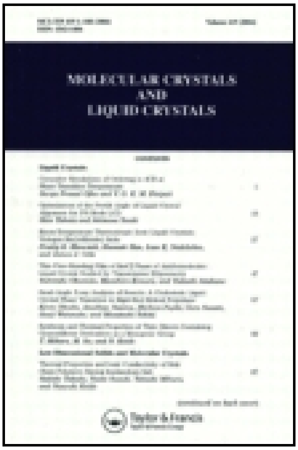

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Polarisation sensitive liquid crystalline filter

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POLARISATION SENSITIVE LIQUID CRYSTALLINE FILTER

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The liquid crystalline (lc) filter which creates the distributed form of a light transmission has been described in detail. Distribution of the transmission in considered filter may be altered by means of an incident light polarization.

The applied alignment of the liquid crystal layer is arranged in such a way, that on the one side, inside the filter, the lc layer is aligned as planar, while on the opposite side of the filter it is aligned in form of circles. The filter basis is so called adiabatic following in a twisted nematic lc layer (Mauguin regime). As Mauguin regime is fulfilled then the specific lc layer alignment causes polarization sensitive transmission. Such filter seems to provide new possibilities in a polarisation difference image analysis so may be convenient tool for a polarimetric image processing.

Keywords: filter; liquid crystal; polarization imaging

INTRODUCTION

Once viewed as contamination in remote sensing measurement, polarisation effects are now perceived as potential new source of information. Polarisation analysis of objects in a scene allows features to be distinguished according to their light – reflection properties or, sometimes, light transmission properties. It provides additional data about analysed scene. The randomly scattered ambient light is likely to be unpolarized, whereas ambient light reflected from a smooth surface is likely to have a

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preferential polarisation direction [1]. The unpolarized light component my be removed from the resulting image by taking difference between scene illuminated by means of two perpendicularly polarised beams. That way is known as polarisation-difference imaging (PDI) [2]. The liquid crystal micropolarizer array made by photolitography technology has been reported lately for that aim [3]. The efficiency of that micropolarizer array was very low and no diffraction phenomena had been taken into account.

In this article we propose another kind of the liquid crystal (lc) device for polarisation affected object imaging. Reported device allows to extract the smoothly altered polarised component of the image. So it also provide data for the PDI procedure. Properties of this filter have been analysed in here. It means especially such properties, which could modify a polarisation selectivity of the filter. Some of considered filter construction has been described earlier as a tool for wavelet transform of an image [4]. Here the most important features of the examined device have been characterised in detail. Especially the dependence of the filter parameters on the lc substance properties has been characterised.

FILTER ARRANGEMENT AND TOPIC INSPIRATION

The lc layer alignment in the analysed filter is like in Figure 1. The lc filter with such an alignment of the lc layer has been described already by Sato and others [5]. Unfortunately the transmission has not been described theoretically in there. There was no any lc medium effects analysed also. Further propositions for potential application of the considered filter continued this task open [6]. Nevertheless for the reasons explained above it seems to be important how the lc layer influences the filter properties.

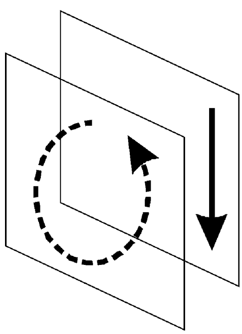

FIGURE 1 Schematic view of the lc alignment on both sides of lc layer inside investigated filter.

FIGURE 2 The light reflection on the filter when part of the filter (corners) are not covered with the polarising sheet.

Considered filter basis is so called adiabatic following in twisted nematic lc layer. It appears that the electric field of the electromagnetic wave transmitted across the lc layer remains parallel to the local director as the wave propagates in twisted nematic lc medium. It just follows the twist of the director field as optical path is long enough [7]. In such situation the resulted transmission in crossed polarizer is like in Figure 2. The polarising sheet covers only part of filter body to underline role of lc specific alignment. Upper right and bottom left corners have not been covered by polarising sheet. Polarised direction is along sheet edge while planar alignment is parallel to arrow visible in the picture.

If the considered filter co-operates with the tuned half-wave liquid crystalline phase shifter, like in Figure 3, then the area of transmission will rotate on the filter plane in accordance with the entrance light polarisation (see [4]).

The prisms located between phase shifter (1 in Fig. 3) and filter (2 in Fig. 3) causes polarisation disturbance (see [4]). One can observe that different edges are exposed in dependence on transmitted polarisation

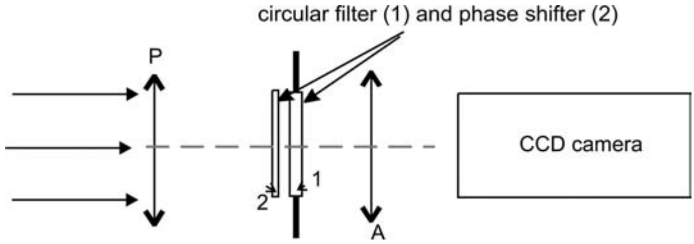

FIGURE 3 The scheme of the experimental measurement of the light transmission across the filter.

(see Fig. 4). The question arises if and how the transmitted polarisation may be selected more sharply and what are possible constraints for that. The answer is the main purpose of that article. This answer is important because of edges elevation by means of analysed filter. It is illustrated in Figure 4. For this feature filter seems to provide new tool for the edge extraction.

THEORETICAL ANALYSIS OF THE TRANSMISSION

When Jones vectors, say J, are used for the wave polarization description, then the transmission in twisted lc medium should be treated as (see [7]):

$$T = |J'MJ|^2 \tag{1}$$

The matrix M depends on the lc medium and the ϕ angle denotes rotation of an electric vector of the electromagnetic wave inside the lc layer. When adiabatic following regime is fulfilled then the *f* angle is equivalent to twist

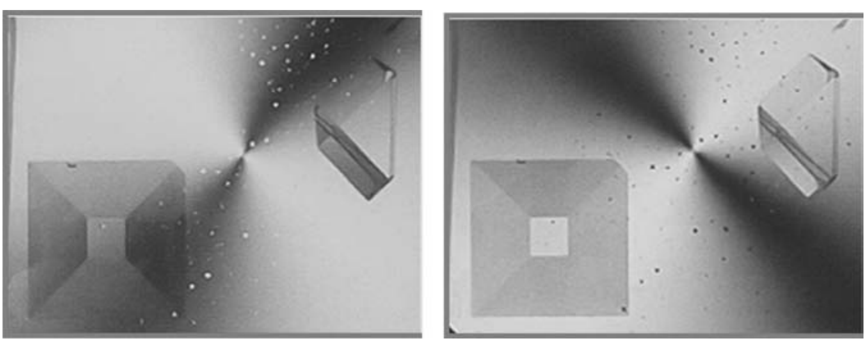

FIGURE 4 The sample of transmission across the prisms deposited between phase shifter and polarizer [4].

angle of the lc layer:

$$M - \begin{pmatrix} \cos f & -\sin f \\ \sin f & \cos f \end{pmatrix} \begin{pmatrix} \cos V - i\frac{\delta}{2}\frac{\sin V}{V} & \phi\frac{\sin V}{V} \\ -\phi\frac{\sin V}{V} & \cos V + i\frac{\delta}{2}\frac{\sin V}{V} \end{pmatrix} \qquad (2)$$

Item *shift* denotes the phase variation in a transmitted wave:

$$\mathit{shift} = \frac{2\pi}{\lambda}\Delta n d \qquad (3),$$

and:

$$V = \sqrt{f^2 + \left(\frac{\mathit{shift}}{2}\right)^2} \qquad (4)$$

The Δn is birefringence of the lc medium, and d is the lc layer thickness. The Jones vectors can be described in terms of polarizer and analyser arrangement:

$$J = \begin{pmatrix} \cos\phi_{ent} \\ \sin\phi_{ent} \end{pmatrix}; \qquad J' = \begin{pmatrix} \cos\phi_{exit} \\ \sin\phi_{exit} \end{pmatrix} \qquad (5)$$

The exact meaning of the angles has been explained in Figure 5.

We manage to notice that twist angle distribution over the filter body may be characterised by means of the simple function:

$$f(x,y) = \frac{\pi}{2}Cos\left(ArcTan\left(\frac{y}{x}\right)\right) \qquad (6)$$

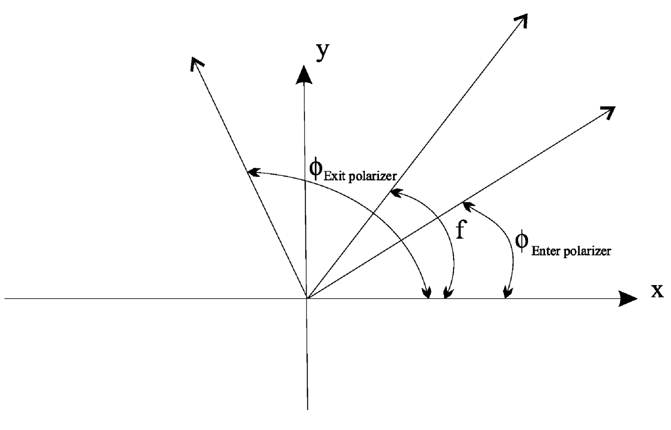

FIGURE 5 The angles in formulae (1–5) with x, y co-ordinate centred in the filter body.

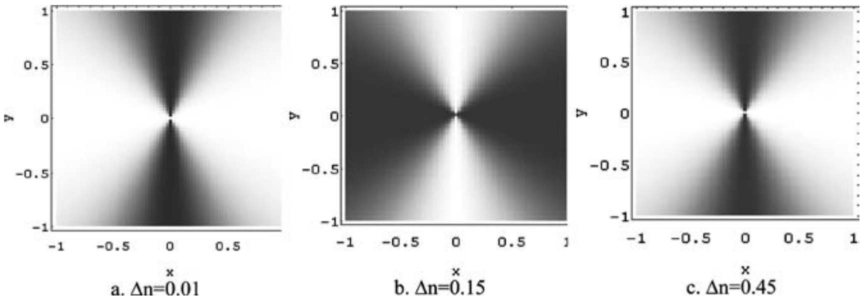

FIGURE 6 The intensity transmission versus lc birefringence (placed as a, b, c) at $\lambda = 700\,\text{nm}$. Items x, y are distances along filter side.

The co-ordinates centred in the middle of the filter has been denoted as x, y.

In Figure 6 the dependence of the transmission on the lc birefringence has been illustrated. It has been calculated in accordance with formulae (1–6). One can see that polarization may be selected well or worse in dependency on a given lc substance birefringence, and lc layer thickness. The best result seems to be obtained for a high birefringence.

The dependence of the transmission on reference orientation of polarizer and analyser has been shown in Figure 7. It can be seen that reference position of entrance and exit polarizer results in expected improvement of light polarization selection.

The transmission in the analysed device is sensitive on the light colour. The reason of such situation is explained in Figure 6. The intensity level as

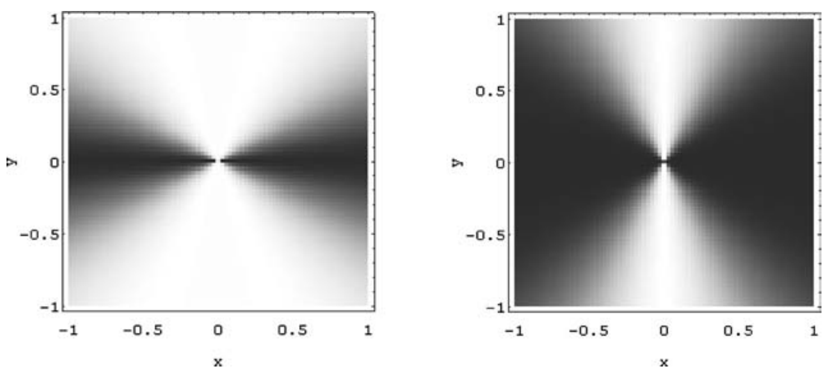

FIGURE 7 The transmission when polarizer and analyser are crossed (on the right) and parallel (on the left).

well as transmitted intensity distribution may be different for distinct component of visual spectrum range in dependence on reference position between polarizer and analyser.

CONCLUSIONS

Very useful perceive about twist angle distribution over the filter body allow us to simulate its optical properties. Intensity transmission in liquid crystalline polarising filter with mixed, circular-planar lc alignment, has been analysed in detail theoretically and illustrated experimentally. The theoretical and experimental transmissions are tightly the same (e.g., see Figs. 1, 4 and 6).

The analysed filter occurs polarisation sensitive. The dynamics of the transmitted signal and its distribution over filter body depends on the transmitted spectrum range (Fig. 6). The reference orientation of the entrance and exit polarizer decides about the final shape of transmission also.

The liquid crystal birefringence influences the transmission as well (Fig. 6). The higher birefringence causes an improvement in selection of the polarisation. So as a component of optical system that filter may be optimised, and main criteria of optimisation are collected in here. In the Figure 4 one can see that two perpendicular polarization may be selected from an image by means of analysed filter. So it seems to be very promising and rather new tool for polarimetric imaging. One can see in the Figure 4 that edges in the picture can be extracted to some extent. This is important for pattern recognition. This is a reason to investigate such kind of the lc filter.

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