USE OF POROUS GLASS-LIQUID CRYSTAL HETEROGENEOUS SYSTEMS FOR INFORMATION DISPLAY DEVICES

F. M. Aliev, V. N. Baushev, G. N. Dul'nev,
I. K. Meshkovskii, and S. V. Tikhonov

UDC 537.533.001

Theoretical and experimental studies of an information display device based on a porous glass-liquid crystal heterogeneous system are presented.

Liquid crystal readouts are a widely known example of passive readouts used mainly in devices intended for use by a single individual. A number of studies have been dedicated to devices for information display on a large screen, but nevertheless, the search for new materials and physical phenomena which can be used in information displays suitable for large group use is still a pressing problem.

In [1] the present authors demonstrated the possibility of using a porous glass-liquid crystal heterogeneous system to form a planar cell which would serve as an element of a large screen display device, capable of operating under high ambient light levels. Below we will describe a concrete realization of this possibility in the form of a single digit readout, together with a study of the temperature dependence of transmission contrast ratio and response speed of the device.

Each element of the indicator is a thin plate (thickness ≈0.6 mm) of porous glass, filled with a material having a liquid crystal phase. The pore volume of the glass comprises ~40% of the total specimen volume, and the mean pore diameter is 3000-4000 Å. The intense spatial optical inhomogeneity of the original specimen causes intense scattering of light, so that the light transmission of the original glass at a thickness of ~1 mm is less than 0.5% over the visible spectrum.

No well-defined molecular orientation of specified texture is required in the liquid-crystal substance filling the pores.

The physical basis of element operation is the effect of light scattering in a porous medium, which can be thermally controlled by phase transitions in the liquid-crystal substance introduced into the pores; this substance is selected so that at room temperature it crystallizes in the solid phase and the element scatters light intensely (transmission <0.5%). When the liquid-crystal material is heated above the temperature of transition into the isotropic phase the indices of the isotropic crystal material and the matrix become equal and the element transmission reaches its maximum value (T = 90%). At temperatures where the liquid-crystal phase exists, the element is in a state analogous to that found in "sandwich" cells, operating in the dynamic light scattering regime.

Figure 1 depicts the operating indicator. A thin layer of chromium is vacuum sputtered onto the rough porous glass back surface of each element. Since this layer has high absorbing power, due to the high dispersion of the chromium particle size in the plate pores, in the maximum light transmission mode the black background created by this film becomes visible. When a current is passed through this film it performs the function of a heater. The light-colored indicator elements (Fig. 1) are at a temperature corresponding to the solid-crystal phase of the material within the pores (minimum transmission), while the dark elements have the material in the isotropic liquid phase (maximum transmission).

The optical characteristics (extinction coefficient ε and transmission contrast ratio k) of an indicator element without the absorbing layer were determined by standard methods using an SF-26 spectrophotometer. The results presented are for matrix pores filled with cholesteryloleate. Figure 2 shows ε and k as functions of temperature for an incident light wave-

Leningrad Institute of Precision Mechanics and Optics. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 4, pp. 664-669, October, 1982. Original article submitted August 17, 1981.

 0022-0841/82/4304-1168$07.50

length of λ = 550 nm. The quantity $\varepsilon = (\ln (I_0/I))/L$, while the transmission contrast ratio is defined as $k = I(t)/I(t_0)$, where $I(t_0)$ is the intensity of the light passing through the cell at the temperature t_0, corresponding to the solid crystal phase of the material in the pores, and I(t) is the intensity of the light passing through the cell at temperatures above the temperature of fusion into the liquid-crystal phase (t_1).

It is evident from the figure that three modes of element operation are possible. At temperatures $<t_1$ the cell is characterized by a high ε value (the cell transmits practically no light). With increase in temperature above t_1 the value of ε decreases by an order of magnitude.

After transition of the material filling the pores into the liquid-crystal phase the cell is in the second state. In this state the cell structure can be considered as consisting of a large number of static disclinations which produce intense light scattering.

At temperatures above the liquid-crystal–isotropic liquid transition temperature (t_2) the optical anisotropy of the material within the pores becomes equal to zero, although the index of refraction of the isotropic liquid does differ slightly from the index of refraction of the porous matrix and ε does not reach its minimum value. Further increase in temperature leads to equalization of the indices of refraction and ε decreases, approaching its minimum value (maximum transmission). It is also evident from Fig. 2 that the maximum value of k is 200:1 and remains constant over a wide temperature range, while change of k from 1:1 to 200:1 with temperature makes possible device operation in a half-tone mode.

We note that the power per cm^2 required to double contrast comprises 0.01 W/cm^2. An important property of this element is the fact that the image which it forms retains sufficient contrast over an observation angle range of 10-170°. This makes the porous glass-liquid-crystal cell superior to traditional "sandwich" type liquid-crystal cells which produce a clear image over only a very narrow angular range of the order of 5° [2].

Cholesteryloleate is not the only substance suitable for use in the liquid-crystal-porous glass composition. Similar operation was found to occur with use of cholesterylpelargonate, cholesterylcaprinate, cholesteryllaurate, mixtures of these, and a number of other materials.

The service life of such an indicator is determined to a significant degree by the physicochemical properties of the liquid-crystal material used. In our experiment the device operated successfully for 30 h of continuous use.

Important parameters for operation of such a readout device are the element switch-on and switch-off times. Since transition of the element from the state with minimum transmission to that with maximum transmission (switch-on) and the reverse transition (switch-off) occur due to temperature change, determination of the corresponding times involves calculation of a space–time temperature field.

We will analyze the temperature field using a one-dimensional model of the readout (Fig. 3), since estimates show that heat losses from the element endfaces can be neglected. The model chosen corresponds to an isolated element, both surfaces of which exchange heat convectively with the surrounding environment; close contact of the element with the mounting surface degrades operating characteristics. In calculating the temperature field we will not consider the temperature dependence of thermal conductivity, specific heat, and density of the material. These quantities were determined experimentally and have values of λ = 0.42 W/m•°K, c = 1500 J/kg•°K, ρ = 2000 kg/m^3 at t = 300°K. Energy losses to the phase transition can be neglected since these comprise ≈3% of the energy which must be supplied to the element to turn it on (transition to the state with largest k). During heating the temperature field will be significantly nonuniform along an axis perpendicular to the plane of the element (x axis), so that the mathematical formulation of the problem has the form

$$\frac{\partial^2 t}{\partial x^2} = \frac{1}{a}\frac{\partial t}{\partial \tau}, \tag{1}$$

$$\left[\lambda \frac{\partial t}{\partial x} - \alpha_1 (t - t_{m1})\right]_{x=0} = 0; \quad \left[\lambda \frac{\partial t}{\partial x} + \alpha_2 (t - t_{m2})\right]_{x=L} = q(\tau), \tag{2}$$

$$t(x, 0) = t_0. \tag{3}$$

The dependence $q(\tau)$ permits control of the switch-on time. In fact, if we supply a power level equal to that calculated for the stationary state, turn-on occurs over a quite long

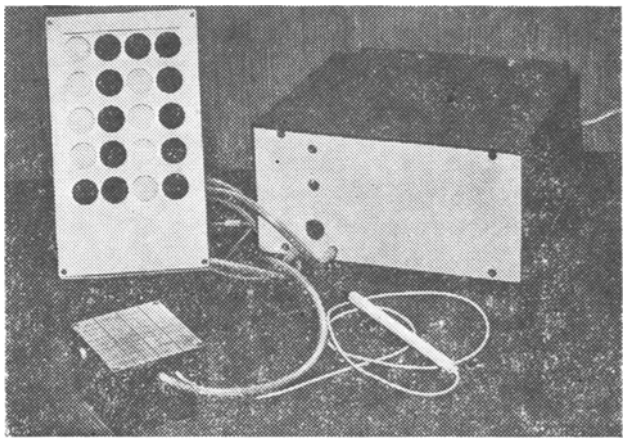

Fig. 1. Operating indicator (explanation in text).

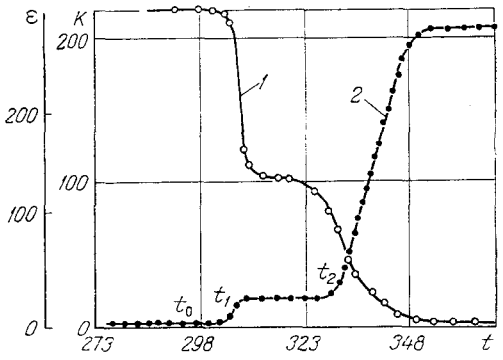

Fig. 2

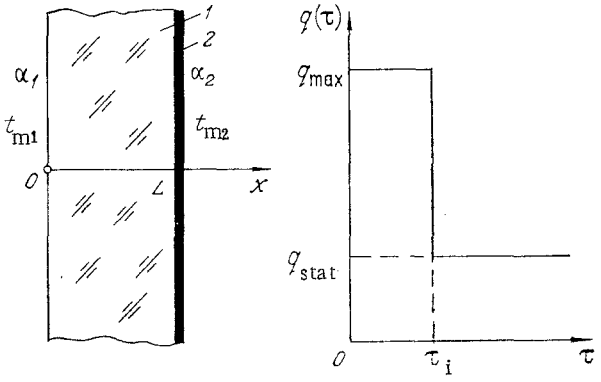

Fig. 3

Fig. 2. Extinction coefficient ε (curve 1) and contrast ratio k (curve 2) versus temperature t for porous glass plate filled with cholesteryloleate. ε, m^{-1}; t, °K; k, dimensionless.

Fig. 3. One-dimensional model of readout element (1, porous glass, filled with liquid crystal; 2, film heater) and graph of control power q(τ) versus time.

time interval. On the other hand, power increase is limited above by the process of thermal decomposition of the liquid crystal, which sets in at some characteristic temperature. We note that cooling of the readout elements to liquid nitrogen temperature did not degrade their operational properties. For q(τ) the law depicted in Fig. 3 was used.

Solution of Eqs. (1)-(3) for the special case $t_{m1} = t_{m2} = t_0$ was performed by the method of finite integral conversions [3] giving

$$t(x, \tau) = t_0 + \frac{L^2}{\lambda} \sum_{k=1}^{\infty} \frac{1}{C_k \eta_k^2} V_k(x) \Theta_k(\tau) V_k(x = L),$$

$$V_k(x) = \eta_k \cos \frac{\eta_k x}{L} + \mathrm{Bi}_1 \sin \frac{\eta_k x}{L}, \qquad (4)$$

$$C_k = \frac{L}{2} \left[(\eta_k^2 + \mathrm{Bi}_1^2) \left(\frac{\mathrm{Bi}_2}{\eta_k^2 + \mathrm{Bi}_2^2} + 1 \right) + \mathrm{Bi}_1 \right],$$

$$\Theta_k(\tau) = \begin{cases} q_{max}(1 - \exp(-\eta_k^2 a\tau)), & \tau \leqslant \tau_i, \\ q_{max}(\exp(-\eta_k^2 a(\tau - \tau_i)) - \exp(-\eta_k^2 a\tau) + q_{stat}(1 - \exp(-\eta_k^2 a(\tau - \tau_i)), & \tau \geqslant \tau_i, \end{cases}$$

with eigenvalues η_k determined by solution of the transcendental equation

$$\mathrm{ctg}\, \eta_k = (\eta_k^2 - \mathrm{Bi}_1 \mathrm{Bi}_2)/[\eta_k (\mathrm{Bi}_1 + \mathrm{Bi}_2)], \quad \mathrm{Bi}_1 = \frac{\alpha_1 L}{\lambda}; \quad \mathrm{Bi}_2 = \frac{\alpha_2 L}{\lambda}.$$

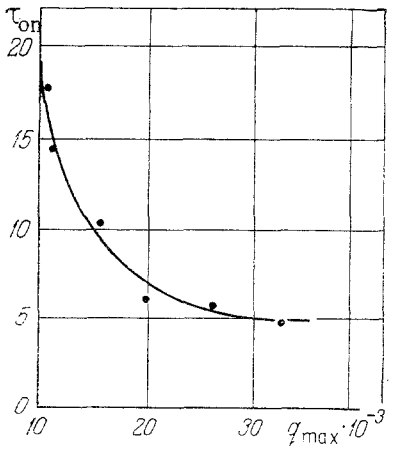

Fig. 4. Switch-on time τ_{on} (sec) versus power q_{max} (W/m^2); points) experiment; line) calculation.

The solution obtained, together with the experimental data of Fig. 2 (curve 1), permits calculation of the element switch-on time for various operating modes. Figure 2 (curve 1) shows the value $\varepsilon = f(t)$ which permits calculation of radiation transmission for an isothermal element. In the conditions depicted in Fig. 3 the element temperature field is nonisothermal and nonstationary. We will proceed as follows: We arbitrarily divide the element into plane layers perpendicular to the x axis, of a thickness such that the temperature of the layer can be considered constant and equal to the mean, which can be found from Eq. (4). Considering the repeated attenuation of radiation as it passes through such a system, we can determine the intensity of the radiation exiting the element as a function of time. The moment of time at which the transmission reaches 90% of the maximum value will be considered as the switch-on time τ_{on} [4].

The technique described above was realized as a computer program. Computer calculation with variation of the parameters q_{max}, τ_i, using values of $\alpha_1 = \alpha_2 = 15$ W/m•°K, $L = 6 \cdot 10^{-4}$ m, gives a minimum switch-on time of $\tau_{on} = 1.2$ sec at $q_{max} \approx 7 \cdot 10^4$ W/m^2 for the liquid-crystal material used.

Figure 4 shows the function $\tau_{on} = f(q_{max})$, calculated by the method described above, and determined experimentally. The readout switch-off time was determined experimentally, and for the given readout and cell construction proved to depend mainly on the heat-exchange coefficients with the surrounding medium α_1 and α_2. In our case the switch-off time did not exceed 5 sec.

NOTATION

L, cell thickness, m; I_0, I, intensity of light incident on element and exiting element; a, thermal diffusivity of element material, m^2/sec; $q(\tau)$, heater surface power, W/m^2; τ, time, sec; t, temperature, °C; t_{m_1}, t_{m_2}, temperature of medium on two sides of plate, °C; α_1, α_2, heat-exchange coefficients with both sides of plate, $W/m^2 \cdot K$; t_0, initial element temperature, °C.

LITERATURE CITED

1. F. M. Aliev, V. N. Baushev, G. N. Dul'nev, I. K. Meshkovskii, and A. M. Prokhorov, "Optoelectronic cell using thermally controlled light scattering based on porous glass—liquid crystal heterogeneous system," Dokl. Akad. Nauk SSSR, 253, No. 3, 598-600 (1980).
2. Z. Yu. Gotry (ed.), Liquid Crystal Readout Devices [in Russian], Sov. Radio, Moscow (1980).
3. A. V. Lykov, Heat-Mass Transfer Handbook [in Russian], Energiya, Moscow (1978).
4. B. Lekner, F. Marlow, E. Nester, and Yu. Talts, "Matrix readout devices using liquid crystals," Tr. Inst. Inzhener. Elektrotekh. Radioelektron., 59, No. 11, 30-52 (1971).