

COLOUR DISPLAY WITH SERIALY-CONNECTED LC FILTERS

The invention relates to coloured displays in which the colours are produced by electrically controllable cholesteric colour filters connected in series.

Hitherto three main methods have been used for producing coloured liquid crystal displays.

The first and commonest method is used mainly for direct vision displays (in contrast to projection systems) and is based on a colour filter matrix in which each picture dot (each pixel) is divided into three adjacent sub-pixels provided with a red, green or blue filter respectively. A colour filter matrix of this kind, based on light absorption, has low light transmitting capacity and requires three times as many controlled pixels as a black and white display having similar resolution.

The second method is applicable only to projection displays. The light from the projection lamp is divided into separate paths of rays for the three primary colours. A liquid crystal display is disposed in each of the three paths of rays. The three images of the displays are aligned on the screen by suitable optical systems. This method has about three times the light-transmitting capacity of the first, since there is no subdivision into sub-pixels, and also the display needs no higher resolution than a corresponding black and white display. The main disadvantage of this method is the non-linear path of the rays, which makes the optical system large, heavy and, because it is complicated to adjust, therefore expensive.

In a third, as yet unpublished method, the light from the illuminating lamp is sequentially switched from red to green to blue by electrically switchable filters and the display is supplied in synchronism with the picture information correlated with the corresponding colour. This arrangement has the disadvantage as before of light transmission reduced by a factor of 3 (in this case

because of the temporal sequence of colours) and the high speed required for the sequential image build-up.

The invention combines the advantages of the aforementioned methods without sharing their disadvantages. More particularly it relates to a display with an extremely compact linear path of the rays, having high light transmitting capacity and not requiring increased speed from the liquid crystal displays. Cholesteric liquid crystal filters are used both as colour filters and as polarization filters, i.e. the entire arrangement contains no absorbing components and this greatly adds to its photostability. Cholesteric filters are characterized by great brightness and colour purity. The invention is particularly suitable for projection systems, particularly those mounted on light-room projectors, but can also be used to construct direct vision displays. Another advantage of the invention is that it can be combined with the illumination optical system having high light transmitting capacity described in EP-A-407 830.

Possible exemplified embodiments of the invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a diagram of a projection display system according to the invention;

Fig. 2 shows a detail of a switchable band-block filter (SBBF); and

Fig. 3 shows measurements of transmission through a SBBF.

Fig. 1 shows a projection display system comprising a lamp 1, the light from which is projected through a collector lens 2 in a parallel beam on to a matrix 3 of microlenses. A matrix of this kind is described e.g. by H. Hamada et al., Society for Information Display (SID) Digest 1992, page 269. The lens matrix focuses the light on to each pixel of the switchable band-block filter (SBBF) 6. The purpose of the SBBF, described in detail hereinafter, is to fade out (or reflect) one of the primary colours red, green or blue to a varying extent for each pixel according to the desired picture

information. The remaining light is projected through the microlenses 4 on to the next SBBF 7, which fades out the second primary colour to a varying extent. The remaining light is again focused by a microlens matrix 5 on to a third SBBF 8, where the third primary colour is faded out in accordance with the picture information before being finally projected through the projection lens 9 on to the screen.

The microlenses are for increasing the light efficiency. Holographic scattering patterns, Fresnel lenses or matrix arrangements of graded index lenses can be used as an alternative to microlenses of the kind cited. If the pixels, relative to the spacing between SBBFs, are sufficiently large to prevent any unacceptable parallax error occurring at the desired beam divergence, the microlenses can be omitted. If the path of the rays is conical, as e.g. in the case of light-room projectors with Fresnel lenses, the three LCDs can be given slightly different sizes for optimum adaptation to the path of the rays.

Arrangements similar to SBBFs are described in US Patent 4 726 663. The novel feature of the present invention is colour switching for each pixel, which results in a display three times as bright and yet does not impose any difficult requirements on the speed of the liquid crystal cell. This basic advantage of the invention can be explained as follows. Let the amount of incident light during a picture period be made up of nine parts, three for each colour, divided into three sub-periods. The total light available therefore is $3R+3G+3B$ (if restricted to the available polarization, all methods under discussion lose 50% of the light, since they operate with only one polarization). If bright white is to be shown, according to the invention the three SBBFs 6-8 are operated in their transmission range during the entire period, i.e. the transmitted light is $(3R+3G+3B)$, whereas in the case of sequential filters the transmission is R in the first period-third, G in the second and B in the third, i.e. a total of $(R+G+B)$, that is three times smaller than according to the invention. The case is similar when the pixel is divided into three coloured sub-pixels. Bright white means that one-third of each pixel is red, green and blue

respectively, i.e. the total signal as before is (R+G+B), that is three times smaller than according to the invention. This also applies if the sub-pixels are formed by cholesteric filters as in the reflective display described in EP-A-600 349.

Fig. 2 shows the construction of an SBBF. The drawing shows three possible switching states, i.e. completely dark (lower half of the drawing) and completely bright (upper half). Other control voltages on the liquid crystal cell 13 give intermediate colours as required. The SBBF comprises a cholesteric filter 11, $\lambda/4$ plates 12 and 14, a liquid crystal cell 13 and a cholesteric filter 15.

The construction of a cholesteric filter and possible monomeric and polymeric cholesteric liquid crystals is known e.g. from M. Schadt et al., Jpn. J. Appl. Phys. 29, No. 10 (1990), pages 1974 ff or from R. Maurer et al., SID 1990 Digest, pages 110-113. The most important property of cholesteric filters is that they reflect a circular polarization component of the incident light within a certain wavelength range (of the selective reflection band) and transmit all other light substantially without attenuation. Depending on the direction of rotation of the cholesteric liquid crystal, either the right or the left circular polarization is reflected (R or L filters respectively). Likewise, the position and width of the selective band can be chosen in known manner via the pitch and double refraction of the cholesteric liquid crystal.

Fig. 2 shows only the polarization state of the light within the selective band, there being no change in the polarization state of natural non-polarized light outside the selective band. Non-polarized light 10 within the selective band strikes the cholesteric L-filter 11. Only R-polarized light is transmitted, whereas L-polarization is reflected and can be used to increase the light efficiency according to EP-A-407 830. The transmitted R-light is converted by the $\lambda/4$ plate 12 into linear polarized light ("p" stands for polarized parallel to the vertical, "s" stands for polarized at right angles thereto). The liquid crystal cell 13 can polarise the light elliptically to a varying extent, the two limiting cases "p" and

"s" illustrated being special cases thereof. The many possible kinds of liquid crystal cells which can serve this purpose are listed hereinafter. After the liquid crystal cell 13, the light strikes another $\lambda/4$ plate 14 and a cholesteric R-filter 15.

In the upper path of the rays the liquid crystal cell 13 rotates the p-polarization through 90° to s. In the drawing this is indicated by a $\lambda/2$ plate tilted 45° to the vertical, or alternatively it could be a twisted nematic (TN) cell in polarization-conveying mode. The s-polarization after the cell 13 is converted by the $\lambda/4$ plate 14 into L-circular polarized light which is transmitted without attenuation by the cholesteric R-filter 15, i.e. the filter is in the bright state (16).

In the lower path of the rays the p-polarization is retained during transit through the liquid crystal cell 13. In the drawing this is indicated by the fact that one main axis of double refraction is parallel to the polarization. However, the same optical effect could be had from a homoeotropically oriented liquid crystal layer. After the cell 13 the light is converted by the $\lambda/4$ plate 14 into R-circular polarized light. This light cannot travel through the cholesteric R-filter 15. The lower of the two paths of rays therefore corresponds to the dark state of the filter. The intermediate states correspond to grey values or various colour co-ordinates.

Consequently, the SBBF shown in Fig. 2 has exactly the property required from filters 6, 7 and 8 in Fig. 1, i.e. it can fade out a wavelength range to a varying extent.

The non-transmitted light reflected by filter 15 must not be reflected back from any layers (e.g. electrode layers of the liquid crystal cell 13), particularly in the dark state, since otherwise the contrast will be greatly reduced. Since, however, such reflections can never be completely avoided, care must be taken that this reflected light is so polarized that it cannot pass through the filter 15, i.e. is R-circular polarized. This is the purpose served by the $\lambda/4$ plate 14, since it re-converts the reflected R-light into linear

polarized light before any reflections can occur at contacts. If these reflections still occur, e.g. at cell 13, they are still linear polarized and are again R-polarized on transit through the $\lambda/4$ plate 14. If the $\lambda/4$ plate 14 is left out, the R-light will be converted to L-light on reflection in 13 and can pass through the filter 15. The $\lambda/4$ plate 14 is therefore critical in obtaining high contrasts. It is not present e.g. in the switchable colour-filter arrangement by S. Sato and M. Wada (IEEE TRANSACTIONS ON ELECTRON DEVICES, Volume ED-21, No. 2, February 1974, NEW YORK US, pages 171-172).

In contrast to sequential actuation, no requirements are made on the polarization properties of the light transmitted by the SBBF, since its intensity is the only important factor. Consequently, a SBBF can be built up of identical cholesteric filters 11 and 15. Interchange between light and darkness occurs depending on the chosen orientation of the elements 12-14. It will be clear to a person skilled in the art that there are number of possible orientations of the liquid crystal cell 13 and the $\lambda/4$ plates 12 and 14, having substantially the same properties as the embodiment in Fig. 2.

The characteristic optical properties of cholesteric filters (sharp filter edges, purely dielectric effect without absorption) result in bright, photostable displays with excellent colour saturation. This is in contrast to displays based on dichroic dyes (see EP-A-509 727), which have weaker colour saturation and, owing to their absorption, are also less photostable.

A number of liquid-crystal cells are suitable as electro-optical cells 13. They must meet the condition that they can convert a given linear polarization (p in Fig. 2) into elliptic polarization to a varying extent (depending on the applied voltage) two limiting values being included for optical contrast, i.e. 1) no change in polarization and 2) rotation of polarization through 90° . In addition it must be possible to modulate all desired picture elements (in the extreme case a two-dimensional matrix containing several million pixels) by suitable methods at the

desired picture rate. Modulation can be brought about by direct actuation or by multiplexing (including active addressed multiplexing) or by means of an active matrix. The following are examples of these LCDs: TN-LCDs, STN-LCDs, ECB-LCDs, DAP-LCDs, OMI-LCDs, polymer-dispersed LCDs or cells or DHF-LCDs or other ferroelectric LCDs capable of generating grey values (e.g. charge-controlled SSF-LCDs, SBF-LCDs or anti-ferroelectric LCDs).

Fig. 3 shows the transmission spectrum of a SBBF according to Fig. 2 for non-polarized light. The cholesteric filters 12 and 14 each comprise two ground glass plates coated with polyimide at a spacing of 8 m with a cholesteric liquid crystal mixture in between, with suitable double refraction and pitch of the cholesteric helix. The construction of such cells is known e.g. from M. Schadt et al., Jpn. J. Appl. Phys. 29, No. 10 (1990), pages 1974 ff. The liquid crystal cell 13 is a conventional TN cell. The $\lambda/4$ plates are commercial retarder films with a pitch difference of 140 nm. All the components are stuck with optical adhesive. Fig. 3 shows the transmission spectrum in the bright state (0 V on the cell) and in the dark state (10 Vpp, 1 kHz square wave at the cell). The good contrast and the sharp filter characteristic are clearly visible.

The main applications of the invention are on the one hand to very compact, highly informative liquid crystal projection displays, e.g. for high-definition TV projectors (version with microlenses) or displays with larger pixels or other picture elements without microlenses, where the brightness and colour quality of the present invention result in important improvements. In neither case are requirements made on the liquid crystal cells other than those already made on commercial displays today. This is in contrast to sequentially actuated displays, where the speed of modern displays is still inadequate. Direct vision displays based on the invention are also possible (omitting the projection lens 9 in Fig. 1), but the angle-of-vision range will be somewhat restricted by the characteristic dependence of selective reflection on the angle.





Claims

1. An electrically controllable coloured bright display device with compact linear light guidance, comprising three switchable colour filters optically connected in series, each comprising two cholesteric filters, two $\lambda/4$ plates and one electrically switchable liquid crystal display with segmented electrodes, each filter being adapted to attenuate one of three different colours by electrical control.
2. A display according to claim 1, wherein a matrix of microlenses, holographic lenses, Fresnel lenses or graded index lenses is disposed in front of each filter.
3. A display according to claim 1 or 2, wherein the liquid crystal cells used in the filters are of one of the following kinds: TN-LCD, STN-LCD, ECB-LCD, DAP-LCD, OMI-LCD, polymer-dispersed LCD or cells or DHF cells or other ferroelectric cells capable of generating grey values (e.g. charge-controlled SSF-LCDs, SBF-LCDs or anti-ferroelectric LCDs).
4. A display according to any one of claims 1 to 3, which is a projection display.
5. A display according to any one of claims 1 to 3, which is a projection attachment for a light-room projector.
6. A display according to any one of claims 1 to 3, which is a direct vision display.
