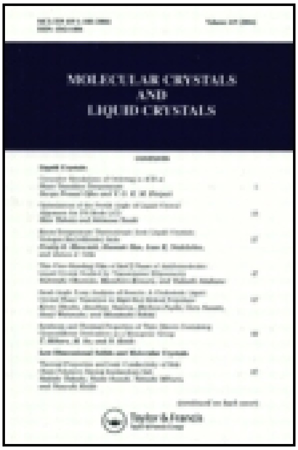

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Three-Dimensional Viewing and Imaging System Using Cholesteric Liquid Crystals

D. Makow [a]

[a] National Research Council of Canada, Division of Physics, Ottawa, K1A OR6, Canada

Version of record first published: 17 Oct 2011.

To cite this article: D. Makow (1983): Three-Dimensional Viewing and Imaging System Using Cholesteric Liquid Crystals, Molecular Crystals and Liquid Crystals, 99:1, 117-122

To link to this article: http://dx.doi.org/10.1080/00268948308072033

Mol. Cryst. Liq. Cryst., 1983, Vol. 99, pp. 117–122
0026-8941/83/9904–0117/$18.50/0

Printed in the United States of America

Three-Dimensional Viewing and Imaging System Using Cholesteric Liquid Crystals†

D. MAKOW

National Research Council of Canada, Division of Physics, Ottawa, Canada K1A OR6

(Received March 3, 1983)

A system is described that permits 3-D viewing of an object from two images derived from a stereopair. The images are transferred onto layers of cholesteric liquid crystals (CLC's) deposited on the opposite sides of a transparent halfwave retardation plate. This is done by irradiating these layers with UV which shifts the reflectance spectra of the exposed CLC elements outside the visible range. The CLC elements that were not irradiated split the incident light into two circularly polarized components. A CLC with a left handed (right handed) molecular helical structure will reflect a left handed (right handed) circularly polarized component and transmit almost without absorbtion a right handed (left handed) component. The halfwave retardation plate converts the left handed (right handed) circularly polarized component image into a right handed (left handed) one. When the images are viewed through spectacles, having one eye piece passing the left handed circularly polarized component and the other one the right handed, the object appears in three dimensions. The principle outlined above has been confirmed experimentally.

I. INTRODUCTION

The visual experience of 3-D and depth perception is based on the fact that the retinal images of an object in space are slightly different in the two eyes. This is because due to separation of the eyes by about 65 mm, the object is seen by each eye from a different angle. The brain fuses the two different perspectives to give the impression of depth. In order to reproduce this experience when viewing a two-dimensional photograph two images of

†Presented at the Ninth International Liquid Crystal Conference, Bangalore, India, December 6–10 1982.

the object taken from suitable different angles must be present in the photograph superimposed or side by side and should be viewed by each eye separately.

The principle of 3-D perception was first recognized by Euclid in A.D. 280.[1] Practical devices that permit separation and viewing of the two images date from 1838 with the introduction of the Wheatstone stereoscope[1] and were followed by several different methods thereafter. These methods utilize mirrors or prisms that convey each image to the corresponding eye,[1,2] slit plates[3,4] paralax barriers,[5] fly's eye lens sheets[6] or lenticular elements[7-9] which permit each eye to see only the appropriate image. A review of the above methods and holography is given in a recent book on the subject.[10]

Still other methods utilize alternate switching of the two images[11] anaglyph prints in which the two images are printed in complimentary colors,[12] and vectograph prints in which the two images are printed on opposite surfaces of a plastic sheet having linearly polarizing coatings with the polarization planes at right angle to each other.[13] In these three methods viewing spectacles are used. In the first the eyepieces have shutters synchronized with the frequency of the alternating images; in the second they have color filters permitting each eye to see one image only, and in the third each eyepiece is equipped with a linear polarizer that passes light of the corresponding polarization. Most of these methods have their limitations. For example people viewing anaglyph prints report excessive fatigue, and the vectograph system requires an elaborate process to prepare the substrates and transfer the images.

The method described in this paper takes advantage of the fact that layers of cholesteric liquid crystals (CLC) are natural reflectors of the left (right) handed component of circularly polarized light[14] and transmit without absorption the right (left) handed component. In addition an image can be transferred onto such layer by relatively simple processes. Spectacles have to be used having eyepieces equipped with filters that pass the component having the required handedness of circularly polarized light.

II. GENERAL DESCRIPTION

The light reflected from layers of cholesteric liquid crystals is circularly polarized and the handedness of polarization is the same as the handedness of the CLC helicoidal molecular spiral.[14] The light transmitted is also circularly polarized but of opposite handedness. Using filters that discriminate the handedness of polarization it is possible to see a left or a right-handed CLC layer depending on the filter used, even when the two layers are superimposed. Such filters consist of a quarter-wave retarder and linear polarizer. Depending on the orientation of the linear polarizer with respect to the quarter-wave retarder they transmit the left or the right handed component respectively.

The use of a separate left and right handed CLC material for this purpose is not practical because such materials are usually different organic compounds having different thermotropic temperature ranges and width of spectral reflection bands. A more practical way is to use layers of either the left or right handed material, the same on the top and bottom side of a half wave retardation plate.[15] Such a plate converts the left handed (right handed) reflection of the bottom layer into a right handed (left handed) one. Thus as viewed from the top the left and right handed reflections are seen separately when viewed by the above-described filter equipped eyepieces. The retardation plate with the two CLC layers should be placed on a black substrate or be coated on one side with black paint in order to absorb all wavelengths outside the reflection band.

It is possible to imprint images on the CLC layers on the opposite side of the retardation plate. This can be done by irradiating a UV sensitive CLC layer through a positive mask of the image using ultraviolet light. The spectral reflection bands of the irradiated elements will then shift outside the visible range leaving only the un-irradiated image elements to be seen. Thermal methods of transferring the image onto CLC layers were also investigated.

In order to see an object in three dimensions, the upper layer is imprinted with one and the lower layer with the other image of the stereopair of the object. Generally the two images will partly overlap as shown in Figure 1. Since the lower image will shine through the upper image, the irradiated elements of the upper image should be fully transparent. This will be the case if after irradiation they will still retain the CLC properties. The spectral reflection bands of the irradiated elements should be therefore shifted to the near infrared, or to a different visible wavelength band, depending on whether a nearly black color or a different color is desirable. The degree of irradiation may thus provide a method of introducing color. Also advantage may be taken of the additive color properties of CLC's[16] by using additional CLC layers to produce colored images.

When the spectral bands of the two CLC layers on either side of the retardation plate are the same, each eye will see through its eyepiece light having a peak reflectance of about 0.5 and the respective circular polarization. The unaided eyes will see nearly 1.0 peak reflectance as the two polarization components will add as shown in Figure 2b. When the wavelength bands of the CLC layers are not the same (Figure 2a) the perceived color will be the additive mixture of the two colors produced by the two

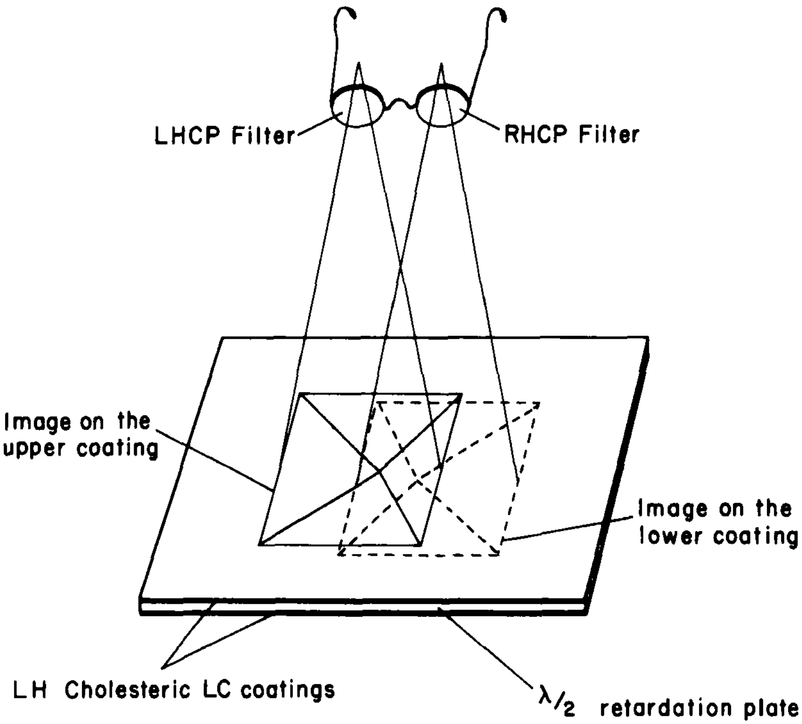

FIGURE 1 Schematic representation of the principle of operation. Light reflected from the images of the stereopair imprinted on the upper and lower coating has a left and a right-handed circular polarization (LHCP and RHCP) respectively. The filters in the viewing eyepieces of the spectacles discriminate the polarization and pass the upper image to the right eye and the lower image to the left eye thus permitting seeing the image in 3-dimensions.

spectral bands and its saturation will depend on the spectral separation of the latter. Thus, by making the two CLC layers of a different color, still another means is provided to introduce color into this method of three dimensional viewing.

III. EXPERIMENTAL RESULTS

A commercially available plastic half-wave retardation plate was coated on both sides with a 100 μm layer of encapsulated CLC's. One image of a stereopair of a pyramid such as shown in Figure 1 was imprinted on the upper and the other image on the lower side of the plate using UV irradiation through a mask. The lower side was then painted black. In another

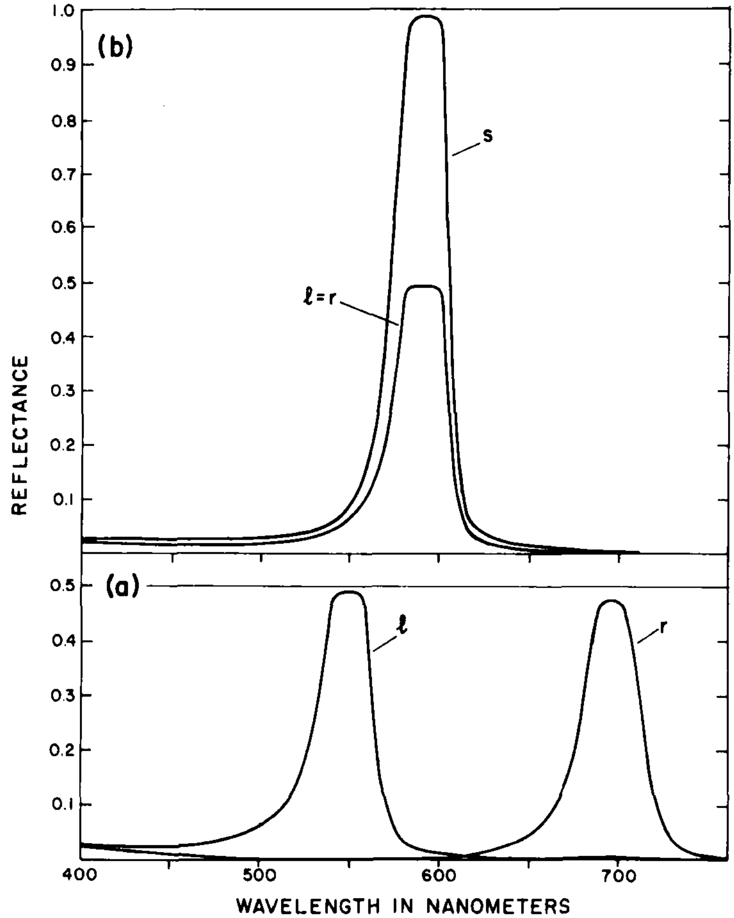

FIGURE 2 Reflectance curves l and r as a function of wavelength, of the left and right-handed cholesteric liquid crystal coating respectively:
(a) The two coatings reflect at different wavelength. The left eye sees a red image and the right eye a green image;
(b) The two coatings reflect at the same wavelength. Both eyes see images of the same color each having a reflectance of about 0.5 (curve $l = r$). Without viewing glasses the reflectance is the sum of the two (curves).

experiment a polymeric liquid crystal was used and the images were imprinted using heated exposed parts of a metal stamp.

Spectacles with filter-equipped eyepieces that passed the left or the right-handed component respectively of circularly polarized light were constructed from inexpensive commercially available plastic quarter-wave retarders and linear polarizers. When viewing the pyramids through these spectacles with one eye closed, one could see the corresponding image, with the other image being almost invisible. When viewing the pyramids from a suitable distance with both eyes open the images fused into a 3-dimensional form of the pyramid. One could still see faintly the outline of the two original images of the pyramids on each side of the 3-dimensional form. The ratio of the peak spectral reflectance from the wanted and the unwanted images was measured through each eyepiece and was found to be about 45 : 1. This represents the degree of rejection of the unwanted polarization component. One could improve this ratio by employing spectrally matched filters and retardation plates of higher quality than those used in this experiment.

IV. CONCLUSION

The method described represents a new approach to 3-D viewing. For the reasons discussed above, cholesteric liquid crystals are particularly well suited for this purpose. Some of the many potential applications are in the areas of terrain mapping, stereomicrography, 3-D large screen projection and graphics.

Acknowledgment

Thanks are expressed to Mr. R. Fink for competent support in the laboratory, and Dr. A. R. Robertson for reading and commenting on the manuscript.

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