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Cholesteric reflective display: Drive scheme and contrast

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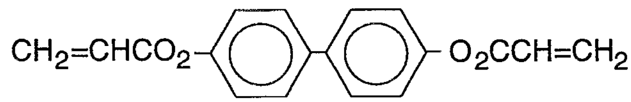
We studied the electro-optical response of a bistable cholesteric texture (BCT) display to ac voltage pulses. The material can be driven into states where planar and focal conic textures coexist at zero field and gray scale memory is achieved. According to the properties of the BCT display we designed two drive schemes; one for binary operation and the other for gray scale operation. We made a 320×320 pixel reflective display with a resolution of 80 lines/in. on a passive matrix. Measurement in an integration chamber showed that the display has higher contrast and better viewing angle than a reflective super twisted nematic display.

The bistable cholesteric texture (BCT) display has two stable optical contrasting states at zero field;[1–4] one state reflects colored light and the other state is weakly scattering. The reflecting and scattering states correspond to the planar and focal conic textures, respectively. In the planar texture the liquid crystal is a periodic helical structure with the helix axes perpendicular to the surface of the cell and reflects light of wavelength $\lambda = nP$, where n is the average refractive index and P is the pitch length.[5] In the focal texture the liquid crystal is in a poly-domain structure with the helix axes oriented randomly throughout the cell and scatters light weakly. A BCT display cell typically has a cell gap of a few μm and the back plate of the cell is painted black. In the planar texture the cell reflects colored light while in the focal conic texture the cell is almost transparent and appears black because of the painted black background. The transformation between the reflecting and black states of a cell can be achieved by application of an ac voltage pulse whereby the reflecting state is obtained after the application of a high voltage pulse and the black state is obtained after the application of a low voltage pulse. The cholesteric material can be used to make high definition flat panel displays on a passive matrix because of its bistability.[6] The display does not need polarizers and can be operated in front-lit conditions. The reflected light is brilliant under room light conditions.

The liquid crystal used in our experiment is a mixture of E48, CB15, ZLI4572, and CE1. E48 is a nematic liquid crystal and CB15, ZLI4572, and CE1 are chiral agents. The mixture reflects green light and the color shift in the temperature region of 0–80 °C is less than 30 nm. The display cell consists of two indium tin oxide (ITO) glass plates and the cell gap is controlled by 5-μm glass fiber spacers. The ITO glass plates are coated with polyimide and buffed for the homogeneous alignment of the liquid crystal. Small amounts of a biacrylate monomer and photoinitiator are added to the mixture. The monomer has the structure shown below:



The monomer is polymerized under ultraviolet (UV) irradiation to form a cross-linked network. The function of the polymer is to stabilize the focal conic texture, reported as polymer-stabilized cholesteric textures (PSCT) display,[3] and to improve the optical contrast of the display.[4]

We studied the response of the PSCT display cell to pulses of various voltages to examine the gray scale using the following procedure: First, we drove the cell into the reflecting state or the scattering state; then we applied a pulse of certain voltage to the cell. Finally, we measured the reflection of the cell 2 s after the application of the pulse in order to obtain a stable value. In the experiment the incident unpolarized light was monochromatic (tuned to the reflection peak) and collimated. The incident angle was 22.5° and the reflected light was detected with a collection cone of 70° centered at the reflection angle of 22.5°. The intensity of the reflected light was normalized to that of the incident light. The width of the applied pulse was 20 ms. The result is shown in Fig. 1 where curve a is the response of the cell in the reflecting state prior to the pulse. For voltage below 20 V, the reflection is not affected by the pulse. When the voltage of the pulse is between 20 and 34 V, the reflection decreases approximately linearly with the increasing voltage. Stable gray scale is obtained in this region. The reflection of the cell reaches its original value when the voltage is above 46 V. Curve b is the response of the cell in the scattering state prior to the pulse. In this case the reflection of the cell is unchanged by the pulse of voltage below 44 V. The cell is switched into the reflecting state by a pulse of voltage above 50 V.

We measured the iso-contrast of PSCT displays in an integration chamber where the incident light was isotropic and unpolarized. The result is shown in Fig. 2. The PSCT

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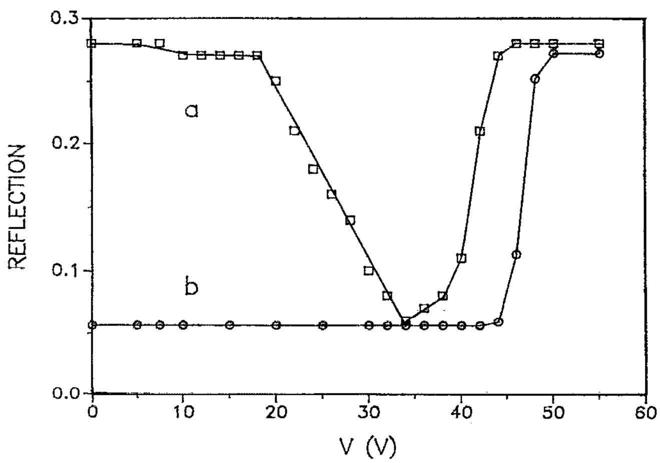

FIG. 1. Reflection of the PSCT cell vs the voltage of applied pulse. The reflection was measured 2 s after the application of the pulse. (a) The cell is in the planar texture prior to the pulse; (b) the cell is in the focal conic texture prior to the pulse.

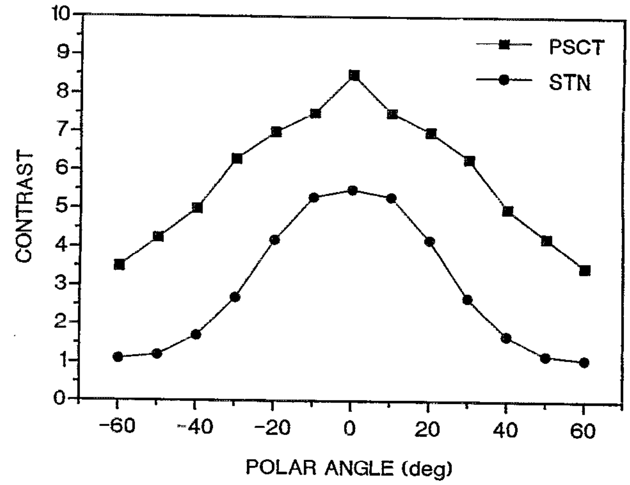

FIG. 3. Contrast of the PSCT cell and reflective SNT cell vs the polar angle, where the incident light is isotropic and unpolarized.

display has no polarizers and therefore the contrast is symmetric about the azimuthal angle. In Fig. 3 the contrast of the PSCT display is plotted versus the polar angle. The contrast of a reflective STN (super twisted nematic) is also shown for the purpose of comparison. The PSCT display has a higher contrast and better viewing angle than the STN.

We designed two drive schemes for the PSCT display: one for binary displays and the other for gray scale displays. For the binary display, let us consider an example of a 3×3 pixel display shown in Fig. 4 to illustrate the drive scheme. The voltages given here are for the display whose electro-optical property is shown in Fig. 1. The row voltage is either 35 V for the selected row or 0 V for the nonselected row. The column voltage is $V_R = 15$ V for obtaining the reflecting state and 0 V for obtaining the scattering state. The row and column voltages are ac square pulse and have opposite phases. Hence, for the pixels in the selected row the voltage across the pixel is either 50 V to obtain the reflecting state or 35 V to obtain the scattering state. For the pixels in the nonselected row the voltage across the pixel is either 0 or 15 V under which the states of the pixels are unchanged. Therefore once a pixel of a multiplexed display is addressed into the reflecting or scattering state, it will remain in that state. The contrast ratio of the image is independent of the number of rows. We made a 320×320 pixel display with a resolution of 80 lines/in. A picture of Escher's Water Fall on the PSCT display is shown in Fig. 5. In this drive scheme there is, however, a problem that the frame time is long and not fast enough for video rate operation.

For the gray scale display, first the display has to be freshened, that is, a high voltage pulse applied to all the pixels to drive them into the reflecting state. The row voltage is 20 V for the selected row and 0 V for the nonselected row. The column voltage is between 0 and 15 V, depending on the gray scale. The row and column voltages are ac square pulses and have opposite phases. The voltage across the pix-

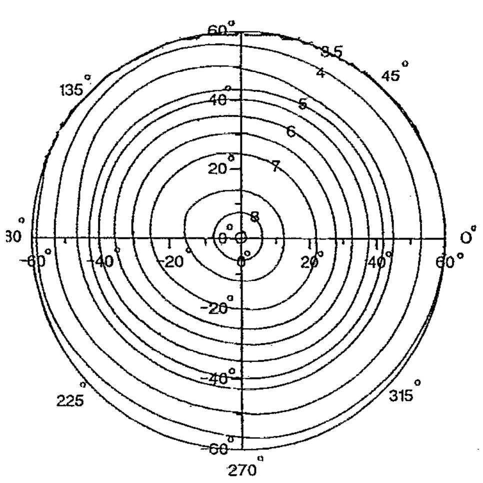

FIG. 2. Iso-contrast of the PSCT cell where the incident is isotropic and unpolarized.

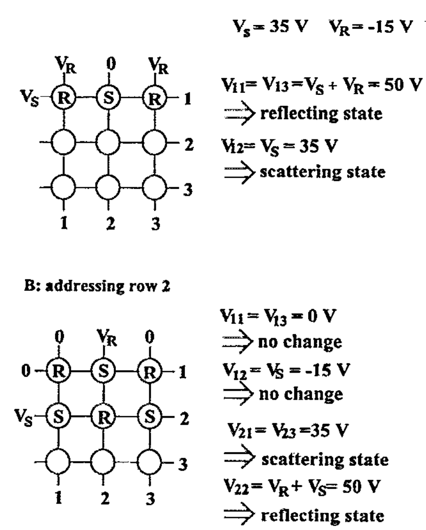

FIG. 4. Drive scheme for binary PSCT displays.

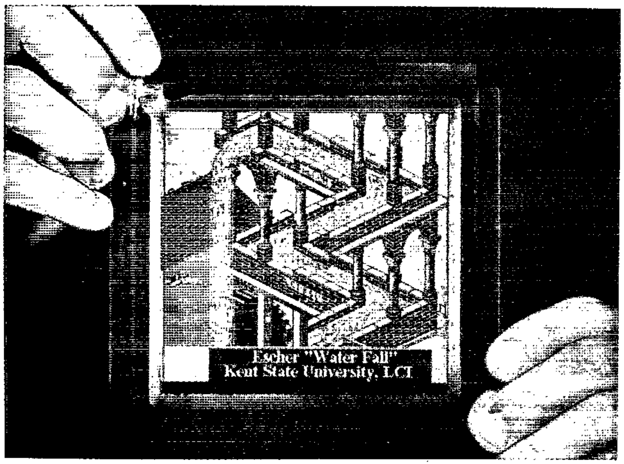

FIG. 5. Photograph of Escher Water Fall on the 320×320 pixel PSCT display.

els on the selected row is between 20 and 35 V, where the gray scale is obtained. The voltage across the pixels on the nonselected row is between 0 and 15 V and therefore the states of the pixels are unchanged.

We have demonstrated that BCT material has gray scale memory and can be used to make high definition displays on passive matrices. There is no cross-talking effect and the contrast ratio is independent of the number of rows. The BCT display does not need polarizers and can be operated in front-lit condition. The display looks brilliant under room light conditions. BCT has a higher contrast and wider viewing angle than the reflective STN. The thickness tolerance for the binary display is small and the manufacturing cost is low. The dynamic response time of the BCT material is, however, fast enough for video rate operation with the passive drive scheme. Research is under way to improve the response time and design new drive scheme.

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[1] D.-K. Yang, L.-C. Chien, and J. W. Doane, Conf. Res. IDRC. SID, San Diego, CA, 1991, p. 49.
[2] D.-K. Yang and J. W. Doane, SID Dig. Tech. Papers, 759 (1992).
[3] J. W. Doane, D.-K. Yang, and Z. Yaniv, in Proceedings of the 12th International Display Research Conference, Hiroshima, Japan, 1992, p. 73.
[4] D.-K. Yang, J. West, L.-C. Chien, and J. W. Doane (unpublished).
[5] See, for example, P. G. de Gennes, *The Physics of Liquid Crystals* (Oxford University Press, London, 1974).
[6] E. Kaneko, *Liquid Crystal TV Displays: Principles and Applications of Liquid Crystal Displays* (KTK Scientific, Tokyo, 1986), pp. 77–90.