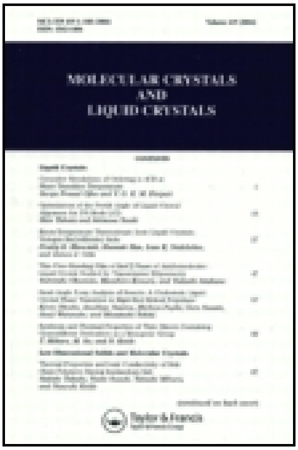

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Polarization Difference Imaging System with LC Filter

M. Sutkowski [a], P. Garbat [a], J. Parka [b], A. Walczak [c], E. Nowinowski-Kruszelnicki [b] & J. Woznicki [a]

[a] Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Warsaw, Poland

[b] Institute of Applied Physics, Military University of Technology, Warsaw, Poland

[c] Institute of Computer Science, Military University of Technology, Warsaw, Poland

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Polarization Difference Imaging System with LC Filter

M. Sutkowski[1], P. Garbat[1], J. Parka[2], A. Walczak[3], E. Nowinowski-Kruszelnicki[2], and J. Woznicki[1]
[1]Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, Warsaw, Poland
[2]Institute of Applied Physics, Military University of Technology, Warsaw, Poland
[3]Institute of Computer Science, Military University of Technology, Warsaw, Poland

Methods of polarization analysis in imaging systems are quite new approach. It allows to remove the polarized light component from recorded images, and is known as Polarization Difference Imaging (PDI). The use of liquid crystals (LC) in PDI was proposed in 2002. Modified LC unit with properly oriented LC layer was proposed by the authors.

In this work specific LC filter and set-up for image analysis are presented. The examination of the azimuthal detectivity of PDI system is performed. The method of digital analysis of acquired images and detectivity determination is presented. Obtained results are shown and discussed.

Keywords: liquid crystals application; optical image processing; polarization difference imaging

1. INTRODUCTION

Imaging systems based on intensity information have some kind of disadvantages when objects are to be detected and background has quite identical luminance. The reflection properties of the object and background are supposed to differ thus employing the method of light analysis (i.e., determining reflection and scattering properties versus

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Address correspondence to M. Sutkowski, Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, 15/19 Nowowiejska Str., Warsaw 00-865, Poland. E-mail: sut@imio.pw.edu.pl

change of registered scene polarization) can allow the improvement of the detectivity of the imaging system. When randomly scattered light is unpolarized, the reflection surfaces produce waves with preferential polarization direction [1]. When two images taken by means of perpendicular polarizers are successively used, then polarized light component is removed.

An optical element designed for polarization imaging based on liquid crystal technology was presented firstly in [2]. LC filter with circular-planar LC alignment and transmission characteristic represented as an orthogonal set of functions can be understood as another kind of optical component for PDI [3,4]. The set of functions mentioned above set of functions may be obtained in reference to the incident light polarization as well as in reference to the wavelength of the transmitted light. In the paper some theoretical basis of the circular LC filter is described. Experimental examination of the filter' sensitivity dependent on field of view of PDI system and diaphragm of imaging optics is performed and presented.

2. CIRCULAR LC FILTER

In the Figure 1 the common LC cell structure has been presented. However, in case of the LC filter used for PDI the ITO layer is not necessary, the presence of this layer can be useful when additionally standard intensity image is necessary to be acquired (the applied voltage over the threshold level can remove the specific polarization properties of the filter).

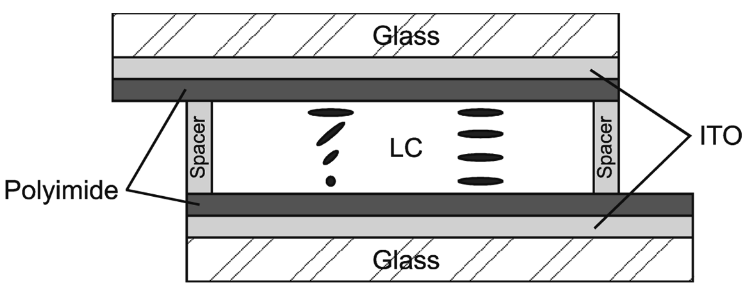

FIGURE 1 The basic LC cell structure. Note that at the image above liquid crystal molecules are presented symbolically to imagine, for example, two different orientation stages (twisted on the left and perpendicular on the right) depending on the orientation layer configuration. These two orientation cases are present on perpendicular axes (x and y) when we assume the planar-circular configuration.

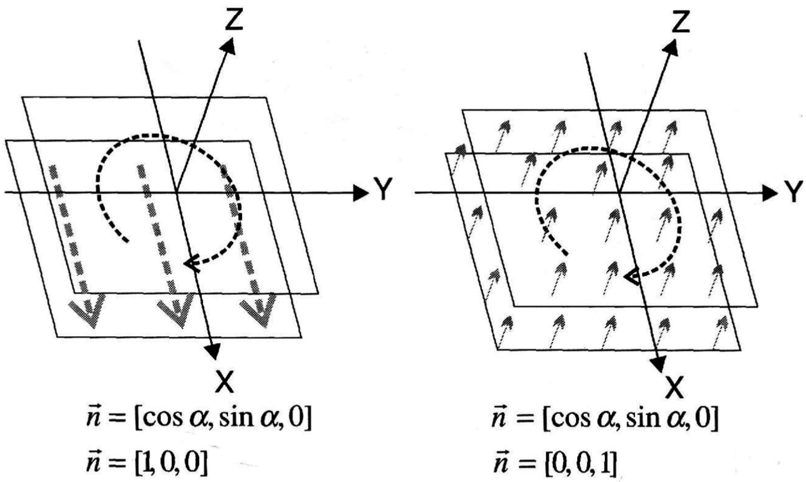

FIGURE 2 Schematic view of the two general LC alignment on both sides of LC layer inside filter. The arrows exhibit the director field orientation on both sides of the LC layer that is described for both surfaces below the pictures.

Two general possible configurations of the orientation layers (polyimide layers) can be selected thus two general types of LC filter for PDI can be produced—as shown in Figure 2. In this work, we have focused on the first type—planar-circular.

3. TRANSMISSION OF THE CIRCULAR LC FILTER

Transmission of the twisted LC medium can be described as (with Jones matrix standard):

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

In the formula (1) matrix M denotes LC layer properties:

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

The twist angle in the LC layer is represented as angle $\phi(x, y)$, which is dependent on the position on the filter plane. The sign δ denotes the phase variation in a transmitted image plane (4), and V is:

$$V = \sqrt{\phi^2 + \left(\frac{\delta}{2}\right)^2} \tag{3}$$

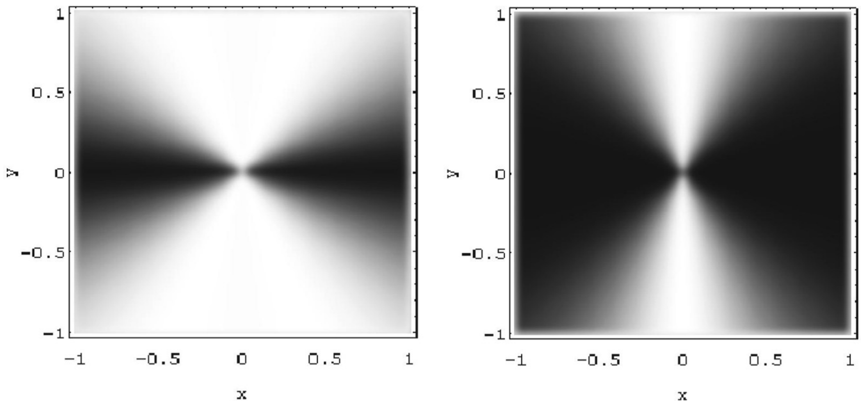

FIGURE 3 Numerical simulation of the transmission of the LC filter for PDI (based on the theory shown in this paper). Images are corresponding for angles between analyzer and polarizer 0 and 90 degrees respectively.

$$\delta = \frac{2\pi}{\lambda} \Delta n d \tag{4}$$

The Δn is a birefringence of the LC layer and d is the LC layer's thickness. The Jones vectors J and J' can be described in terms of polarizer and analyzer angular position:

$$J = \begin{pmatrix} \cos\phi_{ent} \\ \sin\phi_{ent} \end{pmatrix}; \quad J' = \begin{pmatrix} \cos\phi_{exit} \\ \sin\phi_{exit} \end{pmatrix} \tag{5,6}$$

Calculated transmission of the LC filter is shown on the Figure 3.

4. SENSITIVITY

One of the most important parameters of the PDI imaging system is its sensitivity. The spectral sensitivity was described in [3] and the spatial one was examined and presented in [5,6]. As a spatial sensitivity (D) the ratio between the medium intensity difference of the analyzed areas (S) to the maximum noise level (S') can be described as:

$$D = \frac{\left| \frac{1}{MN} \sum_{m=o}^{M} \sum_{n=o}^{N} I(m,n) - \frac{1}{M'N'} \sum_{m'=o}^{M'} \sum_{n'=o}^{N'} I'(m',\ n') \right|}{\max(S, S')} \tag{7}$$

$$S = |\max(I(m,n)) - \min(I(m,n))| \tag{8}$$

$$S' = |\max(I'(m',n')) - \min(I'(m',n'))| \tag{9}$$

The intensity I and I' mentioned in these formulas can be understood as two local intensities of the images of test object with different polarization azimuths (in this case polarization azimuth difference was set to $\Delta\alpha = 45°$).

5. EXPERIMENT

In this paper, presented experimental work regards the examination of spectral sensitivity of presented PDI system in dependence of:

1) distance between the image plane and LC circular filter plane (d),
2) focal length of the imaging lens (f), and
3) aperture stop (y).

On the Figure 4 the experimental set-up for mentioned tasks is shown. The observed object was illuminated with the scattered and diffused continuous light generated by halogen source. This is done

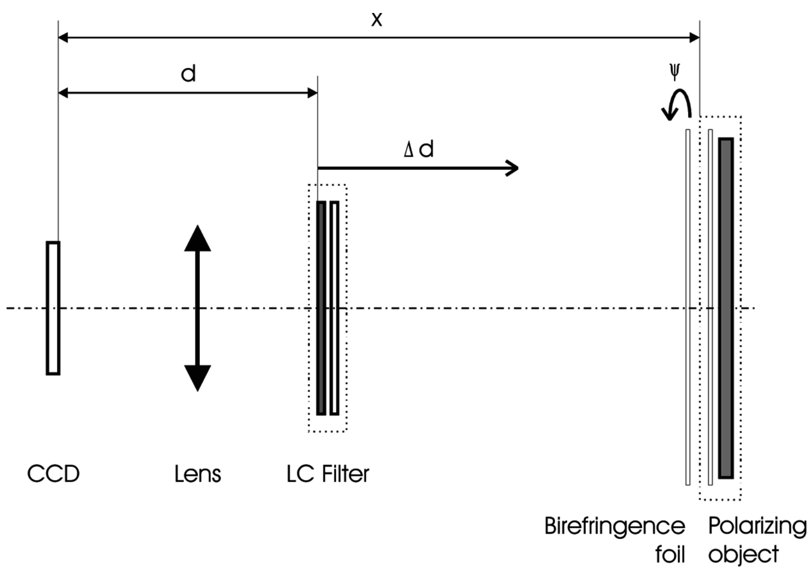

FIGURE 4 Experimental set-up for spatial sensitivity of the PDI imaging system examination. d – distance between image plane and LC filter plane, Δd – increment of d, x – object distance, ψ angle of rotation of birefringence foil (around z axis), Lens – imaging lens characterized by two general parameters: f – focal length and y – aperture stop (usually marked as f/y, i.e.: $f/1.4$ or $f/8$), LC filter-this is a combination of properly oriented LC layer in a glass cell (as on. Fig. 1) and the analyzer placed on it, Polarizing object – prepared as a reflection type polarizer combined with a birefringence foil.

TABLE 1 Assumption for Reported Experiments. Note that Parameter β Denotes Enlargement in Imaging System; to Maintain this Parameter Constant When the Focal Length f is Changed, Object Distance x has to be Modified

L.p.	Constant parameters	Variable parameters
1	$f = 50$ mm, $y = 1{,}8$, $x = 950$ mm	$d = 300$–600 mm
2	$y = 1{,}8$, $d = 350$ mm, $\beta \approx 0{,}06$	$f = 20$–50 mm, $x = 600$–950 mm
3	$f = 20$ mm, $x = 650$ mm, $d = 100$ mm	$y = 1{,}8$–11

to eliminate eventually polarization component from illumination. The only polarized component in experiment comes from the object. On the Table 1. the assumptions of the experimental work are listed. The angle ψ denotes the rotation of the birefringence foil to set desired polarization azimuth difference for two consecutive frames used in calculations as a source for the local intensities determined (I and I' – see chapter 4). Note that $\Delta\psi \equiv \Delta\alpha$ Goal of this activity is to determine optimum configuration of the PDI system with LC filter.

6. RESULTS

The results of the experiment are calculated as described in chapter 4 and set in a 2-dimensional graphs.

Note that some local errors and/or discontinuities appear on the graphs. It is caused by the existence of unwanted factors in high resolution images i.e., image noise, artefacts on the object plane caused by external factors. The quality of images nor resulting graphs were not improved due to the possibility of intensity values flattening.

On the Figure 5 results of spatial sensitivity obtained when parameter d was changed are presented. It can be easily observed that the sensitivity betters together with increasing of d. This is caused by the fact that at higher d values systems uses larger LC filter area than in lower ones. These results prove the existence of curiosity at the center of circular LC filter. In this case, when the center of the filter is oriented nearby optical axis of the imaging system this curiosity is causing strong degradation of the sensitivity.

On Figure 6 the influence of the focal length on the PDI system sensitivity can be noticed. These results confirm the previous ones – regarding the curiosity and sensitivities degradation when the work area of LC filter decreases.

The changes of the spatial sensitivities of the PDI system as a function of aperture stop y are shown on Figure 7. Following graphs show that sensitivity is best for optimal aperture values of the imaging optics.

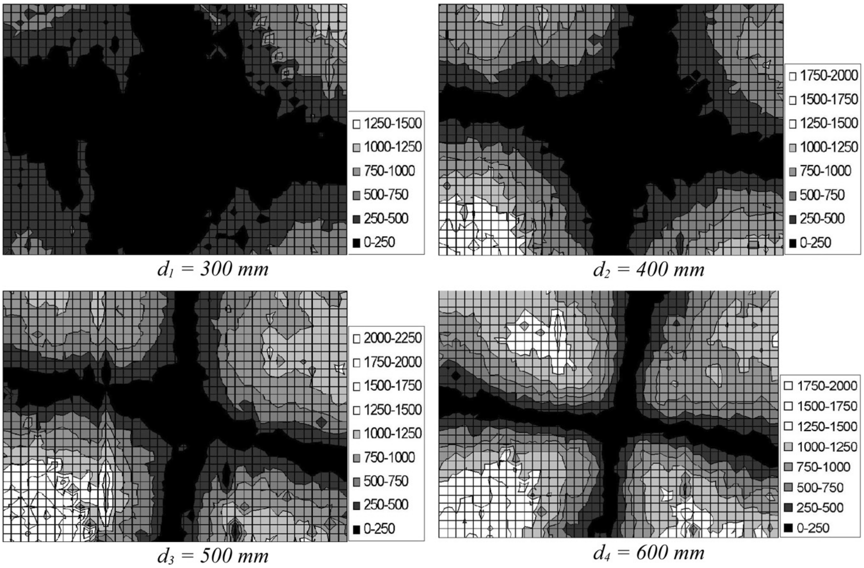

FIGURE 5 Influence of distance *d* on the sensitivity of the PDI system with LC filter. The diagram shows local changes in gray level values (absolute from 16-bit grayscale images) calculated in the way described in Eq. (7).

This is caused by cutting external light beams when the diaphragm is closing and thus the LC filter works locally with a smaller area than when the aperture is fully open. When the optimal aperture value (approx. $f/5{,}6$ to $f/8$) is exceeded, the sensitivity is decreasing. It may be caused by decreasing of optical quality of the imaging system and/or or by working with too small filter area.

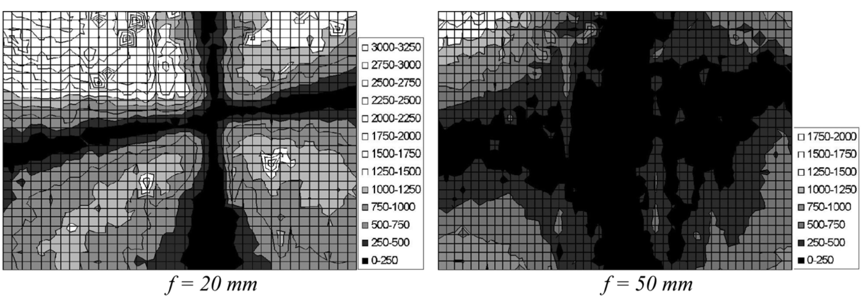

FIGURE 6 Influence of the focal length *f* on the sensitivity of the PDI system with LC filter. The diagram shows local changes in gray level values (absolute from 16-bit grayscale images) calculated in the way described in Eq. (7).

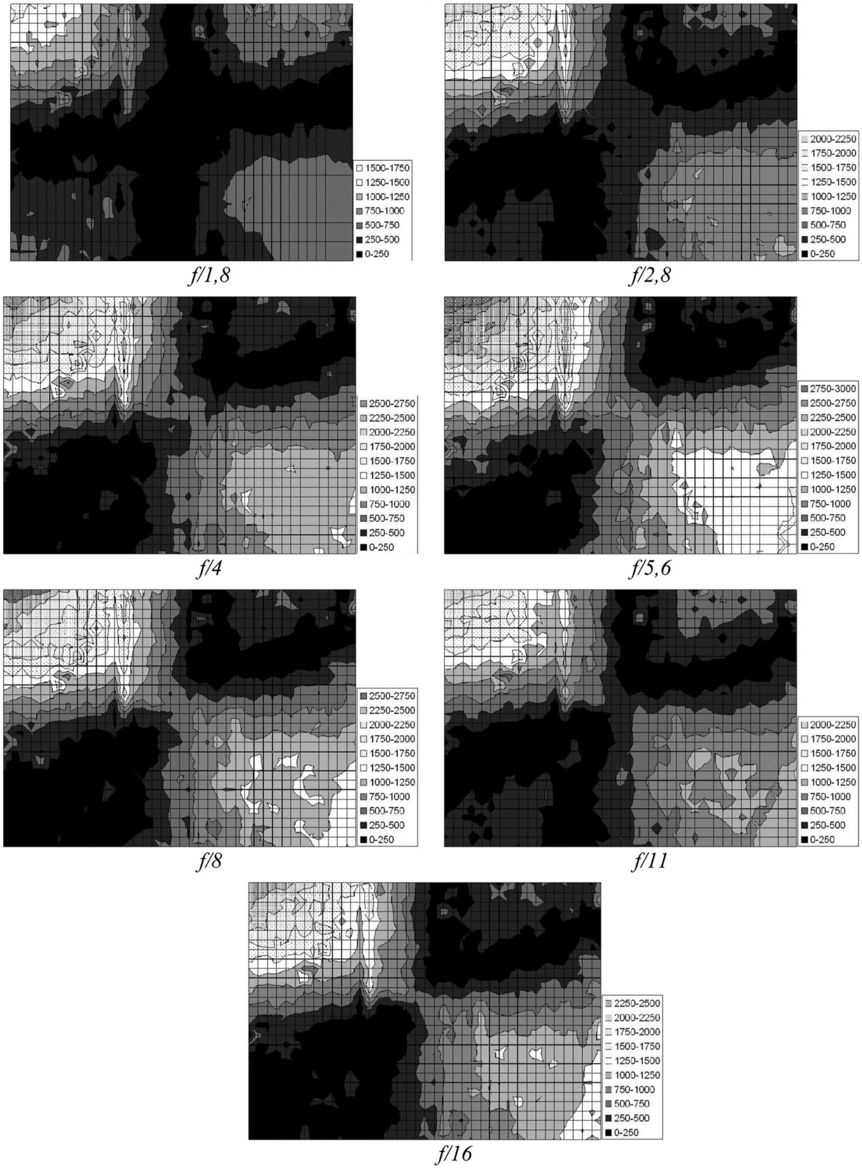

FIGURE 7 Influence of the aperture value *y* on the sensitivity of the PDI system with LC filter. The diagram shows local changes in gray level values (absolute from 16-bit grayscale images) calculated in the way described in Eq. (7).

7. CONCLUSIONS

To sum up, some general conclusions regarding examined PDI system with circular LC filter should be listed as follows:

1. The work area of the LC filter has strong influence on the systems' sensitivity. Thus imaging system has to be configured to cover the most possible area of the filter. When one imaging lens is changed for another one, with higher focal length (smaller angle of view), then LC filter should be withdrawn from the image plane.
2. The curiosity of the circular LC filter is totally degrading systems' sensitivity. Thus at the moment it is strongly recommended to place the center of the filter out of the image area. The further work leading to eliminate or minimize this curiosity is needed.
3. The sensitivity of the PDI system is reaching optimum when the aperture value is set to the medium range (approx. optically optimum). The PDI system should be used at this range of apertures.

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