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Study of photorefractive effect in crystals $Pb_5Ge_3O_{11}$:Cu and $Pb_5Ge_3O_{11}$

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Abstract. For the first time photorefractive properties of $Pb_5Ge_3O_{11}$:Cu were studied and compared with those of $Pb_5Ge_3O_{11}$ crystals. Diffraction efficiency of holographic grating registered on $Pb_5Ge_3O_{11}$:Cu and $Pb_5Ge_3O_{11}$ crystals was 2.5% and 2.2% for λ = 632.8 nm as well as 0.4% and 5.3% for λ = 496.5 nm, respectively. Amplification factor value measured at λ = 632.8 nm was found to be 1.14 cm^{-1} for $Pb_5Ge_3O_{11}$ and 2.43 cm^{-1} for Cu-doped $Pb_5Ge_3O_{11}$.

Keywords: photorefaction, holography, lead germanate.

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A possibility of existence of phororefractive effect in lead germanate was reported as far back as in [1]. Its varied characteristics were investigated intensively in [2,3]. In general, crystals of lead germanate have a natural domain structure and growth defects. A value of their spontaneous polarization also depends on conditions of their growing, presence of impurities, etc. [4]. Possibly because of the said reason phororefractive effect studying in lead germanate [5] was performed using a beforehand monodomained sample. Authors of [6,7] reported on observing phororefractive effect in non-monodomained doped crystals $Pb_5Ge_3O_{11}$:Cu and $Pb_5Ge_3O_{11}$:Nd. Photorefractive characteristics of $Pb_5Ge_3O_{11}$ and $(Pb_{1-x}Ba_x)Ge_3O_{11}$ are described in [8].

In our work, Cu-doped lead germanate crystals $Pb_5Ge_3O_{11}$:Cu were investigated, which contained 0.2 and 0.5 molar % Cu in blend. They were transparent crystals of green colour with pretty good optical quality, and were sliced in the form of plates with thicknesses of 3 mm and 3.5 mm. Non-doped crystals of lead germanate were transparent, pale-yellow, having pretty good optical quality. They were sliced in the form of plates with thicknesses of 3.5 and 3.7 mm. Crystals under investigation were not monodomained beforehand, and during the experiment external electrical field was not applied.

For studying photorefractive characteristics of named crystals the standard scheme of two wave interaction was used (Fig. 1).

A grating was recorded by radiation of an argon laser with the total intensity of two similar writing beams ~100 mw/mm^2. During this recording, intensities of input beams were checked. Along with it, the weak radiation of a helium-neon laser was used for indication of a grating refraction factor. Directions of the crystal spontaneous polarization vectors and an interference pattern coincided. The polarization vectors of writing beams were perpendicular to the plane of their convergence.

Crystals of lead germanate $Pb_5Ge_3O_{11}$ have shown photorefractive characteristics in beams of argon laser at wavelengths λ = 514.3 nm and λ = 496.5 nm. Diffraction efficiency of the recorded grating made 5.3%. Time of the grating decay (time of photoinduced recovery of the crystal), when reproducing the grating by one of the writing beams, made 2.5 s. Time of the crystal response (time required for writing the holographic grating) was equal to parts of second.

Crystal $Pb_5Ge_3O_{11}$:Cu containing Cu 0.2 molar % in blend has shown photorefractive characteristics at the wavelength λ = 496.5 nm. Diffraction efficiency of the grating refraction factor made 0,4%. When reproducing the grating by one of the writing beams, the time of grating decay was equal to 25 s. Thereby, at equal terms of creation and erase of grating, time of photoinduced recovery of crystal $Pb_5Ge_3O_{11}$:Cu by one of the writing beam differs from corresponding time for $Pb_5Ge_3O_{11}$ crystal by one order.

Time dependency of diffracted light intensity at the grating erase in $Pb_5Ge_3O_{11}$ and $Pb_5Ge_3O_{11}$:Cu crystals by one of the writing beams is plotted in the Fig. 2.

It is interesting that crystals $Pb_5Ge_3O_{11}$:Cu and $Pb_5Ge_3O_{11}$ show photorefractive characteristics in beams of helium-neon laser (λ = 632.8 nm) as well. Total in-

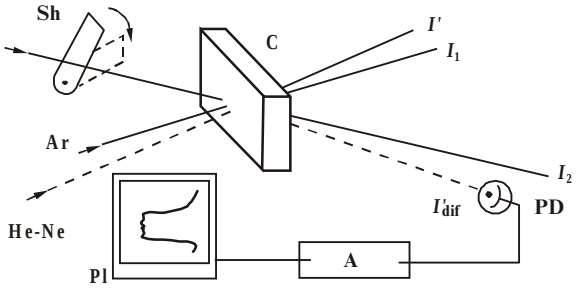

Fig. 1. Scheme of record and indication of hologram. C – sample of crystal, I_1,I_2 - writing beams of Ar laser, I', I'_{dif} – probe and diffracted beams of He-Ne laser, PD – photodetector, A – amplifier, Pl – plotter, Sh – shutter.

tensity of similar writing beams was fixed at a rate of 20 mW/mm^2. Diffraction efficiencies of refraction factor grating recorded in $Pb_5Ge_3O_{11}$ and $Pb_5Ge_3O_{11}$:Cu with the concentration of Cu 0.5 molar % in blend made accordingly 2.2% and 2.5% under beams interference angle being 20°. Time of crystal response depended on the interference angle of writing beams as well as the crystal axis orientation and varied from several seconds to several minutes. In general, so long-lasting time of response is not characteristic of photorefractive crystals (time of response of these material, when recording a grating by argon laser, made parts of second only).

At the wavelength $\lambda = 632.8$ nm, for each of two writing beams of an identical intensity, the amplification factor G was measured at two wave interaction. For its calculation, an expression from [5] was used:

$$\Gamma = \frac{1}{d} \ln \frac{I_{1,A} / I_{1,0}}{2 - I_{1,A} / I_{1,0}} \qquad (1)$$

where $I_{1,0}$ is an initial value of intensity of measured beam (second beam is shuttered), $I_{1,A}$ is an intensity of the same beam, when crystal is illuminated by two beams, d is the crystal thickness.

The amplification factor for the crystal $Pb_5Ge_3O_{11}$ is 1.14 cm^{-1}. Directions of interference grating vectors and spontaneous polarization of the crystal coincided in that case. Polarization vector of light beams was perpendicular to the plane of their entering. Interference angle of writing beams made 18°.

As to the sample $Pb_5Ge_3O_{11}$:Cu, energy exchange was not found for such a crystal placement. But in the case, when the axis of the crystal was perpendicular to the plane of beams convergence, a change of intensity of beams passed through the crystal was observed. Fig. 3 shows how the intensity of donor beam is changed in the course of time under such conditions. The amplification factor measured at interference angle of beams 16° was 2.43 cm^{-1}.

Duration of holographic grating existence depending on time of crystal illumination was also investigated at fixed intensity of writing beams.

When crystals were illuminated not very long (up to 5 min.), holograms recorded in such a way demonstrated constant diffraction efficiency and completely disappeared in the process of reproduction.

When crystals were illuminated during long-lasting time, the following phenomenon was observed. For the crystal $Pb_5Ge_3O_{11}$, a holographic grating recorded during two hours could not be erased by one of the writing beams within one hour. Left in dark, it was spontaneously erased for 15 hours approximately that differs it from that described in [5]. As to the crystal $Pb_5Ge_3O_{11}$:Cu, a grating recorded during two hours and more, under any orientation of the crystal could not be erased by one of the writing beam within one hour, and left in dark it did not decay for certain time. This characteristic of crystals can be used for the conservation of optical information for the certain time.

It is pertinent to note that in the case of short exposures certain dynamics of holographic grating characteristics is observed. So, when irradiating the crystals by two beams during approximately 40 seconds using the argon laser (Fig. 1) and approximately 2-3 minutes using the helium-neon laser and subsequently shuttering both writing beam, at first, diffracted beam went out, af-

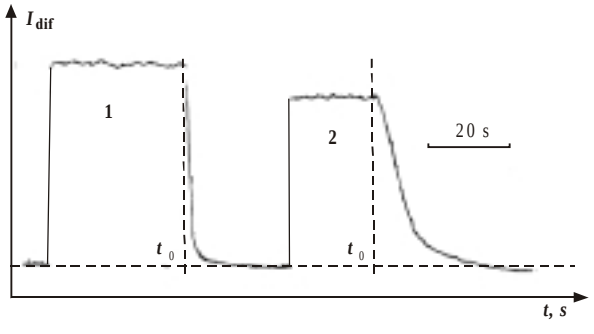

Fig. 2. Temporal dependency of diffracted beam intensity I'_{dif} for crystals $Pb_5Ge_3O_{11}$ (1) and $Pb_5Ge_3O_{11}$:Cu (2), t_0 is a moment of shuttering the reference beam.

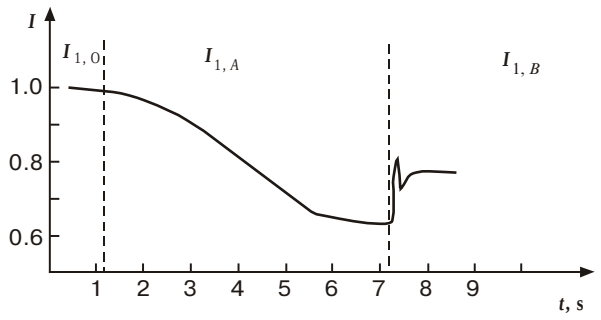

Fig. 3. Temporal dependency of donor beam I_1 when recording a holographic grating in crystal $Pb_5Ge_3O_{11}$:Cu : without reference beam ($I_1 = I_{1,0}$), with reference beam ($I_1 = I_{1,A}$), after a moment of shuttering the reference beam ($I_1 = I_{1,B}$).

Table1

№	Characteristic under investigation	$Pb_5Ge_3O_{11}$	$Pb_5Ge_3O_{11}$:Cu
1	Diffraction efficiency of holographic grating:		
	λ = 496.5 nm	5.3 %	0.4 %
	λ = 632.8 nm	2.2 %	2.5 %
2	Time of crystal response		
	λ = 496.5 nm	parts of second	parts of second
	λ =632.8 nm	seconds - minutes	seconds - minutes
3	Time of photoinduced reconstruction		
	λ = 496.5 nm	2.5 s	25 s
4	Amplification factor		
	λ = 632.8 nm	1.14 cm^{-1}	2.43 cm^{-1}
5	Length of existence of grating at exposure		
	during 2 hours	15 h	24 h

terwards lighted up and gradually went out again. If to shutter one of the writing beams, first, diffracted signal is not seen, afterwards it appears and gradually went out. Possible reason of this effect can be a simultaneous presence of varied types of traps and different types of charge carriers in the crystal, which have various physical parameters (mobility, life time, and etc.). This brings about superposition of holographic gratings having different temporal parameters and being non-correlated as to the phase.

In summary table, results displaying photorefractive characteristics of explored samples are represented.

Received results allow to state that crystals of non-doped lead germanate and Cu-doped ones are interesting objects for studying the physical processes in photorefractive crystals and for possible use in dynamic holographic schemes of optical information processing. Presently further studies of photorefractive characteristics of lead germanate crystals are carried out, in particular, of the neodymium-doped and lithium-doped ones.

References

1. P.V.Ionov, V.V.Voronov, V.T.Gabrielyan, Finding of photo-induced change of refraction in ferroelectric lead germanate (in Russian) // **17**, (4), p. 1144-1148 (1975).
2. N. Uchida, T. Saku, H. Iwasaki, Electro-optic properties of ferroelectric $5Pb{\cdot}3GeO_2$ single crystal // *J. Appl. Phys*. **43.** p. 4933-4936 (1972).
3. V.T.Gabrielyan, P.U.Ionov, K.A.Mikhailina, Growing and some characteristics of monocrystal $5Pb{\cdot}3GeO_2$ (in Russian)/ / *Crystallography* **19,** p. 176-178 (1974).
4. V.A.Kizel, V.I.Burkov, Gyrotropy of crystals (in Russian), «Nauka», Moscow (1980).
5. W. Krolikowski, M. Cronin-Golomb, Bo Su Chen, Photorefractive effect in ferroelectric lead germanate // *App. Phys. Let.* **57**(1) p. 7-9 (1990).
6. L. Pryadko, O. Gnatovsky, V. Linnik, T. Semenets, Photorefractive effect studying in crystals $Pb_5Ge_3O_{11}$:Cu, and $Pb_5Ge_3O_{11}$ // *Proc. SPIE* **2795,** p. 208-212 (1995).
7. L. Pryadko, O. Gnatovsky, V. Linnik, Z. Yanchook, Photorefractive effect studying in crystals $Pb_5Ge_3O_{11}$:Nd // *Proc. SPIE* **3488,** p. 259-261 (1997)
8. X. Yue, S. Mendricks, Y. Hu, H. Hesse, D. Kip, Photorefractive effect in doped $Pb_5Ge_3O_{11}$ and in $(Pb_{1-x}Ba_x)Ge_3O_{11}$. // *J. Appl. Phys.* **83,** p. 3473-3437 (1998).