Impact of rare-earth doping upon micro-periodical anisotropy

V.A. Smirnov[a], L.I. Vostrikova[a,b]

[a]Rzhanov Institute of Semiconductor Physics SB of RAS, Pr. Acad. Lavrentieva 13, Novosibirsk, Russia, 630090, vostrik@isp.nsc.ru

[b] Departments of Mathematics and Nature Sciences and Informational Technologies of NSUEM, Kamenskaya st. 52/1, Novosibirsk, Russia, 630099

ABSTRACT

The possibility for creation of the optical anisotropy with small periodicities up to nano-scale in amorphous materials is perspective in future for obtaining of different miniature elements for optoelectronics. In this paper the investigation results of the impact of rare-earth doping upon the process of the creation and also on the properties of the photo-induced micro-periodical anisotropy in different samples are presented. The influence of the variations of the chemical rare-earth components is analyzed and the physical mechanisms are discussed.

1. INTRODUCTION

By using the basic and double frequencies of a powerful YAG:Nd laser it is possible to form the modulations of the optical anisotropy inside the previously center-symmetrical isotropic amorphous mediums and to create corresponding long-lived photo-integrated spatially-periodic microstructures of the second-order susceptibilities ($\chi^{(2)}$ lattices)[1-17]. This photo-modification of the isotropic materials may be used for the manufacturing of new patterns of the laser frequency micro-scale converters in future. The occurrence of the anisotropy in the isotropic amorphous samples is considered as a formation of a spatially-periodical electric field owing to charges separation by an arising coherent photovoltaic current or as a local distribution of the charges with the formation of a long-lived static polarization. As a result, in an amorphous center-symmetrical isotropic medium in the photo-integrated second-order susceptibility there are possibility for an arising of the nonlinear three-wave interactions, such as the frequency conversion of light with the generation of the second harmonic and also the parametrical amplification of light. One of a basic task of the investigations is to create the samples on the base of the photo-integrated structures of the second-order susceptibilities which are perspective for the possible practical applications in different areas of laser physics, optoelectronics and may be also for biophotonics, in particular, for creation of the microscale converters of the coherent light radiations. Thus, it is necessary to receive the samples not only with high efficiency of radiation conversion on the photo-integrated anisotropy, but also with the long lifetime and stability to various kinds of influence.

In this paper the investigation results of the action of rare-earth elements on the process of the creation and also on the properties of the photo-induced micro-periodical anisotropy in different samples are presented. The influence of the variations of the chemical rare-earth components is analyzed and the physical mechanisms are discussed.

2. EXPERIMENTAL RESULTS AND DISCUSSION

As a rule the experimental set-up on base of a pulsed powerful YAG:Nd^{3+}-laser is used for the photo-modification of the different isotropic center-symmetrical materials with the creation of the photo-integrated spatial-periodic second-order susceptibilities ($\chi^{(2)}$ lattices) in samples by all-optical poling process. So, the basic and doubled frequencies of laser radiation are separated in space on two channels by use the optical elements and filters. Than the separated radiations are focused inside different investigated isotropic samples in a small some micron spot or inside a core of a fiber. YAG:Nd^{3+}-laser can be pulsed one with nano- or picoseconds so that in samples the intensity for the basic frequency radiation have the values in interval 0,5÷35 GW·cm^{-2} and for the doubled frequency radiation have the values in interval $3{\cdot}10^{-4}$÷2 GW·cm^{-2}. During this illumination of materials with use the powerful inter-coherent two-frequency radiation (in other words during the process of all-optical poling) the spatial-periodic electrostatic field E and, correspondingly, the photo-integrated micro-structure of the second-order susceptibility ($\chi^{(2)} \sim \chi^{(3)}E$) had been accumulating in region of the interaction of beams. The nonlinear three-wave conversions of light waves take place in investigated isotropic samples inside the accumulating second-order susceptibilities $\chi^{(2)}$. When only the basic frequency radiation falls on the photo-integrated microlattice $\chi^{(2)}$ then the process of the nonlinear doubling of light frequency (i.e. second-harmonic generation $P_{shg}(2\omega)$) is observed on it in experiment. The growth of signals of the light power of the photo-induced second harmonic generation $P_{shg}(2\omega)$ up to saturation is fixed on computer in real time.

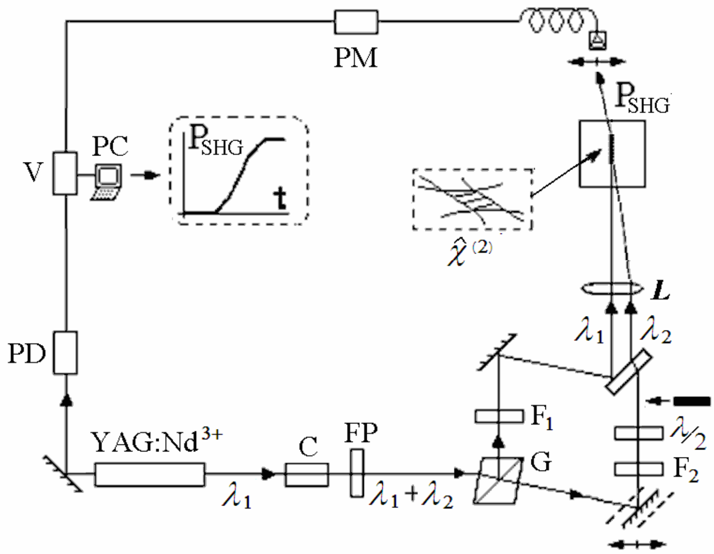

Figure 1. Experimental set-up used by us for investigations of light harmonic generation process in photo-integrated second-order susceptibilities $\chi^{(2)}$.

The obtained results of the investigations of the nonlinear light harmonic generation in the micro-structures of the second-order susceptibility ($\chi^{(2)} \sim \chi^{(3)}E$) photo-induced in various isotropic materials on the base of the silicate, germanium and phosphate glass matrixes with additional different small concentrations of the rare-earth elements from 0,02 up to 5,5% are presented in figure 1. Here η_g is the value of the maximal efficiency of the transformation of the basic frequency radiation into second-harmonic generation signal.

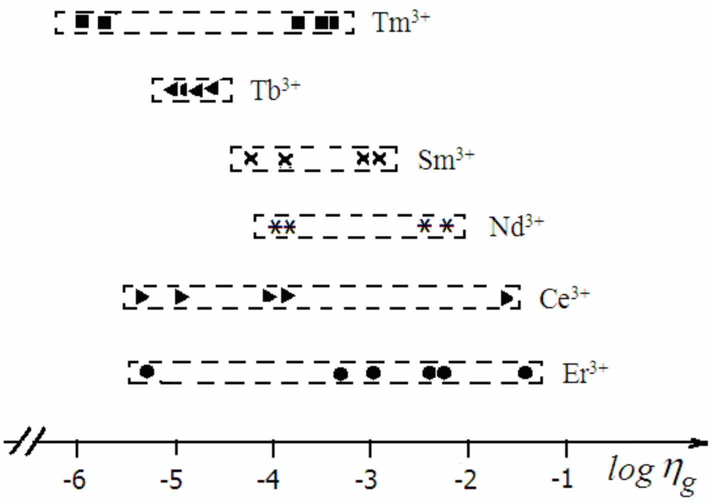

Figure 1. Experimental results of impact of different rare-earth elements

The performed experiments show that there are the sufficiently different efficiencies (up to some orders of values, see Figure 1) for the generation of the nonlinear second harmonic in the photo-induced micro-structures of the second-order susceptibility $\chi^{(2)}$ in different glass materials with containing additional rare-earth elements. The small concentrations rare-earth elements (Er^{3+}, Ce^{3+}, Nd^{3+}, Sm^{3+}) are effective additions. Some samples with sufficiently high values up to 10^{-2} have been obtained in glass mediums with content of small concentrations of rare-earth elements Er^{3+} and Ce^{3+}. The writing times for the photo-induced microlattices $\chi^{(2)}$ up to maximum saturation in different investigated samples are from some minutes up to some hours and the maximal obtained efficiencies correspond to the maximal writing times. On the base of the presented experimental results can be performed the comparative analysis of influence of chemical elements. The photo-induced microlattices of the second-order susceptibility $\chi^{(2)}$ can be used in future for creations of the broadband sources of the nonlinear harmonic generation for micro- and may be for nano-optoelectronics but in the materials containing rare-earth elements the additional investigations must be performed for obtaining more high efficiencies. Note, by us opinion for now the glass materials containing additional concentrations of rare-earth elements are seem the most perspective.

ACKNOWLEDGEMENTS

The authors are grateful to group of Prof. O.S. Schavelev, Vavilov General Optical Institute of Saint-Petersburg, and to group of Prof. V.V. Sokolov, Nikolaev Institute of Inorganic Chemistry SB RAS of Novosibirsk, for offered number of synthesized samples for our investigations. The work was supported by the Russian State Project No. 0306-2014-0019 "Coherent and nonlinear phenomena in homogeneous and structured media in their interaction with intense laser radiation".

REFERENCES

[1] Balakirev, M. K., Kityk, I. V., Smirnov, V. A., Vostrikova, L. I., Ebothe, J., “Anysotropy of the optical poling of glass,” Physical Review A 67, 023806-8 (2003).
[2] Dianov, E. M., Starodubov, D. S., “Photoinduced second-harmonic generation in centrosymmetrical mediums,” Quant. Electron. 22, 419-432 (1995).
[3] Antonyuk, B. P., “All optical poling of glasses,” Opt. Commun. 174, 427-429 (2000).
[4] N. Tsutsumi, K. Nakatani, ”$\chi^{(2)}$ polarization induced in molecular glass of conjugated compound by all-optical poling,” Opt. Commun., 259(2), 852-855 (2006).
[5] Hirao, K., Qian, G., Wang, M., et. al., “Second-order nonlinearity in bulk azodye-doped hybrid inorganic-organic materials by nonresonant all-optical poling,” Chem. Phys. Lett. 381, 677-682 (2003).
[6] Balakirev, M. K., Smirnov, V. A., Vostrikova, L. I., Entin, M. V., “Relaxation of the optical density of glass modulated with bi-chromatic radiation,” JETP Letters 63, 176-181 (1996).
[7] Balakirev, M. K., Smirnov, V. A., Vostrikova, L. I., “Photoinduced amplification of the subharmonic of light in oxide glass,” Opt. Commun. 178, 181-184 (2000).
[8] Daengngam, C., Heflin, J.R., Hofmann, M., Wang, A., Xu, Y., Liu, Z., “Demonstration of a cylindrically symmetric second-order nonlinear fiber with self-assembled organic surface layers,” Optics Express 19(11), 10326-10335 (2011).
[9] Kassab, L.R.P., Ozga, K., Slezak, A., Da Silva, D.M., Miedzinski, R., “Influence of gold nano-particles on optically stimulated in TeO_2–ZnO and GeO_2–PbO amorphous thin films,” Opt. Commun. 283(19), 3691-3694 (2010).
[10] Balakirev, M.K., Smirnov, V.A., Vostrikova, L.I., Kityk, I.V., Kasperczyk, W., Gruhn, J., “Giant increase of the second harmonic radiation’s absorption during optical poling of oxide glass,” Journal of Modern Optics 50(8), 1237-1244 (2003).
[11] Baskin, E. M., Entin, M. V., “Hopping mechanism of coherent photo-voltaic effect and photoinduced polar anisotropy in glass,” Proceedings of International Workshop in Chicago 19-22 May USA & Kluwer Academic Publishers London, 191-202 (1998).
[12] Bolshtjansky, M.A., Churikov, V.M., Kapitzky, Yu.E., Savchenko, A.Yu., Zel’dovich, B.Ya., “Polarization effects on induced $\chi^{(2)}$ tensor properties in bulk glass,” Pure Appl. Opt. 1, 289-293 (1992).
[13] Kopp, V.I., Mochalov, I.V., Nikonorov, N.V., Salahutdinov, I.F., ”Light-induced nonlinear second-order susceptibility in lead-silicate glasses and planar wavequides on their basis,” Bulletin of the USSR Academy of Sciences - Physics 58, 146-149 (1994).

[14] Valeev, A.I., Kundikova, N.D., Petrovsky, G.T., Churikov, V.M., Schavelev, K.O., Schavelev, O.S., Jakobson, N.A., ”New class of the glasses for the second-harmonic generation,” Journal of Optical Materials 68, 49-54 (2001).

[15] Huang, Z., Chen, A., Chen, Z., Deng, L., “Control of absorption and Kerr nonlinearity based on quantum coherence without driving field,” Modern Physics Letters B 24(30), 2921-2930 (2010).

[16] Odane, C., Tsutsumi, N., ”Phase-matched noncentrosymmetric polarization in a polymeric waveguide induced by all-optical poling,” JOSA B 20(7), 1514-1519 (2003).

[17] Liu, Y. L., Wang, W.J., Gao X.X., Zhang B.Y., Li, H., “Preparation and second-order nonlinearity of organic/inorganic hybrid materials doped with organic chromophore,” J. At. Mol. Sci. 2, 334-341 (2011).