



F. HOFFMANN-LA ROCHE AG, BASLE, SWITZERLAND

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Light control systems with liquid crystals

The invention relates to light control systems consisting of a combination of liquid crystal cells and polarisers.

In conventional arrangements with liquid crystal cells, they are usually operated with one or more linear polarisers. Where circular-polarised light was available and had to be controlled, it was converted to linear-polarised light, e.g. with a $\lambda/4$ plate and, if required, was re-converted to circular-polarised light after the liquid crystal cell again with a $\lambda/4$ plate. The rotary or TN (=Twisted Nematic) cell, in particular, requires linear-polarised light for its mode of operation in which the direction of polarisation of the incident light is rotated with the helix structure in the switched-off state (wave-guiding mode).

It has now been found that there is one type of operation possible and in many respect advantageous, i.e. direct operation of liquid crystal cells with circular-polarised light, the circular-polarised light being produced either with conventional circular polarisers or with monomeric or polymeric cholesteric liquid crystals.

The invention is accordingly characterised in that light control systems of the type referred to the in



- 2 -

preamble are provided with means for supplying circular-polarised light to liquid crystals.

The invention is explained hereinafter with reference to exemplified embodiments illustrated in the drawings wherein:

Figure 1 shows an arrangement with a TN-cell in the conventional mode of operation.

Figure 2 shows an arrangement with a TN-cell in operation with circular-polarised light in transmission.

Figure 3 is a similar arrangement to Figure 2 but in reflection.

Figure 4 shows an arrangement with a parallel-oriented cell in reflection with circular-polarised light.

Figure 5 shows an arrangement with a vertically oriented DAP cell in operation with circular-polarised light.

The arrangement shown in Figure 1 comprises a light source 1, whose light is converted into dextrorotatory circular light in a circular polariser 3. The latter is followed by a $\lambda/4$ plate 4, which converts the circular-polarised light into linear-polarised. The direction of polarisation is indicated by a double arrow. The $\lambda/4$ plate 4 is followed by a TN cell 5 which, in the switched-off state, rotates the direction of polarisation of the light through 90° in known manner. This rotated light can pass without attenuation a linear polariser 6 following the TN cell 5 and turned through an angle of 90° with respect to



- 3 -

the direction of polarisation before the cell. If voltage is applied to the cell 5, the rotatory effect is eliminated and the light, which is now not rotated, cannot pass the polariser 6. The TN cell 5 thus operates in the conventional mode, in which the direction of polarisation of the incident light is rotated in the switched-off state (wave-guiding mode).

In order further to increase the polarisation quality after the $\lambda/4$ plate in this arrangement, a low-polarisation linear polariser can be incorporated between the $\lambda/4$ plate and the TN cell to improve the linear polarisation without appreciably affecting the brightness of the system.

Figure 2 shows another mode of operation. The dextrorotatory circular-polarised light produced as described above is fed directly to a TN cell 7. For this mode of operation, the cell must have a minimal optical pitch difference of $\delta = \Delta n \cdot d = \lambda/2$ between the switched-off and switched-on states. If this condition is satisfied, the direction of rotation of the circular-polarised light changes as it passes, i.e. in this case from dextrorotatory (+) to laevorotatory (-). The TN cell 7 is followed by another circular polariser 8 which is in this case transparent to the opposite direction of rotation to the first circular polariser 3, i.e. laevorotatory. When the TN-cell 7 is switched on and thus becomes optically uni-axial, it does not affect the state of polarisation of the light, so that it is blocked by the circular polariser 8.

Any known form of circular polarisers may be used for the circular polariser 8, e.g. including wavelength-selectively reflecting low-pitch cholesteric coatings. The light reflected by them is, of course, circular-



polarised. In colour projection systems this light is controlled by downstream liquid crystal cells. It is advantageous in such circumstances if it is possible to dispense with prior conversion to linear-polarised light.

As already stated, operating TN cells with circular-polarised light gives a distinct shift of the control voltages required towards lower values. It is also possible to produce steeper voltage-transmission characteristics of the kind required, for example, for multiplex operation.

The arrangements shown in Figures 1 and 2 yield a positive contrast if the principle is used to construct display cells. Negative contrast is possible in each case without difficulty and in fact it is possible in Figure 1 in known manner by rotating the linear polarisers at the outlet side through 90° . In Figure 2 this is achieved by using a dextrorotatory circular polariser instead of a laevorotatory.

The arrangements shown in Figure 3 is also based on the fact that, as in Figure 2, circular-polarised light is fed directly to a TN-cell 9. Unlike the TN-cell 7 in Figure 2, however, the TN-cell 9 has a minimal optical pitch difference of $\delta = \lambda/4$ between the switched-off and switched-on states. Thus in the switched-off state it acts as a $\lambda/4$ plate which converts circular-polarised light to linear-polarised. Cell 9 is followed by a reflector 10 which reflects the linear-polarised light back to the cell 9. For symmetry reasons cell 9 converts the linear-polarised light back into circular-polarised light which can pass the circular polariser 3. In the switched-on state the dextrocircular-polarised incoming light passes the TN-



- 5 -

cell. This changes the direction of rotation on reflection at the mirror 10 so that the now laevocircular-polarised reflected beam can no longer pass the circular polariser 3. The reflector 10 can also be directly integrated on the inside of the rearward sub-strate of the TN cell.

Instead of a TN-cell, it is possible to use for this arrangement any other liquid crystal cell giving the required optical pitch difference between the switched-off and switched-on states. Other liquid crystal cells with a helical molecular arrangement, for example the supertwist, SBE and STN cells particularly may be used. Liquid crystal cells with an untwisted structure can also be used in this more novel mode.

Thus Figure 4 shows an arrangement operating in reflection comprising a planar-oriented nematic cell 11 with positive dielectric anisotropy of the liquid crystal i.e. $\Delta\epsilon > 0$. This arrangement corresponds to the above described alternative with a TN-cell whose optical pitch difference between the switched-off and switched-on states is $\delta = \lambda/4$. Thus in the switched-off state the cell acts as a $\lambda/4$ plate, i.e. the circular-polarised light is converted to linear-polarised light. After reflection at a mirror 10 the reverse operation takes place, i.e. the linear-polarised light is again converted to circular-polarised in the $\lambda/4$ cell, passes the circular-polariser 3 without obstruction and is available at the output with the full intensity. If voltage is applied to the cell 11 so that it becomes optically uni-axial it does not affect the state of polarisation of the light. Thus behind the cell dextrocircular-polarised light passes to the reflector 12 which, as already stated, changes its direction of rotation on



reflection. This light which is laevocircular after reflection passes, without being affected by the planar cell 11, to the circular polariser 3 and is blocked by the latter.

An advantage of this reflective configuration too is that the reflector 10 may be disposed directly on the substrate or backwall of the liquid crystal cell so that light-absorbing structures, for example thin-film transistors, etc., are situated behind the reflector and thus do not reduce the aperture or brightness of the active surface of the image element. Another important advantage is that the path of the light after the liquid crystal to the reflector and back is shorter, because there is no intermediate glass substrate, so that with an inclined incident light, i.e. a large viewing angle, the parallax error is smaller than in conventional arrangements.

In the arrangement shown in Figure 5, the circular-polarised light impinges on a DAP-cell 13 which is distinguished in that it is uni-axial in the switched-off state and thus allows light to pass unaffected. The polarisation is thus the same before and after the cell. After the cell 13 there is disposed a second circular-polariser 14 which, depending on its direction of rotation, either transmits or blocks the transmitted light. In the switched-on state, the cell 13 so changes the state of polarisation of the light that the circular-polariser 14 now blocks the previously transmitted light or transmits the previously blocked light.



CLAIMS

RAN 4701/134

1. A light control system consisting of a liquid crystal cell and polariser combination, characterised by means (3) for supplying circular-polarised light to the liquid crystal cell (5).
2. A light control system according to claim 1, characterised in that the means for supplying circular-polarised light comprise a circular-polariser (3).
3. A light control system according to claim 1, characterised in that the means for supplying circular-polarised light comprise a wavelength-selectively reflecting cholesteric liquid crystal layer.
4. A light control system according to claim 3, characterised in that the liquid crystal layer consists of monomeric and polymeric cholesteric liquid crystals.
5. A light control system according to any one of the preceding claims, characterised in that the liquid crystal cell is a TN rotatory cell (7) and the condition $\delta_{min} = \Delta n \cdot d = \lambda/2$ applies for the optical pitch difference between the switched-off and the switched-on states.
6. A light control system according to any one of the preceding claims, characterised in that the liquid crystal cell is a TN rotatory cell (9) and the condition $\delta_{min} = \Delta n \cdot d = \lambda/4$ applies for the optical pitch difference between the switched-off and the switched-on states.



- 8 -

7. A light control system according to any one of the preceding claims, characterised in that the liquid crystal cell comprises a supertwist liquid crystal.

8. A light control system according to any one of the preceding claims, characterised in that the liquid crystal cell (11) comprises a planar liquid crystal with a parallel molecular orientation.

9. A light control system according to any one of the preceding claims, characterised in that the liquid crystal cell is a DAP-cell (13) with an isotropic molecular orientation.

10. A light control system according to any one of the preceding claims, characterised in that a reflector (10) is disposed on the liquid crystal cell substrate.

11. A light control system according to any one of the preceding claims, characterised by a low-polarisation linear polariser in the path of the rays of the light which is possibly incompletely linear-polarised after conversion from circular-polarised light.