The studies of domain structure in ferroics by imaging polarimetry. The case of Rochelle salt.

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Abstract.

The application of imaging polarimetry to the studies of domain structure is presented. Peculiarities of the instrument configuration and operation are considered. Measurement example for the case of Rochelle salt crystals are presented and analyzed. Experimental results, obtained in the paper, demonstrate high measurement accuracy of the imaging polarimeter and its capabilities to visualize domain structure in the ferroelectric crystals. The instrument was designed in the Institute of Physical Optics.

Key words: imaging polarimetry, ferroelectrics, domains, Rochelle salt.

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Introduction

Recently imaging polarimetry has become a pretty powerful method for the studies of inhomogeneous anisotropic media. The applicability of this technique spans wide area. In particular, the different modifications of the method have been described to determine stress analysis in experimental mechanics [l], to high precise control of polarization elements [2,3], solar magnetic field [4,5], to map spatial distribution of polarization across a beam [6], for earth resource investigation [7] and remote sensing [8].

In the Institute of Physical Optics the Jones matrix imaging polarimeter has been developed [9]. The operational principle of the instrument is based on high-informative polarimetric technique [10]. The polarimeter allows whole-field determination of the three parameters, which describe optical anisotropy: orientation and ellipticity of eigen polarization states and relative phase retardation between those. Initially the instrument was designed to measure residual stresses in transparent glass constructions and single crystals and to study gradient optical phenomena. Afterwards the setup has been applied to the studies of domain structure in ferroelectrics.

The information on domains' orientation and behaviour helps to determine a nature of phase transitions and physical properties in ferroelectric crystals. It may be important for application of ferroelectric crystals as active elements in optoelectronic devices. Until the present, optical study of domain structure has been usually performed by polarization microscope. The essential disadvantage of this method is that procedure of getting experimental data is hard to automation and the measurement is still possible only through laborious manual routine.

Instrument design and measurement procedure.

The arrangement of the Jones matrix imaging polarimeter has been described earlier

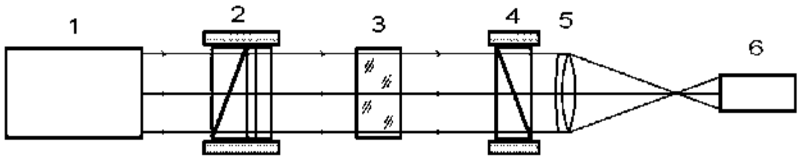

Fig.1. Optical scheme of the imaging polarimeter. 1- light source; 2- polarization generator (polarizer and compensator); 3- sample; 4- analyzer; 5- objective lens; 6- CCD camera.

in the Reference [9]. The optical schematic of the instrument is showed in fig.1. The initially suggested setup was then modified for the new application. In the case of domains' study it is necessary to provide a rate of magnification better than 100×. For this the objective lens were placed in the position of maximal possible magnification that is allowed by the polarimeter dimensions. In the given particular case the degree of optical magnification was of 6.65×. The sample's image was displayed by CCD camera onto the 14" PC monitor. The magnification of this electronic system is of 31×. A total magnification rate of the polarimeter in the given configuration was of 205×. A field of view was approximately of 1 mm with 1.5 μm resolution.

Since the analyzer experiences rotation in the process of collecting experimental data, there appears a significant problem to handle the errors, which are due to beam (and image) wander. Last one occurs because of small wedge, which is inevitably present in polarization prisms. Quite involved, the problem gets especially difficult to treat in the case of high optical magnification. It is evident that the magnification besides image itself also enhances wandering of the images between successive rotation steps. One possible way of handling the task is the instrument's calibration. The calibration performed shows that the amplitude of the image's wander is about of 25 pixels.

For the above discussed purpose of domain structure studies, a typical configuration of the polarimeter has been modified. In particular, the compensator was removed. The visualization of domain structure was achieved through the rotation of crossed polarizer and analyzer in the vicinity of extinction position. For the two neighbouring domains the dependences of light intensity on the azimuth of the crossed polarizers have been obtained. Then those curves were fitted by sine function and the positions of minimum were calculated.

Experimental results and discussion

Among ferroelectric materials, the crystals of Rochelle salt (RS) are classical and convenient for domain structure's studying. They have ferroelectric phase (point group of symmetry 2) in the temperature range of $-18 \div +24$°C. Physical properties and domain structure of RS crystals have been thoroughly studied [11-13].

Imaging polarimeter, described above, have allowed to obtain picture of domain structure in the *x*-cut of the RS crystal (see fig.2). The field of view, showed on this figure, is 0.9 mm in the horizontal direction. Two domain types are visible on the picture, namely *ab*- and *ac*-domains with domain walls oriented on (010) and (001) planes respectively.

For domains, marked on the fig.2, orientation of optical indicatrix was measured. For this purpose scanning of crossed polarizers was performed in the vicinity of extinction. Polarizers have rotated with 0.12° step. Image was readout for each polarizer's azimuth. Intensities of pixels, corresponding to chosen domains were recorded. Azimuthal dependencies

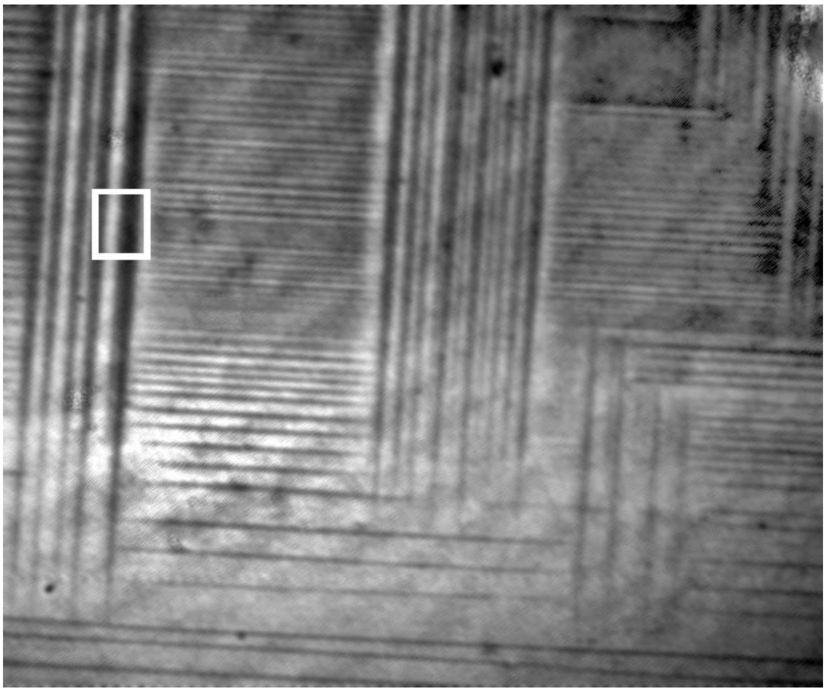

Fig. 2. Domain structure in the *x*-cut of RS. Sample's thickness 0.21 mm.

of intensities are presented in fig.3. These dependencies were fitted by sine function. Minima positions corresponded to optical indicatrix axis orientation was calculated. Temperature dependence of angle Δϕ between indicatrix axes for neighbouring domains is presented in Fig.4. Black circles denote results obtained by means of presented imaging polarimeter. Filled area corresponds to the literature data [12].

Slight discrepancy of the literature data and experimental results may be explained by sample's prehistory [12].

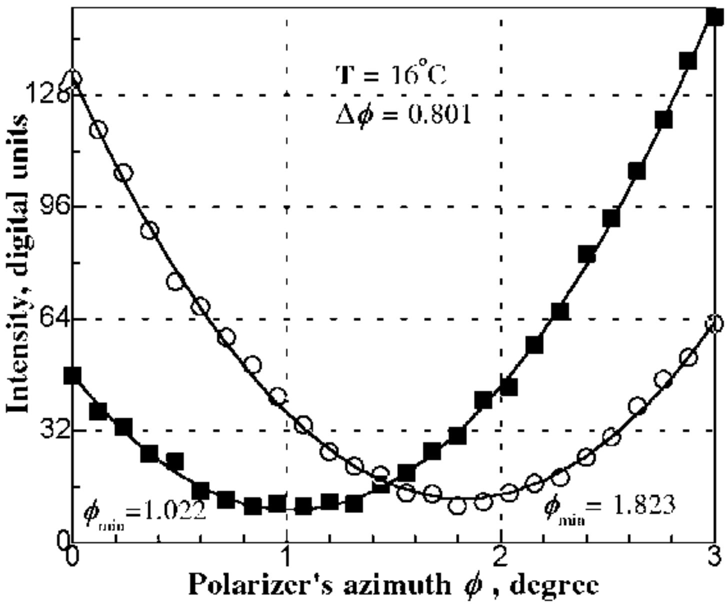

Fig. 3. Angular intensity dependencies for neighbouring domains.

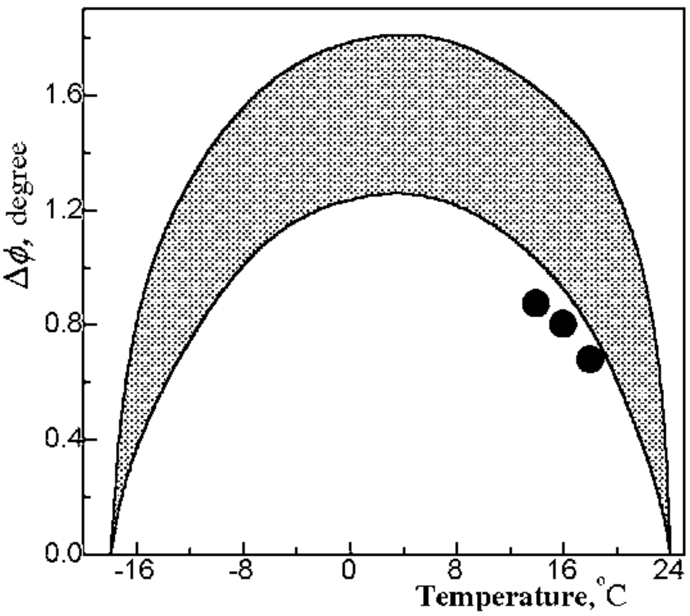

Fig. 4. Temperature dependence of the $\Delta\phi$ angle.

Conclusion

The imaging polarimeter developed in the Institute of Physical Optics [9] is a powerful versatile instrument capable of making measurements on a variety of non-homogeneous anisotropic media, particularly for the automatic measurement of the difference in the extinction positions in domains. The instrument is a valuable tool to study both macroscopic and microscopic samples. Sufficient magnification rate of the polarimeter opens a new opportunities in the optical polarization microscopy. Example measurements of domain structure in Rochelle salt confirm it.

References

1. Kihara T. Automatic whole-field measurement of photoelasticity using linearly polarized incident light. In: Proc. 9th ICEM, Copenhagen, 1990, p.821-827.
2. Pezzaniti J.L., Chipman R.A.. Imaging polarimeter for optical metrology. // Proc. SPIE, 1990, vol.1317, p. 280-294.
3. Pezzaniti J.L., Chipman R.A.. Linear polarization uniformity measurements taken with an imaging polarimeter. // Opt. Eng., 1995, vol.34, № 6, p. 1569-1573.
4. Dunn R.B., November L.J., Colley S.A., Streander G.W.. The National Solar Observatory polarimeter. // Opt. Eng., 1989, vol.28, № 2, p.126-130.
5. Baur T.G., House L.L., Hull H.K. A spectrum scanning Stokes polarimeter. // Solar Physics, 1980, vol.65, p.111-146.
6. Yoshihiro O., Oka K. Polarimeter for mapping the spatial distribution of dynamic state of polarization. In: Proc. SPIE, 1992, vol.1746, p. 42-48.
7. Egan W.G., Israel S., Johnson W.R., Whitehead V.S. High resolution space-shuttle polarimetry for farm crop classification. //Appl.Opt., 1992, vol.31, № 10, p.1542-1548.
8. Coulson K.L., Whitehead V.S., Cambell C.. Polarized views of the earth from orbital altitude. // Proc. SPIE, 1986, vol.637, p.35-41.
9. Krupych O.M., Berezhnyi I.V., Viokh O.G. Automatic Jones matrix imaging polarimeter. //Herald of State Univ. "L'viv Politechnika", 1998, № 348, p. 3-11. (in Ukrainian).
10. Berezhna S.Yu., Berezhnyi I.V. The restoration of a Jones matrix of an object by

means of PCSA-polarimeter. // Optics and Spectroscopy, 1991, vol.70, №.5, p.1107-1111. (in Russian)
11. Jona F., Shirane G. Ferroelectric Crystals. New York, Pergamon Press, 1962.
12. Zheludev I.S. Basics of Ferroelectricity. Moscow, Atomizdat, 1973. (in Russian).
13. Romaniuk M.O., Zheludev I.S. The study of slow processes of Rochelle salt electrical polarization by domain structure observation. // Kristallografia, 1960, vol.5, № 3, p.403-408. (in Russian).