Domain structure studying in the $Pb_3(PO_4)_2$ crystals by the imaging polarimeter

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Abstract.

The imaging polarimeter for the domain structure studying in the $Pb_3(PO_4)_2$ ferroelastics crystals is constructed. Three blocks of domains S_1, S_2 and S_3 are observed at room temperature. The differences in the extinction positions in these blocks are determined as $\Delta\varphi_{12}$=32.04° and $\Delta\varphi_{13}$= -2.83°. In the second and third domain block the difference between light intensity in extinction position and diagonal position is smaller than in the first block. It means that light propagated along *Z*-axis passes through few different domains. Obtained results are discussed on the base of Jones matrix approach. It was shown that studying the orientation of the optical indicatrix in the neighbouring domains it is necessary to take into account the intensities of light transmitted through sample in crossed polarizers. The advantage of the imaging polarimeter for this aim is demonstrated.

Key words: imaging polarimeter, ferroelastics, domain structure, $Pb_3(PO_4)_2$ crystals.

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Introduction

As it was shown [1] the ferroelastic orientation states can split on the suborientation states due to the appearing at phase transition as order parameter not only symmetrical part of the second rank polar tensor that describes the spontaneous deformation but also the antisymmetrical part of this tensor that describes the turning of the lattices of neighbouring domains. Such lattices turning lead to the additional rotation of the optical indicatrix on the small angle (usually few degrees). The determination of this angle by the optical microscope is a quite difficult problem as well as manual method with usual observation possesses low precision. In our previous paper [2] it was shown that imaging polarimeter can be used for the studying of the domain structure of ferroic crystals. The useful exploitation of the image processing for the domain structure studying in the $Pb_3(PO_4)_2$ was already demonstrated in [3]. From other hand on condition of the presence of few domain layers along the light path the extinction position can differ from the theoretically predicted. It means that measuring light intensity is additional source of information in studying optical indicatrix turning in neighbouring domains particularly at the determination of such small angle as distortion angle.

The present paper is devoted to the investigation of the turning of the optical indicatrix in the ferroelastic domains on the example of the $Pb_3(PO_4)_2$ ferroelastic crystals and the demonstration of the performance characteristics of the imaging polarimeter for such aim.

Experiment

Lead orthophosphate crystal is well studied [4-6] ferroelastic material that possesses phase transition at T=180^{o}C with the change of the point group of symmetry $\bar{3}m \leftrightarrow 2/m$. $Pb_3(PO_4)_2$ are layered crystals with cleavage plane perpendicular to the Z axis. Therefore, it is easy

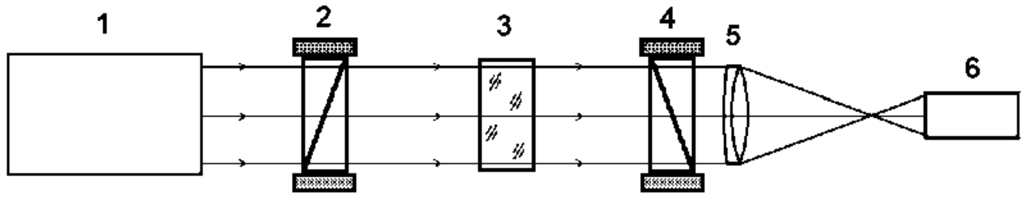


Figure 1. Optical scheme of the imaging polarimeter: 1 - He-Ne laser; 2,4 - polarizers, 3 - sample; 5 - objective lens; 6 - CCD camera.

to prepare thin plate with (001) - orientation. The experiment was held at room temperature. The optical scheme of the imaging polarimeter is shown in Fig.1. As a light source we have used the He-Ne laser. The total magnification of the system was $205^{\times}$. This system is described in [2] in more details. The visualization of the domains was achieved through the rotation of crossed polarizers. For the neighbouring domains, the dependencies of transmitted light intensity on the azimuth of the crossed polarizers have been obtained.

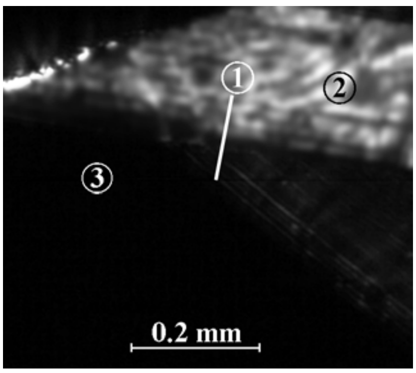
Results and discussion

As it was shown on the Fig. 2, three domain blocks S_1, S_2 and S_3 exist in the sample of the lead orthophosphate. The dependencies of the intensity of transmitted light due to the orientation of the polarizers azimuth in these domain blocks are shown in Fig.3. As it is visible the difference between light intensities in extinction and diagonal position differs in three cases. One can conclude that only in block S_1 light propagates through single domain. The small difference in the intensities of light at the wave propagation through S_2 and S_3 blocks means that these blocks consist of the few domains with different orientations of the optical indicatrix. The difference in the extinction positions calculated from experimental data in these blocks are $\Delta\varphi_{12}=32.04^0$ and $\Delta\varphi_{13}=-2.83^0$. The values of angles can not be explained on the base of usual symmetry approach because the indicatrix axes of domains should be turned on 120° and the extinction in the crossed polarizers should appear at every 30^0. From other hand estimated distortion angle for the lead orthophosphate equals $\delta\varphi=2.26^0$ [1].

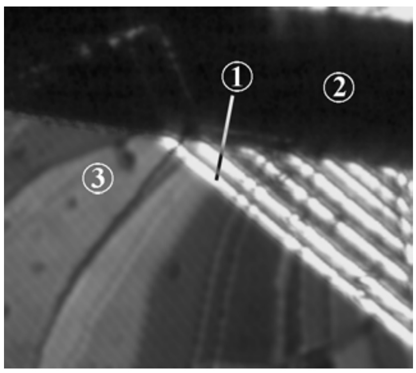
Let us analyse the obtained dependencies on the base of the assumption of the existing of few domains in blocks S_2 and S_3 and computer simulation. The intensity dependencies are fitted by the function

$$I(p)=c+a\cdot\sin^2(2(p-\varphi)), \quad (1)$$

where a, c - are fitting parameters, p - is the azimuth of crossed polarizers and φ - is the azimuth of extinction position for S_2 and S_3 blocks, respectively. Deviation of the fitted lines from experimental points may be caused by

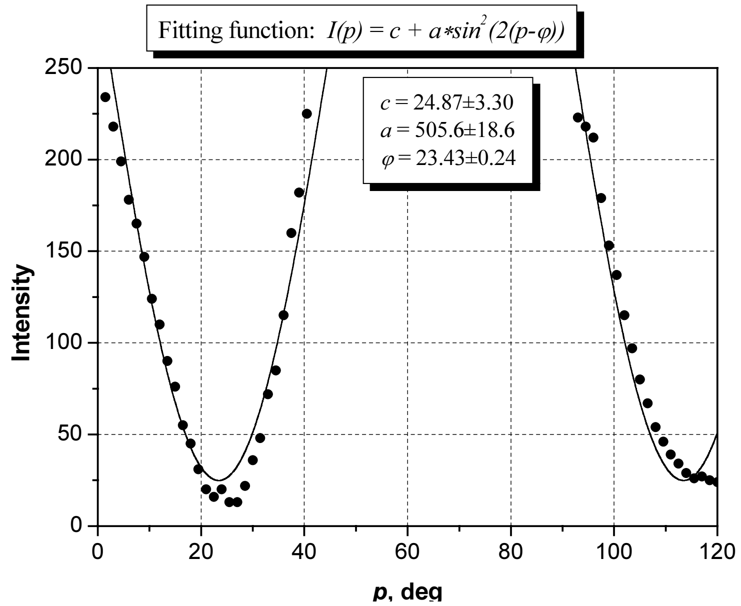


a)

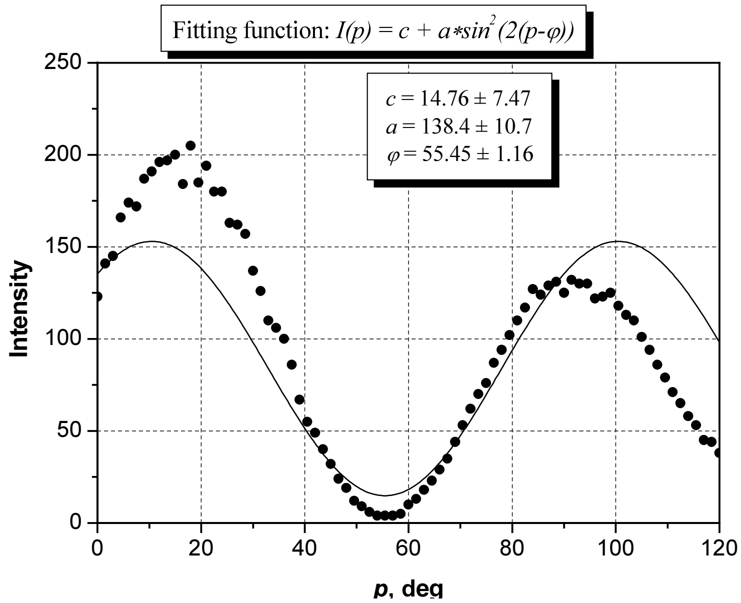


b)

Figure 2. Domain structure of the $Pb_3(PO_4)_2$ crystals. a) S_1 - domain block is in the extinction position (region 1); b) S_2 - domain block is in the extinction position (region 2); region 3 corresponds to the S_3 domain block.



a)



b)

Figure 3. The dependencies of the transmitted light intensity on the polarizers azimuth in S_1 (a) and S_2 (b) domain blocks.

beam wandering due to the polarizers small wedge, which is inevitably present in polarization prisms. Exact analysis of the dependencies on the Fig. 3 allows us to make next conclusion. Magnitudes of fitted functions for distinct blocks are considerably different. To explain this fact following model was analysed. Let us suppose that two layers of different domains that are turned by 120^0 exist in the block S_2. It means that they have relative retardation of Γ_1 and Γ_2 and orientation of φ_1 and φ_2 respectively. Jones matrix of such linear retarders is given by [7]:

$$T = \begin{pmatrix} \cos^2\varphi + \sin^2\varphi \cdot e^{-j\Gamma} & \sin\varphi\cos\varphi \cdot (1 - e^{-j\Gamma}) \\ \sin\varphi\cos\varphi \cdot (1 - e^{-j\Gamma}) & \sin^2\varphi + \cos^2\varphi \cdot e^{-j\Gamma} \end{pmatrix} \qquad (2)$$

Intensity of the light transmitted through such complex optical system consisting of the crossed polarizers and two linear retarders between them is written by the formula:

$$I = |E_o|^2, \quad E_o = A \cdot T_2 \cdot T_1 \cdot E_i, \qquad (3)$$

where T_1 and T_2 – are Jones matrices of retarders, A – is Jones matrix of analyzer and E_i – is Jones vector of the light wave on the input of the sample, E_o – is Jones vector on the output of the analyzer,

$$E_i = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad A = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}. \qquad (4)$$

After substitution of (2) and (4) into (3) and reducing we obtain the expression for I:

$$\begin{aligned} I = {} & 0.5 \cdot \sin 2\varphi_2 \cdot \sin 2(\varphi_1 - \varphi_2) \cdot (\cos \Gamma_2 \cdot \cos 2\varphi_1 - \cos \Gamma_1 \cdot \sin 2\varphi_1) + \\ & + 0.5 \cdot \sin 2\varphi_1 \cdot \sin 2\varphi_2 \cdot \{\sin \Gamma_1 \cdot \sin \Gamma_2 - \cos \Gamma_1 \cdot \cos \Gamma_2 \cdot \cos 2(\varphi_1 - \varphi_2)\} + \\ & + \sin^2 2(\varphi_1 - \varphi_2) \cdot (\sin^2 \varphi_1 \cdot \sin^2 \varphi_2 + \cos^2 \varphi_1 \cdot \cos^2 2\varphi_2) + \\ & + \cos^2 2(\varphi_1 - \varphi_2) \cdot (\cos^2 \varphi_1 \cdot \sin^2 \varphi_2 + \sin^2 \varphi_1 \cdot \cos^2 2\varphi_2) \end{aligned} \qquad (5)$$

As this expression is complicated to analysing, we perform numerical simulation using this formula. Two cases were considered. In the first we assume that $\Gamma_1 = \Gamma_2 = \Gamma/2$, $\varphi_1 = \varphi_2$. This case corresponds to the block S_1. In the second case we assume that $\Gamma_1 = \Gamma_2 = \Gamma/2$, $\varphi_2 = \varphi_1 - 120^0$ (block S_2). For these cases we plot dependencies of intensity I of light transmitted through crossed polarizers and simulated sample between them versus polarizer azimuth p (see Fig.4). We obtain that magnitudes ratio $a_1/a_2 = 4.0$ and this ratio does not depend on the Γ value. Extinction position in the first case is $\varphi^{(1)} = \varphi_1$ and in the second one is $\varphi^{(2)} = \varphi_1 + 30^0$. If $\Gamma_1 \neq \Gamma_2$, $\Gamma_1 + \Gamma_2 = \Gamma$, we obtain that $a_1/a_2 < 4.0$ and $\Delta\varphi = \varphi^{(2)} - \varphi^{(1)} \neq 30^0$. It means that if domain layers do not have equal thickness, the extinction positions in the different blocks may differ on the angle distinct from 30°. From our experimental data after fitting we have calculated that $a_1/a_2 = 3.65$ and $\Delta\varphi_{12} = 32.04^0$.

In the third block, the situation is more complicated. As it is visible from Fig.5, the difference of the intensity in extinction position and diagonal position is very small. It means that the light passes through consequently located three or more domains. In the case of three different domains with equal thickness, intensity I=0 and does not depend on the p azimuth. Therefore in this block we have at least three domains with non-complete compensation of birefringence.

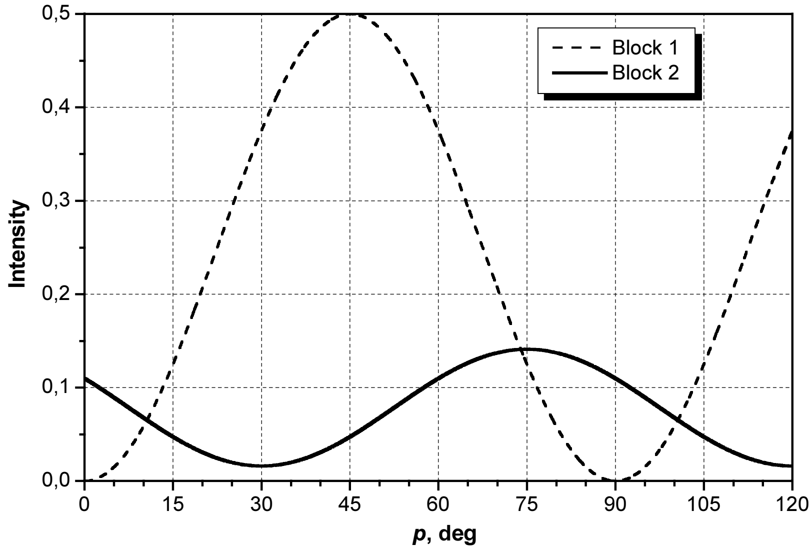


Figure 4. Simulated intensity dependecies for S_1 and S_2 blocks.

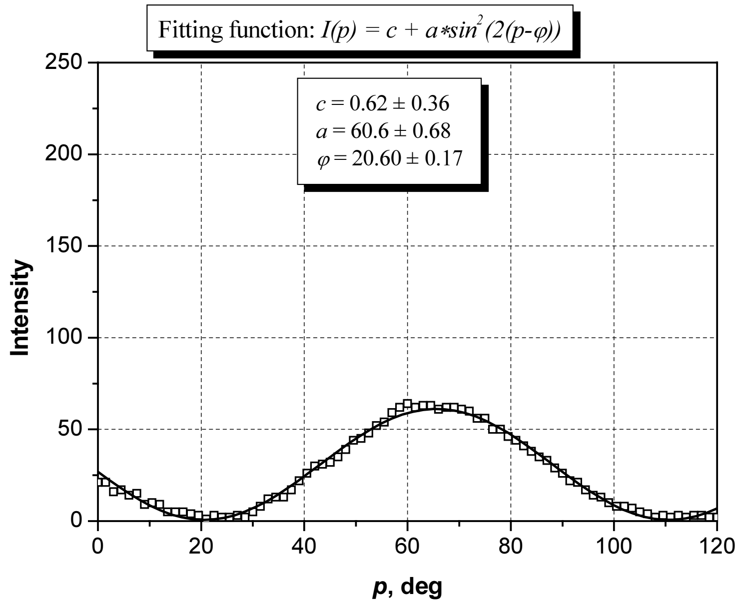


Figure 5. The dependence of the transmitted light intensity on the polarizers azimuth in S_3 domain block.

If to follow the symmetry approach then consequently located three orientation states S_1, S_2 and S_3 with the same thickness should lead to the absence of total birefringence along *Z*-axis as well as $Pb_3(PO_4)_2$ crystals are optically uniaxial in the paraelastic phase.

Conclusions

The imaging polarimeter for the domain structure studying in the $Pb_3(PO_4)_2$ ferroelastics crystals is constructed.

Three blocks of domains S_1, S_2 and S_3 were observed at room temperature. The orientations of the optical indicatrix in these domain blocks were calculated from minima of intensity dependences due to polarizer azimuth in crossed polarizers. The differences in the extinction positions in these blocks are determined as $\Delta\varphi_{12} = 32.04°$ and $\Delta\varphi_{13} = -2.83°$.

Obtained results were analysed on the base of Jones matrix approach and numerical simulation was performed. It was shown that the angle between orientations of extinction positions in neighbouring S_1, S_2 domain blocks may be explained by splitting the sample into two layers with different domain types.

In the third domain block the difference between light intensity in extinction position and diagonal position is quite small and it means that light propagated along *Z*-axis passes through at least three different domains.

The advantage of the imaging polarimeter for this aim is demonstrated.

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