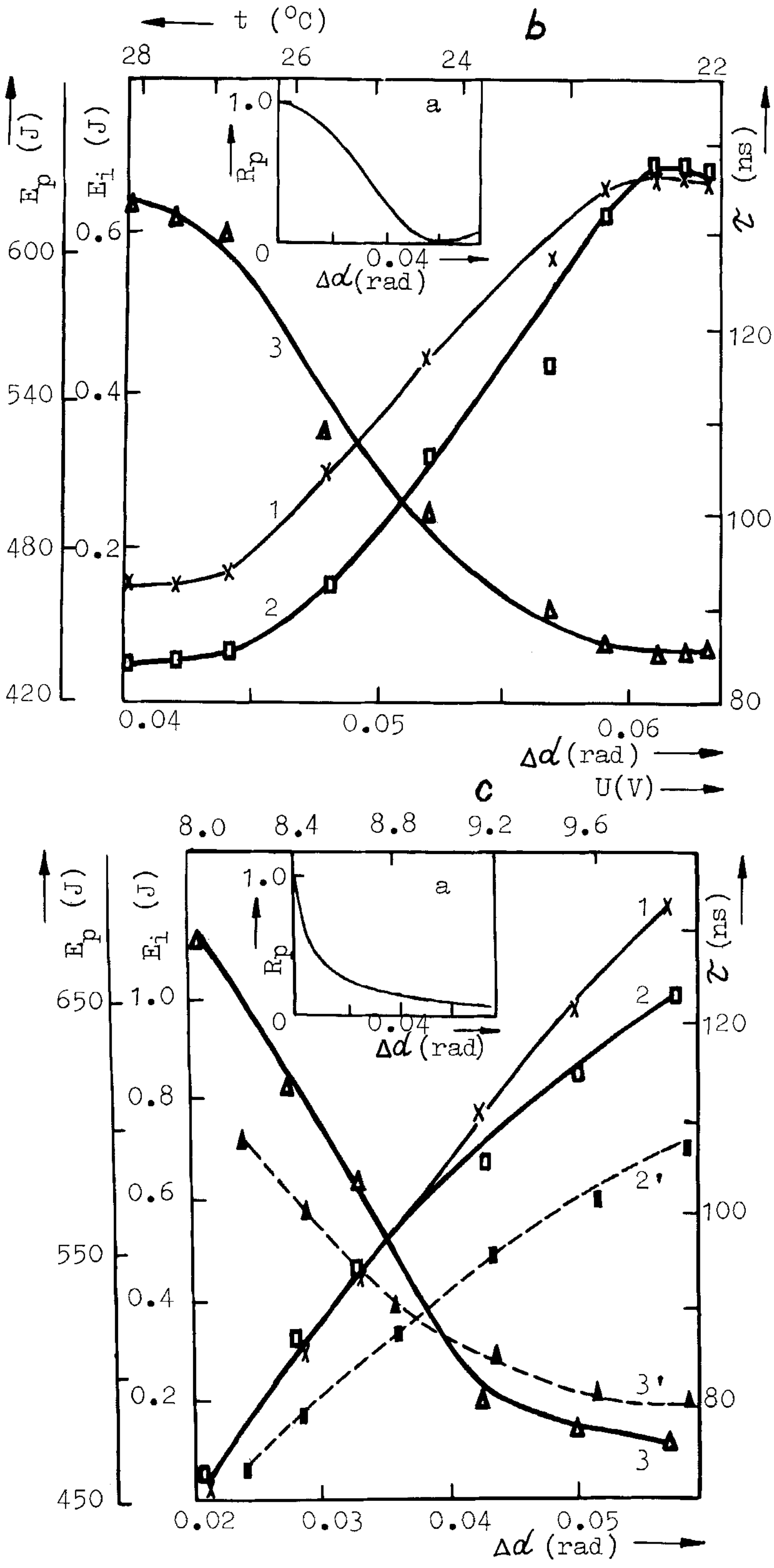

Fig. 3

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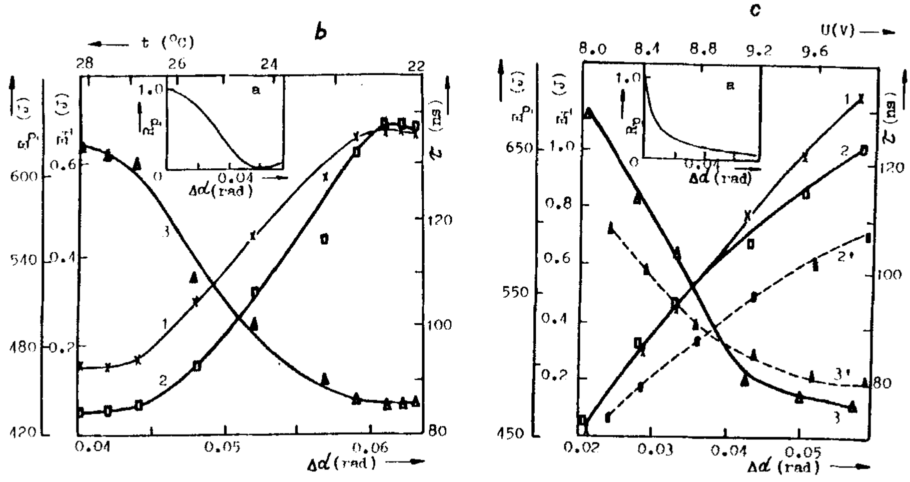

FIGURE 3 Energy reflection coefficient R_p(a) for p-polarized wave E_p(1), E_i(2,2') and τ(3,3') as dependent on $\Delta\alpha = \alpha_0 - \alpha$ (1-3), initial temperature (b,1-3) and control voltage (c,2'-3') for thin (b,d = 1,2 μm) and thick (c,d = 20 μm) layers. α_0 = 1.305 rad, n_1 = 1.793, n_o = 1.519, n_e = 1,730 for λ = 694,3 μm, K_0 = 20 cm^{-1}. The curves 1-3 were obtained for normal and 2',3' planar layer.

LC layers can be effectively used for controlling Q-factor [8].

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