Prolonged microlattices for generation of green light

Vitaly A. Smirnov\textsuperscript{a}, Liubov I. Vostrikova\textsuperscript{a,b}  
\textsuperscript{a}Rzhanov Institute of Semiconductor Physics SB of RAS, Pr. Acad. Lavrentieva 13, Novosibirsk, Russia, 630090; \textsuperscript{b}Novosibirsk State University of Economics and Management, Departments of Mathematics and Nature Sciences and Informational Technologies, Kamenskaya st. 52/1, Novosibirsk, Russia, 630099

ABSTRACT

The creation of new light elements for different microscopy tasks remains actual at present since there are the problems with obtaining of the micro- and nano-scale light sources for investigations of various small objects with high spatial resolution and also for coherent real-time control during the processes of the formations of the high-ordered molecular and atomic systems. In this paper the investigations of the frequency conversion with signal generation of the green light on the micro-scale lattices integrated in the volumetric isotropic mediums are presented. The possibilities for creating of the prolonged microlattices uniformly distributed in volumetric mediums are discussed. The properties of the roused anisotropy in some effective multi-component matrixes are considered and the potential influence of the different elements is compared.

Keywords: volumetric isotropic mediums, frequency conversion, prolonged microlattices, green light generation, multi-component matrixes.

1. INTRODUCTION

It is known that the modulations of an optical anisotropy inside the previously center-symmetrical isotropic mediums (glasses, polymer films, fibers etc.) can be created by using the multicomponent inter coherent powerful optical radiation\textsuperscript{1-19}. For example, the bi-chromatic components of YAG: Nd\textsuperscript{3+} laser are enough to create the long-lived photo-integrated spatially-periodic microstructures of the second-order susceptibilities ($\chi^{(2)}$ lattices). The occurrence of such optical anisotropy is considered as the formation of a stable distribution of the spatially-periodic electric field owing to charges separation by an arising coherent photovoltaic current\textsuperscript{17} or also as a local distribution of the charges with the formation of a long-lived static polarization\textsuperscript{16}. As a result, in the isotropic medium on photo-integrated $\chi^{(2)}$ lattices there are possibilities for the appearance of the three-wave interactions, such as the frequency conversion with the generation of the second harmonic (SHG)\textsuperscript{1,13} and the degenerate parametrical amplification of sub-harmonic of light\textsuperscript{18}.

The basic task of the investigations is to create the samples on the base of the photo-integrated structures which are perspective for the possible practical applications in different areas, in particular, for creation of converters of the light radiations and for manufacturing of new green light micro- and nano-scale sources. But, it is necessary to receive the samples not only with high efficiency of radiation conversion on photo-integrated modulations of optical anisotropy, but also with a long lifetime and stability of the integrated spatially-periodic microstructures to various kinds of inside influences. There are the problems also to receive the rather prolonged and uniform microlattices which are sufficiently broadband for the conversion of different frequency light signals.

In this paper the investigation of the frequency conversion with signal generation of green light on the micro-scale lattices integrated in volumetric isotropic mediums are presented. The attention is concentrated on complex analysis of samples with different chemical components. The possibilities for creating of the prolonged microlattices uniformly distributed in volumetric mediums are discussed. The properties of the roused anisotropy in some effective multi-component matrixes are considered and the influence of different elements is compared. The obtained investigation results are interesting in future for creation of different miniature elements for modern optoelectronics and photonics of molecular systems.

2. FORMATION OF PROLONGED MICROLATTICES

Consider the formation of the prolonged flat tape anisotropic microlattices in isotropic materials by using the special geometry of the interaction of the laser $\omega+2\omega$ bi-chromatic radiations. Let the light beams propagate due to formation of
microlattice inside a sample at small angles to the direction of the y axis, be practically unlimited along the x axis and have a Gaussian profile along the z axis:

$$E_1(r) = E_{10} \exp \left(-\frac{z^2}{2\omega_1^2}\right), \quad E_2(r) = E_{20} \exp \left(-\frac{z^2}{2\omega_2^2}\right), \quad (1)$$

where $w_1$ and $w_2$ are the radii of the beams of the used laser radiations at the half-maximum intensity level in the focal plane. This situation appears in the experiment upon focusing practically collimated beams by a cylindrical lens. By that the region with the induced micro periodical anisotropic lattice has the prolonged form of a thin extended band, see the geometry of the formation in figure 1.

![Figure 1. Geometry for the formation of prolonged anisotropic micro periodical lattice in sample by using the cylindrical optics with Hyper-Gaussian interacting beams.](image)

In this band geometry the expression for the coherent photovoltaic current described as:

$$j(r) = e_j E_{10} E_{20} \exp \left(-\frac{z^2}{2a^2}\right) \cos(\Delta k y), \quad (2)$$

where $a^2 = \frac{w_1^2 w_2^2}{2w_2^2 + w_1^2}$, $e_{jz} = \sigma_1 \cos z_1 \cos \phi_0 + \sigma_2 \cos z_2$, $e_{jx} = \sigma_1 \sin z_1 \cos \phi_0 + \sigma_2 \sin z_2$

Here $e_{jx}$ and $e_{jz}$ are the nonzero components, $\phi_0$ is the angle between the vectors $e_1$ and $e_2$, $\alpha_1$ and $\alpha_2$ are the angles between the vectors $e_1$ and $e_2$ and the $z$ axis, respectively, $\Delta k = 2k_1 - k_2$.

For convenience of the solution, the corresponding notations and dimensionless variables were introduced

$$i \rightarrow \frac{i}{a}, \quad (i = x, y, z), \quad j(r) \rightarrow \frac{j(r)}{E_0}, \quad (3)$$

Taking into account the periodicity of the current density, the solution for the electrical potential is sought for in the form $\phi(y,z) = \phi(z)\cos(\eta y)$ with the boundary conditions $\phi(z \rightarrow \infty) = 0$. The function $\phi(z)$ is found from the solution of this equation and has the form

$$\phi(z) = e_{jz} \sqrt{\frac{\pi}{8}} \exp\left(\frac{\eta^2}{2}\right) \left[\exp(-\eta z)\text{erf}\left(\frac{\eta - z}{\sqrt{2}}\right) - \exp(\eta z)\text{erf}\left(\frac{\eta + z}{\sqrt{2}}\right)\right], \quad (4)$$

$$\text{erf}(\xi) = \frac{2}{\sqrt{\pi}} \int_0^\infty \exp(-\zeta^2) d\zeta.$$
Note the following, for the typical experimental values $a = 1–50 \mu m$, which reflect the effective width of the region of interaction, and the modules of the inverse vector $\Delta k = 0.1 – 2 \mu m^{-1}$ of the induced lattice, we have $\eta = 0.1 – 10^2$. The lattices of a small size with a low number of periods correspond to low $\eta$. It is obvious that induced lattices obtained at relatively large values of $\eta$ are more high-contrast ones.

By our opinion, using the band geometry on the base of cylindrical optics for the formation of the photoinduced anisotropy lattices may be one of the perspective methodic to receive of the rather prolonged and uniform microlattices. In figure 2 the peculiarities of the formation of the anisotropy, which correspond to the induced electrical field by using band geometry, are shown.

Our performed calculations and corresponding investigations, shown that by using the cylindrical optics with Hyper-Gaussian geometry of interactions in volumetric materials there is the possibility to obtain the big size contrast anisotropic lattice’s micro-structures with the varied period (from ~ 40nm to 300nm), and in particular this allowed, by using the specific polarization perpendicular to Hyper-Gaussian profile, to receive rather uniform long (up to 1 cm) and extended flat tape anisotropic micro periodical structures, which are sufficiently broadband for the conversion of different frequency light signals. So, these long photo-induced micro-structures may be perspective in future for the creations of new light micro-sources for various microscopy devices and optoelectronics.

### 3. COMPARISON OF EFFECTIVE MATRIX WITH DIFFERENT ACTIVE ELEMENTS

Here we analyze the results of the investigations of frequency conversion with green light generation on the photo-integrated anisotropy (micro-scale $\chi^{(2)}$-lattices) in various mediums. The attention is concentrated on the results of the study of samples with different chemical components and properties of the induced anisotropy in a number of effective multi-component oxide and phosphate matrixes with the include of the lead-oxide, of the some elements of fourth and fifth groups and the rare-earth elements, which are more influencing on the process of the green light generation. We carry out the comparison of effective matrix with the different active elements.

So, now there are some sets of the synthesized matrixes chosen by sufficiently big efficiency on the base of performed investigations.

One of the sets contains multi-lead phosphate matrixes up to seventy percent of lead-meta-phosphate with containing the oxide additives of rare-earth elements (cerium, titan and niobium etc). It is known that the phosphate glasses have high beam stability and are perspective for creation of various laser elements with a high transparency in visible and near ultra-violet areas. The basic activator for growth of the efficiency of photo-induced green light signals in these media is the big content of lead oxide up to forty percent. It was observed that the lead-containing materials have the efficiency up to two orders of magnitude higher than the pure samples. The sufficiently big efficiency of green light generation $10^5$ has been observed in phosphate matrixes with containing about forty percent of lead oxide and some percent of activator as rare-earth cerium. So, there is an assumption, that the possible activators in glass matrixes can be various rare-earth and elements from of fourth and fifth groups. Therefore in our work, in effective volumetric samples from earlier investigated cerium-containing multi-lead phosphate materials, the influence of the additional activators from fourth and fifth groups (oxides of titanium and niobium) on properties of the photo-induced signal of green light generation on the integrated $\chi^{(2)}$ microlattices was investigated and the more high efficiency $10^4$ for these samples was obtained.
Other set contains the without-lead phosphate matrixes. In early investigations the green signal of the nonlinear photo-induced second harmonic generation on the integrated \(\chi^{(2)}\) microlattices had not been observed in these materials. But now we demonstrate the perspective of these samples. The most high effective medium is the without-lead alkaline glass on the basis of kali meta-phosphate (with concentrate of kali oxide about thirty percent) activated by oxides of niobium and antimonies. A special interest has also the investigation of the samples with the additions of rare-earth elements. Therefore, on the basis of new synthesized matrix of the without-lead phosphate, we investigated perspective samples with containing of the oxides of erbiun, therbium and gadolinium. One more set of investigated materials consists of the synthesized samples from silicate glasses including on the basis of the alkaline silicates. It was studied the influence of the input of the active additions of the oxides of cerium and titanium into the lead-silicate matrix with concentrations of silicon oxide about half the composition and of lead oxide between ten-fifteen percent. The without-lead matrixes, with content of silicon and zirconium oxides and with additional activators of some percent of germanium and cerium oxides were also interesting for investigations since these samples have practically zero signals of the luminescence by using the radiations of the ultra-violet and gamma regions. Therefore, the photo-integrated micro-scale \(\chi^{(2)}\) lattices with very long-lifetime can exist in such materials.

The performed experimental investigations have been shown that there are some of synthesized materials from various sets with photo-integrated micro-scale \(\chi^{(2)}\) lattices which can be perspective in future for the creations of green light micro-sources for various microscopy devices and optoelectronics. According to conclusion on the base of experimental results the more perspective media are the materials on the base of multi-component meta-phosphate matrix doped with some rare-earth elements and on the base of multi-compound oxide matrix with preliminarily suppressed ultra-violet and gamma luminescences. The times of the existence of the photo-integrated microlattices in such materials are the biggest ones at the present moment and the conversion efficiencies about \(10^{4}\cdot10^{5}\) are the greatest of reached values. The studied materials can be used for the further research to obtain of the lengthiest and sufficiently uniformly distributed photo-integrated microstructures so that to create the broadband microscopy sources and other tasks of optoelectronics.

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