Effect of radiation with low degree coherence on the photoinduced light scattering excitation in lithium niobate crystals

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Abstract. Laser radiation with irregular wavefront erases noisy photorefractive gratings in lithium niobate crystals doped with iron. We investigated noisy photorefractive gratings recording and erasing via observing the photoinduced light scattering in LiNbO_3:Fe crystal. Also the effect of the incoherent light on the photoinduced light scattering excitation is considered in the paper.

1. Introduction
Lithium niobate (LiNbO_3) is a ferroelectric crystal with unique electro-optic, nonlinear optical and photorefractive properties [1–3]. LiNbO_3 crystal is convenient model material for studying some features of the holographic storage [4, 5]. One of the most interesting nonlinear optical effects in LiNbO_3 crystals is photoinduced light scattering (PILS). On the one hand, the PILS is a parasitical effect and may strongly limit the application of LiNbO_3 crystals [4]. On the other hand, an analysis of the PILS effect is additional tool for investigation the various properties of LiNbO_3 crystals [5–8].

PILS originates from diffraction of the incoming laser beam at parasitically recorded photorefractive gratings [9–13]. Recording of these gratings is a holographic process [14, 15]. So, the pump radiation must have a sufficient degree of coherence to excite PILS. The degree of coherence can be reduced by disturbance the regularity of the radiation wavefront.

There is very little information in the literature sources about role of the incoming laser beam wavefront in the PILS phenomenon. The possibility of the PILS excitation with laser radiation which has an irregular wavefront is investigated in the work. We also present the results of investigation the effect of incoherent radiation on the PILS in LiNbO_3 crystals.

2. Experimental setup
A diffuser formed an irregular wavefront of laser radiation. A glass plate with a matte surface was used as the diffuser. Laser radiation passed through the diffuser. So, its wavefront was randomly distorted. Laser speckles could be observed on the screen placed behind the diffuser. This pattern is typical only for a coherent radiation.

LiNbO_3 samples were x-cut plane-parallel crystal plates 1 – 1.5 mm thick. LiNbO_3:Fe crystals were used in the experiments.

We compared how two types of radiation effect on lithium niobate crystal: a laser beam without wavefront distortions and a laser beam which wavefront was randomly distorted with a diffuser.
Studies were made with two sources of laser radiation: at wavelengths of 0.53 μm and 0.63 μm. The experimental setup is shown in Fig. 1.

![Experimental setup](image)

**Figure 1.** Experimental setup; 1 – laser (wavelength 632.8 nm, power 60 mW), 2 – diffuser or light filters, 3 – collimator, 4 – convergent lens (focus length 94 mm), 5 – LiNbO$_3$ crystal, 6 – screen.

### 3. Experimental results

It was found that laser radiation which passed through a diffuser and focused into a LiNbO$_3$ crystal did not cause photoinduced light scattering.

To confirm this fact, a comparative experiment was made. The diffuser (together with the collimator) was replaced with a neutral light filter. Measurements of the radiation intensity at the output of the "light filter – convergent lens" system and at the output of the "diffuser – collimator – convergent lens" system were made. Measurements showed that the radiation intensity in experiment with a light filter was no higher than in experiment with a diffuser.

However PILS appeared when a light filter was installed instead of a diffuser. The scattering pattern was clearly observed on the screen and was photographically recorded. The scattering pattern had a clear structure (bright arcs were observed on the screen). The cone angle of the PILS increased during 7 – 8 minutes and then changing stopped.

It was also found that laser radiation with an irregular wavefront erases photorefractive gratings recorded in the crystal earlier.

When PILS is induced in a LiNbO$_3$ crystal and the pump radiation is turned off after some time, recorded noisy photorefractive gratings remain. If the pumping beam is again directed to the same point of the crystal and at the same angle, PILS appears instantly.

However, when recorded gratings in the crystal were illuminated with radiation which had an irregular wavefront, there was no instantaneous recovery of the PILS pattern after the pumping beam turning on. PILS appeared again in typical time for photorefractive gratings record under appropriate conditions.

Similar experiments were also made with a laser with a wavelength of 0.53 μm. The intensity of the radiation passed the diffuser was 6 times higher than the intensity of the radiation passed the light filter. Radiation with an irregular wavefront did not cause photoinduced light scattering, in contrast to radiation with a plane wavefront, which was attenuated by light filter.

Probably the experimental setup is more sensitive to its small oscillations for the case radiation with an irregular wavefront than for the case radiation with a regular wavefront. Due to these oscillations, the phase of the light wave randomly changes at every point of the illuminated area of the crystal. As a result, photorefractive gratings causing PILS cannot be recorded in the crystal.

Radiation with an irregular wavefront erases the photorefractive gratings for the same reason. The phase of the incoming wave and the phases of the waves diffracted at the gratings change randomly. For this reason, the light intensity distribution in an area with gratings changes randomly. Due to the photorefractive effect, the gratings are destroyed.

We used a LED emitting in the visible range (white light), with a power of 0.5 W in order to reveal the effect of incoherent radiation on the PILS process.
The LiNbO$_3$:Fe crystal for 30 minutes was only irradiated with a LED. Then the LED was turned off and laser radiation at a wavelength of 0.63 μm was focused into the crystal. It was found that in this case the rate of the PILS growth sharply increased compared with the case when the crystal was not irradiated preliminarily with the LED. The PILS pattern is shown in Fig.2.

**Figure 2.** PILS in a LiNbO$_3$:Fe crystal. Scattering pattern is elongated horizontally along the spontaneous polarization axis of the crystal.

The growth rate of the PILS can be estimated from the opening time of the scattering cone. The times of opening of the PILS cone are shown in Fig.3.

**Figure 3.** The opening times of the cone of PILS in an LiNbO$_3$:Fe crystal. Squares – without previous LED irradiation; triangles – with preliminary LED irradiation.

4. Conclusion
The effect of the laser beam wavefront irregularity on the noisy photorefractive gratings recording in LiNbO$_3$ crystals is investigated. It was found that laser radiation with an irregular wavefront is not able to record photorefractive gratings. This type of radiation erases photorefractive gratings that were recorded earlier in the crystal. That is attributed to the fact that radiation with an irregular wavefront loses the necessary degree of coherence for holograms recording due to the random oscillations in the experimental setup.
It can be assumed that prolonged irradiation of the crystal with a LED causes depletion of deep centers and charge transport to smaller traps. As a result, the rate of the noisy photorefractive gratings recording can increase.

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