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Simulation of the light propagation in structured matrices with liquid crystal for optical sensor active medium designing

Abstract*. In our paper, the simulation of the ray propagation through the solid-state matrix-liquid crystal structure is described. The rays propagate at a considerable angle to the investigated structure surface. And as a result, it leads to a sharp decreasing of the efficiency coefficient of the structure and, as a consequence, a decreasing of the signal-to-noise ratio. By adjustment of the refraction coefficient and the cholesteric liquid crystal pitch can be possible to change the reflection coefficient, the bandwidth selectively reflection, thereby affecting the parameters of the primary convectors of optical sensors.*

Streszczenie. *W pracy opisano symulację rozchodzenia się promieni przez strukturę matryca półprzewodnikową – ciekły kryształ. Promienie te rozprzestrzeniają się pod znacznym kątem do powierzchni badanej struktury. W rezultacie prowadzi to do gwałtownego spadku współczynnika sprawności struktury, a w konsekwencji do zmniejszenia stosunku sygnału do szumu. Współczynnik załamania światła i skok cholesterycznego ciekłego kryształu, może zmieniać współczynnik odbicia, szerokość pasma selektywnie odbitego, wpływając tym samym na parametry pierwotnego przetwarzania czujników optycznych. (****Symulacja rozchodzenia się światła w matrycach strukturalnych z ciekłym kryształem do budowy czujników optycznych z aktywnym medium****)*

Keywords: optical simulation, rays propagation, liquid crystals, porous solid-state matrix, optical sensors.
Słowa kluczowe: symulacja optyczna, propagacja promieni, ciekłe kryształy, porowata matryca półprzewodnikowa, czujniki optyczne

Introduction

An anisotropic fluid is a sensitive element of LC optical sensors. And the fluid as an active medium requires some design solutions in the system of the primary sensor converter. The introduction of the LC materials into the nanostructured matrix will allow the designing of a solid-state sensitive medium. In terms of practical using, this solution is much more attractive than the liquid substance [1-5].

However, to design such sensitive elements, the optimization of structural and technological solutions requires additional research of light propagation. For today, relatively the high cost of nanostructured matrices leads to a preliminary computer simulation of light propagation process [6-7].

In order to take into account the influence of optical properties of individual elements of the structured matrix-LC system to the primary transducer parameters, the light propagation simulation was carried out by means of Zemax software.

Zemax is a software developed to analyze optical systems based on consistent or inconsistent ray calculations and permits to perform global and local optimization of optical system parameters. The program has all the necessary capabilities to design modern optical systems. Zemax was developed by Zemax Development Corp., Washington (previously Focus Software).

It is used for modelling and analysis of optical elements, tracing of indirect rays of a random light, light propagation within the physical optics approach. It can simulate the light propagation through the optical elements: lenses (including aspheric and gradient), mirrors and diffractive optics. Using Zemax software, the simulation of effects of optical coatings on component surfaces and create the standard intensity distribution diagrams for analysis, including point diagrams and three-dimensional graphs can be provided. Features of light propagation within a geometric optics approach will be useful where diffraction is required, including laser beam propagation, holography, and light inputting to single-mode optical fibres. Zemax software has powerful tools for optimizing lens modelling, automatically adjusting parameters to optimize performance and reduce aberrations.

The optional Zelum software module can be used to develop a lighting optical system, to trace the rays, allowing illuminance, irradiance, luminous intensity, or radiant intensity data to be generated at any surface in the optical system. Zebase and LensVIEW optical-design database allow you to work with the largest library of optical systems. The wave properties of radiation were not taken into account in our simulation.

Experimental results and discussion

The sensitive element of liquid-crystal optoelectronic sensors is anisotropic fluid. To use the fluid in primary sensor converter construction certain design solutions are required. The introduction of a liquid crystal into a nanostructured matrix makes it possible to create a solid-state sensitive medium [8-9]. The simulation results for the case $n_{LC} < n_M$ for the structure thickness 0.25 and 0.5 mm respectively are shown in Fig. 1-2. For all thicknesses, from capillaries with a lower refractive index into a matrix with a higher refractive index the ray extrusion is observed.

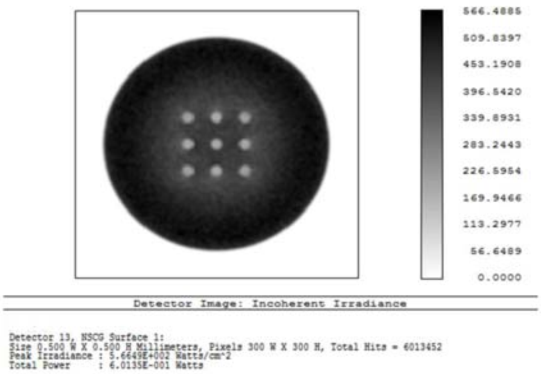
The structure thickness increasing exacerbates this tendency. At all distributions, the low-intensity spots with locations corresponded to the pores locations are pronounced. Changes in the radiation intensity distribution directly in the matrix can be also observed. The first zone arises from the redistribution of radiation between the pores and the central part of the matrix, and the second is caused by the phenomenon of complete internal reflection at the matrix-air boundary. With layer thickness increasing, there is a tendency to equalize the radiation intensity over the entire area of the matrix. Obviously, such a result shows that the proposed conditions lead to a sharp decreasing in the structure efficiency coefficient, and the thickness increasing exacerbates this trend. Table 1 shows the numerical values of the radiation intensity that has passed through the individual elements of the structure.

The obtained results are shown the necessity for a more detailed study of the contribution to the total distribution of radiation propagation through the structure at tangible angles. In Fig. 3-5 the simulation results for the cases $n_{LC} > n_M$ and $n_{LC} < n_M$ for the angles of incidence of the beam 45° and 60° are shown. Figure 4 shows the simulation results for the case $n_{LC} > n_M$. Despite the fact that, the refractive indexes ratio of the structure elements indicates its optical properties, most of the radiation passes through the pores, leading to a sharp decrease in Ke.

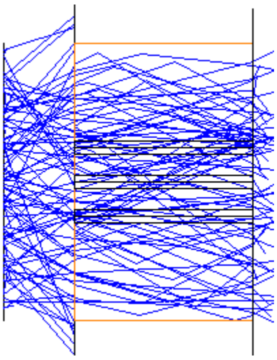
Table 1. The radiation intensity distribution that passed through the individual sections of the simulated structure

Structure parameters	The percentage of radiation that has passed through the structure, (%)			
	matrix	pores with LC		
l = 0.5 mm	0.3569	0.0145	0.0135	0.0134
n_M =1.76		0.0127	0.0137	0.0131
n_{LC} =1.51		0.0129	0.0134	0.0128
l = 0.25 mm	0.3568	0.0177	0.0145	0.0146
n_M = 1.76		0.0157	0.0144	0.0156
n_{LC} = 1.51		0.0157	0.0144	0.0159

a)



b)



c)

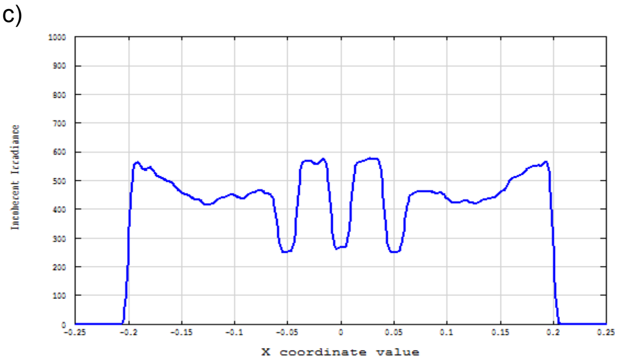


Fig.1. Results of structure modeling for the case l = 0.25mm, n_M =1.76, n_{LC} =1.51. a) detector image in incoherent irradiance, b) in plain light distribution c) cross-section light distribution,

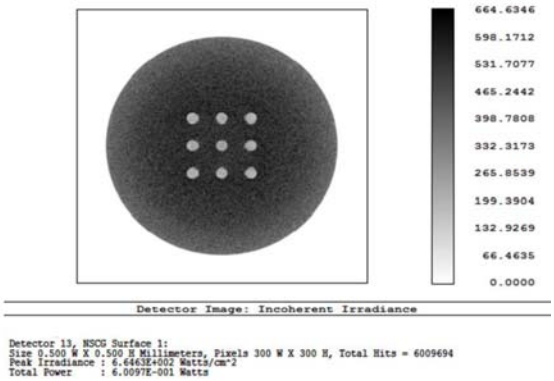
Reducing the incidence angle (relative to the structure plane) and increasing its thickness only aggravates the situation. There is a similar trend here. However, the effective radiation component (which has passed through the pores with LC) is completely absent, since the refractive indices ratio leads to the complete radiation propagation from the pores into the matrix.

For all simulated cases, a high-intensity maximum is formed in the matrix, which in practice will result in a sharp deterioration of the signal-to-noise ratio.

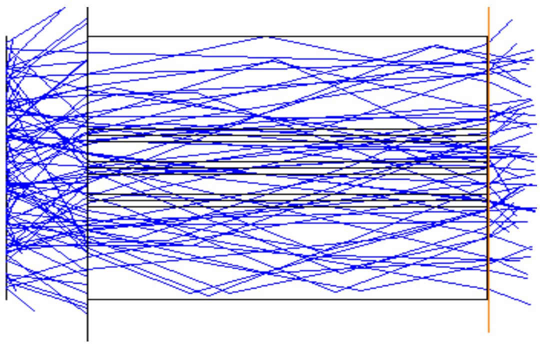
Figure 6 shows the transmission spectrum of porous Al_2O_3 – cholesteric liquid crystal system.

The modelling process and experimental studies of the optical properties of structured matrix-LC systems revealed a number of features, which are necessary for the development of real primary converters based on them. Analysis of existing mathematical models showed that the obtained results of experimental studies for thin samples ($d = 5P$) described adequately. In the thickness of the sample ($d = 21P$) there are differences between the experimental and the calculated values. This can be explained by the fact that mathematical models do not take into account the absorption of radiation in the layer of liquid crystal material. A prerequisite for obtaining a satisfactory reflection coefficient, if the thickness $d \leq 10$ P, is the using the LC materials with high-refractive birefringence (0.3 ÷ 0.4).

a)



b)



c)

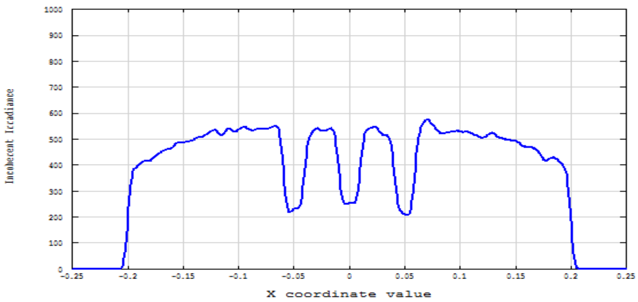


Fig.2. Results of structure modeling for the case l = 0.50mm, n_M =1.76, n_{LC} =1.51. a) detector image in incoherent irradiance, b) in plain light distribution c) cross-section light distribution,

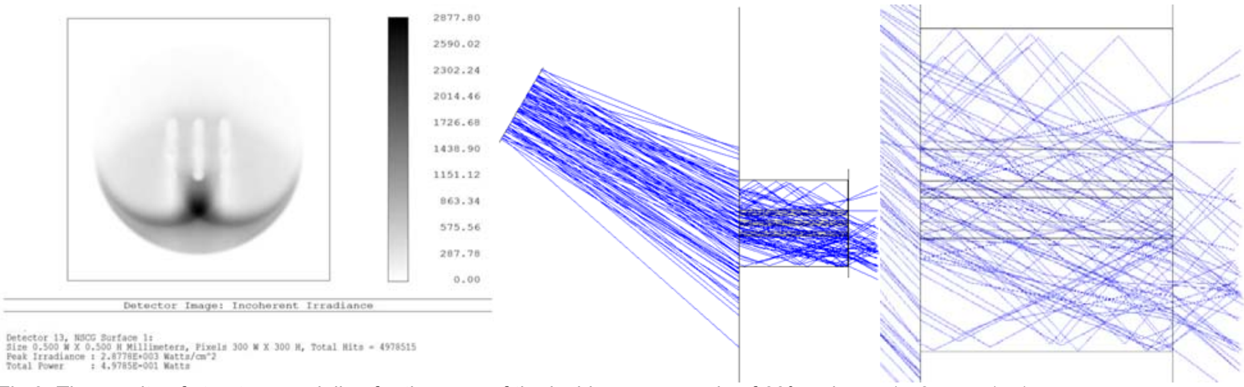


Fig.3. The results of structure modeling for the case of the incidence ray angle of 60° and, n_M =1.76, n_{LC} =1.51

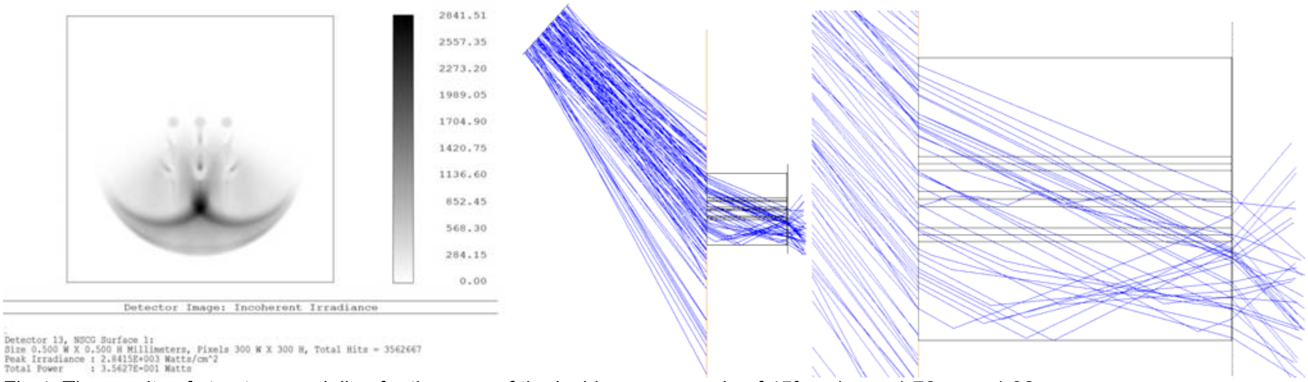


Fig.4. The results of structure modeling for the case of the incidence ray angle of 45° and, n_M =1.76, n_{LC} =1.92

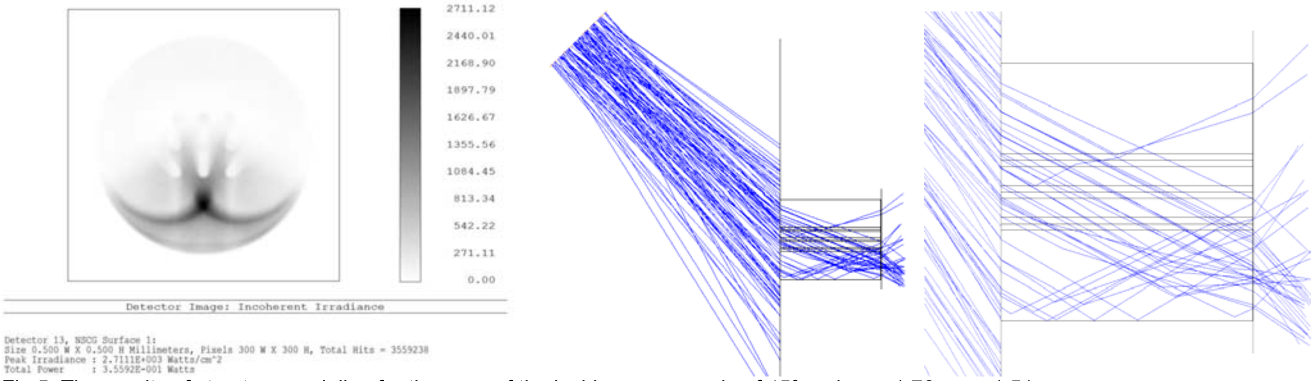


Fig.5. The results of structure modeling for the case of the incidence ray angle of 45° and, n_M =1.76, n_{LC} =1.51

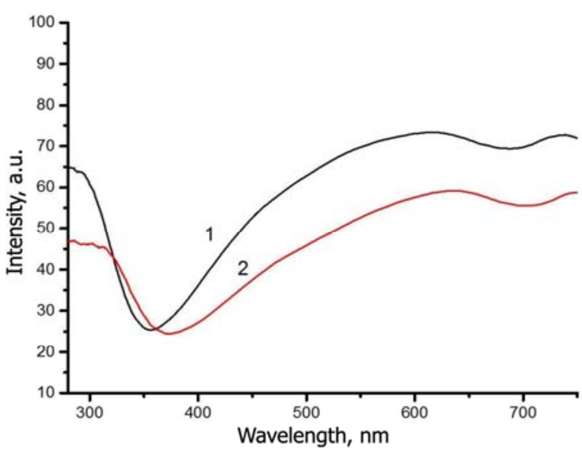


Fig.6. Transmission spectrum of porous Al_2O_3 - CLC system: 1 - normal ray incidence; 2 - ray incidence angle 30°

Conclusion

Simulation of the ray propagation through the matrix-LC structure showed that the rays propagated at a considerable angle to the structure surface leads to a sharp decrease in the efficiency coefficient of the structure and, as a consequence, a decreasing in the signal-to-noise ratio. The rays propagated at an angle to the system surface leads to an increasing the maximum width of selective reflection and, as a consequence, a decrease in the sensitivity of the structure to the detected substance. It is best to use as a reference radiation source a device with a minimum ray divergence angle.

Our studies have shown, that by selecting in a certain way the thickness of the liquid crystal cell, the refraction coefficient and the cholesteric liquid crystal pitch, can be possible to change the reflection coefficient, the bandwidth selectively reflection, thereby affecting the parameters of the primary convectors [10-13].

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