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NON-ISOTROPIC LIGHT REFLECTION BY POLISHED SURFACES OF SINGLE-CRYSTALLINE OPTICAL ELEMENTS

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Abstract

A study is made of the laser optical reflection indicatrix peculiarities of highly polished paratellurite and germanium single crystals. Sharp maxima in the reflection indicatrix were observed at a distant screen in the form of bright narrow bands proceeding from the central normal reflection spot.The number and arrangement of these bands depend on the crystallographic orientation of the sample surfaces, laser beam incident angle and its direction with respect to the unit cell axes. It is shown that the observed features are correlated with the orientation of the cleavage planes of inclined nanosize (10-40 nm) ridges stipulating the reflections in accordance with the rules of geometrical optics.

Keywords: Light reflection, laser beams, paratellurite single crystals, germanium, cleavage planes, roughness parameters.

1. Introduction

Physics of laser crystals has been constantly developing since the invention of the laser in 1960 [1-4]. In the present work we focus our attention on a special problem of the effect of optical crystalline materials on the laser beam refraction indicatrix.

It was emphasized that the usual scattered refraction pattern observed at the screen may be accompanied by bright sharp bands running through the whole field of view in several directions. The light intensity of these features may exceed that of the background by orders of magnitude. Although these peculiarities were often mentioned by the researchers and opticians to date no reasonable explanation was given to this phenomenon. ws given By intuition, it was associated with laser beam nonideality, light polarization, crystal surface defects, speckles [1], properties of the projection screens, videocamera construction specific features, and even with the subjective perception of the observers.

2. Experiment

The surface of paratellurite and germanium single crystals of optical quality were polished to the finish class R II. The roughness parameters Ra were 15 and 22 nm, respectively. The crystal surface were initially examined with a metallographic microscope Axiovert 200 MAT, followed by AFM Solver P47 (in the contact mode in the regime of constant force of interaction), and with high resolution interference profilometer NanoMap1000WLI.

Scheme of the experimental setup for the observation of indicatrix pattern of the crystals is given in figure 1.

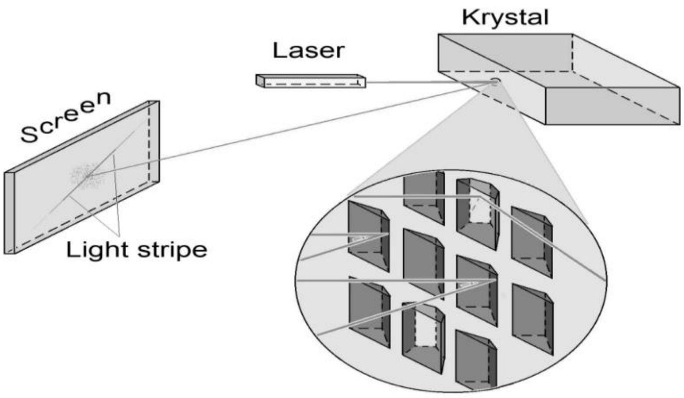

Figure 1: Scheme explaining the appearance of laser beam reflected by the crystal.

3. Results and discussion

During the starting experimental series, the crystals were rotated about the incident laser beam axis. The anomalous bands appear to rotate synchronously with the sample, so it became evident that the effect is related exclusively to the properties of the crystal.

Figure 2 presents the reflections produced by the polished surface of paratellurite crystal. Figure 2(a) corresponds to the plane (001) for which the cleavage planes are orthogonal, and, appropriately, the reflection bands are absent. Figures 2(b) and 2(c) are related to the reflection from the (110) plane forming an angle 45^o with respect to the cleavage plane {100}, when the reflection bands are observed at the screen. Figure 3 shows the reflection from germanium crystal with three bands associated with the reflections from the lower octahedron planes {111}, which are cleavage planes.

To understand the above results it may be recalled that that the crystals break along the cleavage planeswhich are {100} and {111} for paratellurite and germanium, respectively. The abrasive polishing is a continous process of consistent destruction of the highest bumps of the relief with the aid of suspension of abrasive microparticles. It is reasonable to assume that the smallest bumps will be presented by nanoscaled planes coinciding with the cleavage planes.In its turn, this will provide a condition for reflection of weakly divergent rays by some part of the total surface under study.

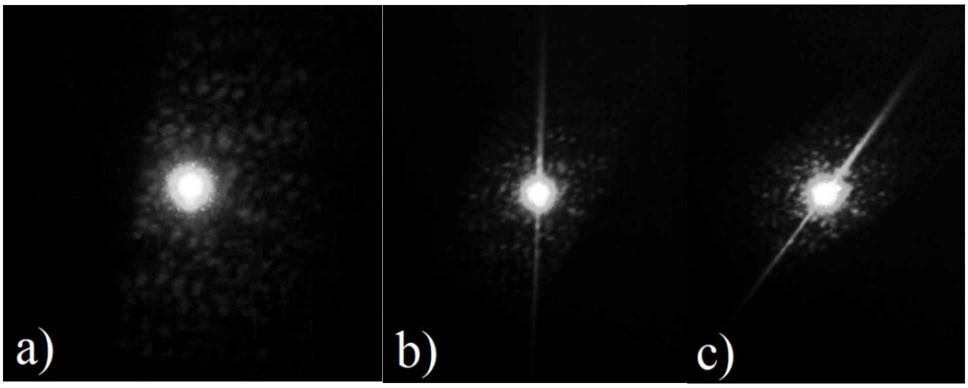

Figure 2 – Reflection of laser light with a wavelength of 533 nm from the (001) plane of paratellurite single crystal polished to surface finish class R II with the roughness parameter Ra = 15 nm (a), and from the plane (110) after rotation of the crystal. The observations were made at a distance of 7 m (b, c). The bands of reflection are elongated along the straight line [$\bar{1}$10].

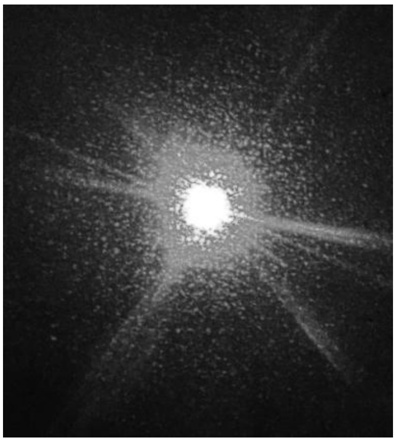

Figure 3 – Laser light reflection from the (111) plane of germanium polished to surface finish class R II with roughness parameter Ra = 22 nm as observed at a distance of 7 m. The reflection bands are elongated along three straight lines [1$\bar{1}\bar{1}$], [$\bar{1}$1$\bar{1}$], [$\bar{1}\bar{1}$1].

Figure 4. presents the 3D reconstruction of surface reliefs of the same crystals obtained by the method of AFM.

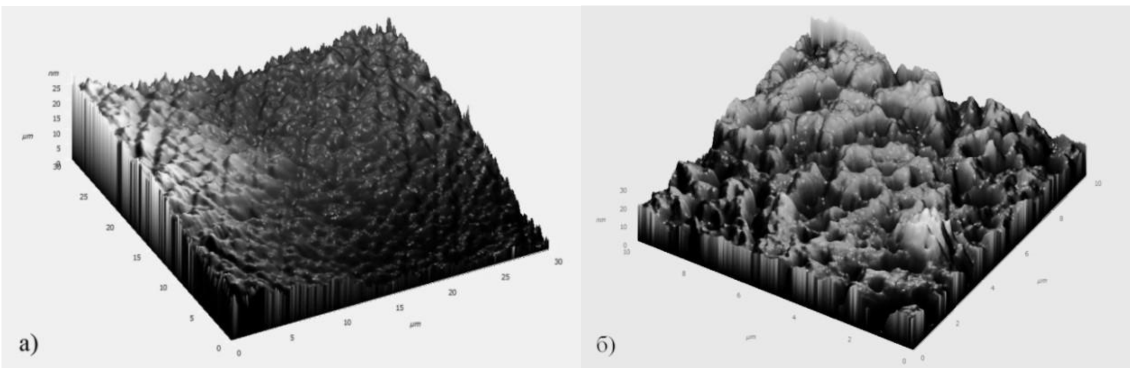

Figure 4 – 3D AFM reconstruction of polished surface of single crystals: (a) – paratellurite, plane (110); (b) – germanium, plane (111).

Similar pictures were obtained with the aid of interference profilometer supported with a special software providing the estimation of relief geometry, In this way we were able to find the average slope angles $\widehat{\varphi}_{TeO_2} = (45 \pm 0{,}5)°$ (when the average line profile coincides with $[1\bar{1}0]$ or $[\bar{1}10]$ directions), which agrees with the orientation of two of four paratellurite cleavage planes {100} with respect to (110) plane subjected to incident light. For germanium plane (111) $\widehat{\varphi}_{Ge} = (109\pm\ 0{,}5)°$ in agreement with the mutual layout of octahedron planes and cleavage planes of germanium {111}.

The nanoscale irregularities (10-20 nm) coincide by orientation with the paratellurite cleavage planes {100} and germanium {111}. Assuming the applicability of classical law of geometric reflection for areas tens of times smaller than wavelength, the multitude of these areas will give their contribution into the maxima of reflected light indicatrix.

4. Conclusions

Laser light reflections with sharp maxima in the form of bands elongated in the directions defined by the cleavage planes due to residual nanoscale irregularities were observed in paratellurite and germanium single crystals with highly polished surfaces. The observed effect correlates with the data given in the literature [1-4], including the assumption that the laws of geometric optics may be applicable to the case of irregularities small compared to the wavelength of light.

Acknowledgments

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