LASER CONOSCOPY OF LARGE-SIZED OPTICAL CRYSTALS

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Abstract. Conoscopic interferometry provides a simple method of non-destructive control of the quality of a number of ferro-piezoelectric and optical crystals. Standard optical microscopes, including some commercial instruments, are easily adapted for implementation of conoscopic studies, though limited to small handy samples with a thickness of the order of 0.5 mm. In the present work we show that the usage of wide convergent or divergent conical laser beams in a simple benchtop configuration makes it possible to examine large-sized optical crystals by the method of conoscopy, including samples elongated along the optical axis direction. As distinct from traditional optical microscopy the conoscopic figures obtained with the aid of the laser installment may contain tens and hundreds of isochrome fringes thus increasing the informative capabilities of the method. Large-sized crystals of $LiNbO_3$ (∅57×95 mm), TeO_2 prisms (44×41×14mm) were examined experimentally at different angles between the optical axis and normal to the crystal surface. The experimental studies of different optical anomalies are confirmed by calculations based on the theoretical analysis given in a previous work of the authors.

1. Introduction

The investigation of optical properties of the birefringent crystals by the conoscopic method has been extensively exploited since long ago [1-2]. In most cases standard polarizing optical microscopes are finding their use for conoscopic examinations. Though quite satisfactory for the study of relatively thin samples with a thickness of the order of 0.5 mm this classical method might not be effective when analyzing technically important crystalline boules of large dimensions frequently exceeding 5…10 cm in length and diameter [3]. Making use of thin slices cut from a large boule does not resolve the problem, because in this case the method becomes destructive. Moreover, successful testing of a small part of a boule by no means guarantees the quality of the remaining part.

The current trends in the development of optoelectronics demand better characterization and modeling of various birefringent devices, especially acoustooptical ones, for which large crystal elements of high optical quality are required. Both theoretical and experimental studies of the conoscopic method including the rarely considered general case of arbitrary orientation of the optical axis (axes) tilt angle are needed.

In the present work we make theoretical calculations and perform direct experimental observations of the conoscopic patterns of a number of large-sized crystal boules in demand for birefringent devices.

2. Results and discussion

The equations of the isochromes based on the solution of the equation for the angle of refraction of the extraordinary ray derived without commonly adopted simplifications in [4] were used in this work. In the general case of an arbitrary orientation of the optical axis with respect to the surface the isochromes are described by curves of 4th order and higher. There is no room for a further consideration of the general case here which will be presented elsewhere. A practically important for the present particular case of the calculations of the effects of sample thickness d, angular aperture A, and refractive indices n_o, n_e on the conoscopic figures is given in figure 1.The modeling was limited by the case of 25 isochromes to restrict the computation time.

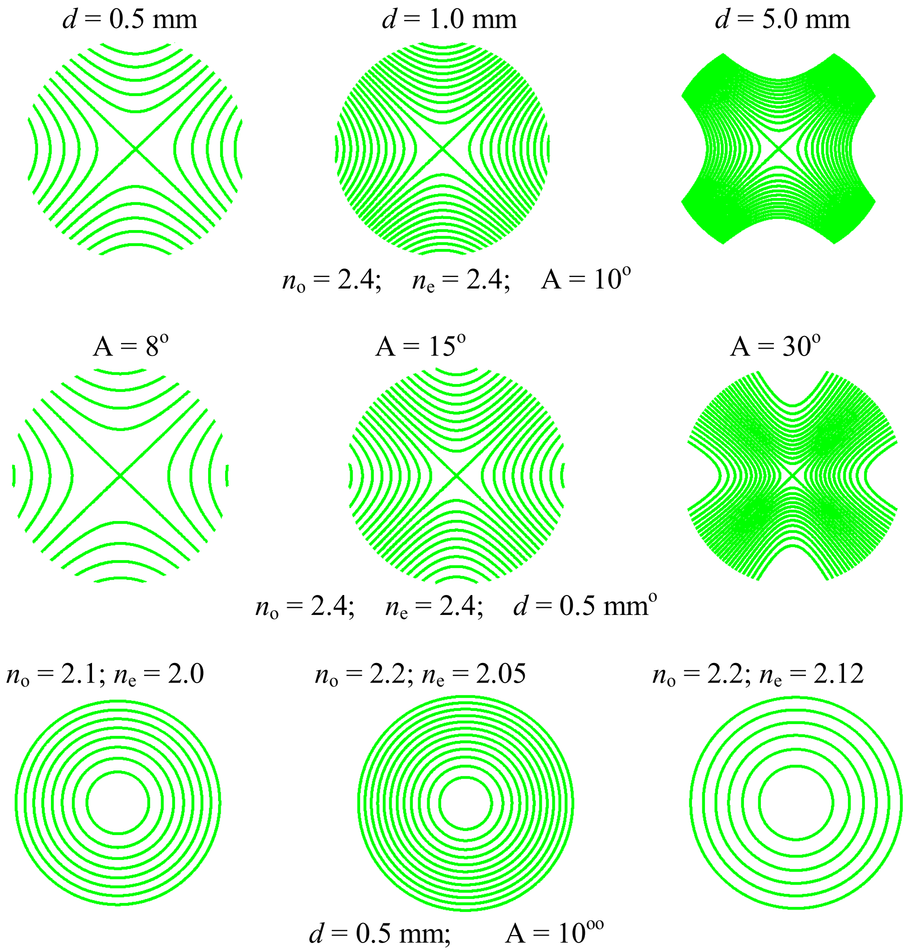

Figure 1. Effect of sample thickness d, angular aperture A, and refractive indices n_o, n_e variations on the conoscopic figures (calculation). Wavelength $\lambda = 500$ nm, focus length of lens 350 mm

A simple computer-based conoscopic benchtop tester was used in the experiment (figure 2). It consists of a source of monochromatic linearly polarized light (YAG:Na^{3+} with frequency doubling $\lambda = 533$ nm). Frosted glass filter served to expand the beam divergence and generate a smooth speckle pattern. The fringe pattern is collected on a projecting screen. It was also possible to get a converged beam with the aid of a lens of high numeric aperture for reducing the screen size and applying a CCD camera.

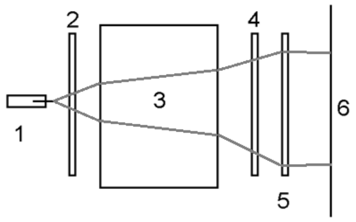

Figure 2. Basic outline of the conoscopic tester. 1 – laser source, 2 – polarizer, 3 – object (crystal), 4 – analyzer, 5 – lens, 6 – screen

Examples of the conoscopic figures obtained after quick check of several crystal bars are shown in figure 3-6. End faces of the samples were hand prepolished to enable the light transmission. It should be mentioned that with conoscopic studies the requirement for the nonparallelity of end faces is much softer compared with that of classical interferometers because in conoscopes the two (ordinary and extraordinary) beams travel along close directions in the crystal and pass similar optical paths [3].

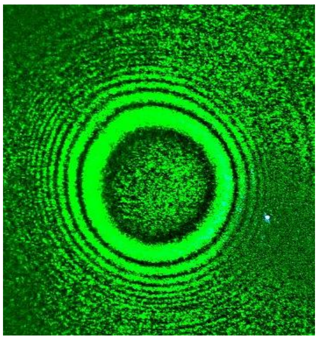

Figure 3. Conoscopic pattern produced by a polar cut of TeO_2 crystal in normal orientation

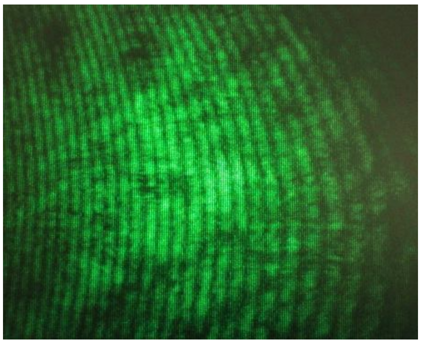

Figure 4. Conoscopic pattern produced by a TeO_2 crystal for an angle of 3° between the optical axis and light cone axis

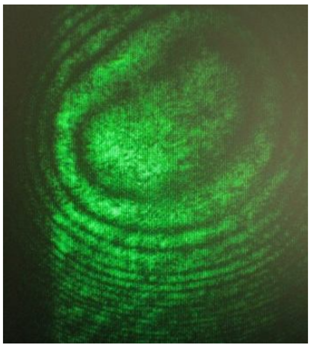

Figure 5. Conoscopic pattern distortion due to mechanical stresses at the edge of the sample

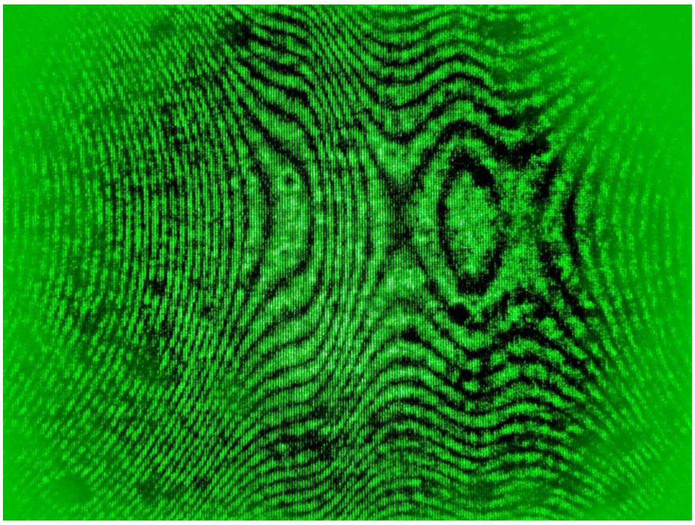

Figure 6. Effect of striations on the distortion of isochromate shapes in paratellurite crystal

Figures 3 and 4 demonstrate normal interference figures formed by a crystal region free of noticable defects. Among the least desirable defects of various types deteriorating the performance of birefringent devices are those affecting the values of refractive indices and/or their distribution in the volume of the material. They may be induced during the crystal growth process and post-growth heat treatments or by mechanical stresses arising in the course of cutting, polishing and assembling the optical components (figure 5). Local distortions of the isochromate shapes may be used for the estimation of $\Delta n = n_o - n_e$ variations, followed by the estimation of mechanical stresses δ_{ij} through the use of piezooptic coefficients $\pi_{\lambda\mu}$ and constants of elastic stiffness C_{ijkl}.

3. Conclusion

The analytical results of the earlier performed first-principle calculations of isochromate patterns in birefringent media were applied to the conoscopic examination of large-sized crystal boules unusable for examination in conventional polarizing optical microscopes with Bertrand lens. In the present work we have shown that the usage of convergent or divergent laser beams in simple benchtop configuration makes it possible to explore big samples by the method of conoscopy including crystals elongated in the optical axis direction. As distinct from traditional optical microscopy the conoscopic figures obtained with the aid of the laser installment may contain tens and hundreds of isochromate fringes, thus increasing the informative capabilities of the method. Large-sized crystals of $LiNbO_3$ (∅65×95 mm), $LiTaO_3$ (∅70×40 mm), TeO_2 prisms (50×50×30 mm) were examined experimentally at different angles between the optical axis and normal to the crystal surface. The capabilities of conoscopic observations as a fast contactless method for characterizing the quality of large boules for their potential use in optical instrumentation were demonstrated.

Among the advantages of using lasers to this end are their high intensity of illumination, monochromaticity and small angular aperture. However, a separate study of the ways of improving the laser beam uniformity and stability (pi-shapers [5], etc.) would increase the functional possibilities of the method. This would also be helpful for the development of computer-controlled scanning conoscope imaging system [3, 6].

References

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