Data of fully optical frequency doubling inside the volumes of glass plates

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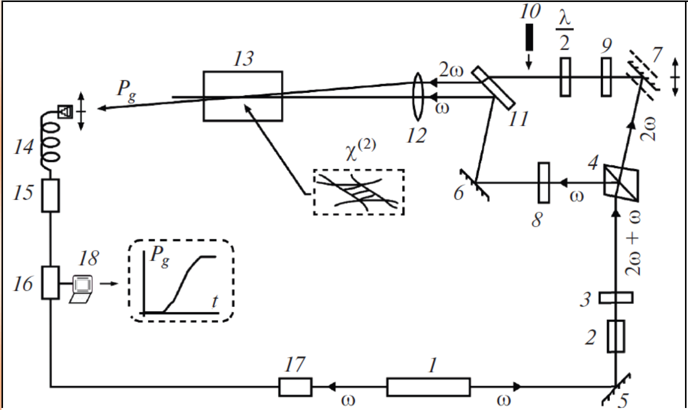
Comparative data of fully optical frequency doubling inside volumes of different glass plates are presented. Typical setup is shown in Fig.1. During illumination with use the powerful inter-coherent two-frequency radiation ω+2ω (as a result of coherent photovoltaic current or local reversible static polarization) inside isotropic mediums the spatial-periodic electrostatic field ***E*** arises and the corresponding photo-integrated micro-structure of second-order susceptibility accumulates in region of ω+2ω interaction:

$$\chi^{(2)}_{ijk}(2\Omega;\Omega,\Omega)=\chi^{(3)}(\boldsymbol{E}_i\delta_{jk}+2\boldsymbol{E}_k\delta_{ij}),\quad \chi^{(3)}=2\pi\chi^{(3)}_{iiii}(\Omega,\Omega,0).$$

The nonlinear three-wave conversions of light waves can took place in investigated isotropic samples on accumulating second-order susceptibility $\chi^{(2)}$. And here arising fully optical nonlinear frequency doubling process is analyzed.



For observe nonlinear process of fully optical frequency doubling, when writing microstructures of second-order susceptibility $\chi^{(2)}$ by laser radiations ω and 2ω up to saturation in different glass plates, incident radiation 2ω was periodically shuttered for several seconds at entrance to sample, and frequency doubling radiation P_g appears on induced $\chi^{(2)}$ as nonlinear transformation of basic frequency radiation. Peak power P_g is registered on PC in real time. Efficiency is $\eta_g=P_g/P_\omega$.

Fig. 1. Scheme of the experimental setup: (*1*) YAG:Nd^{3+} laser, (*2*) converter to the second harmonic based on a KTP crystal, (*3*) phase-shifting plate, (*4*) Glan prism with oblique faces, (*5–7*) mirrors, (*8*, *9*) filters for the radiations of the fundamental and doubled frequencies, (*10*) shutter, (*11*) polarization element, (*12*) lens, (*13*) sample, (*14*) light guide, (*15*) photomultiplier, (*16*) strobe voltage converter, (*17*) photodiode, and (*18*) computer.

Table 1 contains summary results of investigations of fully optical nonlinear frequency doubling in second-order susceptibilities $\chi^{(2)}$ photo-integrated in different volumetric glass materials. The lengths of interaction regions L in Table 1 have values less than 1 cm since the strong focusing of interacting beams in volume of samples was applied. The performed experiments show that there are sufficiently different efficiencies (up to some orders of values, see Table 1) for generation of nonlinear frequency doubling in photo-induced micro-structures of second-order susceptibility $\chi^{(2)}$ in glass materials containing different chemical elements. On base of presented experimental results can be performed comparative analysis of influence of chemical elements. So, some samples with sufficiently big values up to 10^{-4} have been obtained in glass media with content the concentrations of lead-oxide and rare-earth elements. The writing times for $\chi^{(2)}$ micro-structures up to maximum saturation in different investigated samples are some minutes. But lifetimes of photo-integrated $\chi^{(2)}$ micro-structures in all investigated volumetric glasses, see Table 1, are sufficiently small and this is basic task which must be solved in following researches. The photo-integrated $\chi^{(2)}$ micro-structures of second-order susceptibility can be used in future for creation of broad-band sources of nonlinear transformations for micro- and may be for nano-optoelectronics but additional investigations must be performed for obtaining as more high efficiencies as long lifetimes. The work was carried out as part of Russian State Task FWGW-2021-0012.

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Table 1. Data of fully optical frequency doubling inside the volumes of glass plates.

Chemical, mol.%	**d, μm L, cm**	**I_ω, GW/cm^2 $I_{2\omega}$, GW/cm^2**	**Laser data**	**t_w, min**	**t_d; t_ω; $t_{2\omega}$, min**	**η_g**
BS7 {45%PbO}	10 0,006	17 0,07	ML, QS	4	15 15 5	10^{-5}
BS7 {45%PbO}	10 0,006	30 2	ML, QS	5	120 15 -	10^{-6}
BS7 {66%$SiO_2$19%PbO}	50 0,05	7 0,05	ML, QS*	10	$2\cdot10^4$ - -	10^{-6}
JS4 {36%PbO}	5 0,002	50 1,2	ML, QS	10		$2\cdot10^{-6}$
JS4 {66%$SiO_2$16%PbO}	50 0,05	7 0,05	ML, QS*	10	$2\cdot10^4$ - -	10^{-6}
PS5 {55%PbO}	10 0,006	17 0,07	ML, QS	4.5		10^{-6}
PS5 {69%$SiO_2$26%PbO}	50 0,05	7 0,05	ML, QS*	10		$3\cdot10^{-8}$
SK5 {39%$SiO_2$40%BaO+ 15%$B_2O_3$5%Al_2O_3}	100 0,1	13 3	ML, QS	10	$3\cdot10^3$ - -	10^{-7}
F8{50,2%$SiO_2$39,7%PbO+ 3,8%Na_2O5,6%K_2O}	100 0,1	13 10^{-3}	ML, QS	10	60 - -	$5\cdot10^{-8}$
BS4	10 0,006	17 0,07	ML, QS	5		$8\cdot10^{-8}$
K8 {plate PM15}	10 0,006	17 10^{-6}	ML, QS	10	120 120 -	10^{-8}
K8 {74%SiO_2}	50 0,05	7 0,05	ML, QS*	10		10^{-9}
K8 {plate PM40}	260 0,7	4 0,4	PS*	40		10^{-8}
BS8 {55,7%PbO}	50 0,05	7 0,05	ML, QS*	10		10^{-8}
BS8 {63%$SiO_2$26%PbO}	50 0,05	7 0,05	ML, QS*	10		$3\cdot10^{-8}$
JZS19 {62%$SiO_2$35%PbO}	50 0,05	7 0,05	ML, QS*	10		$4\cdot10^{-8}$
HS24, S24 {crystallite}	50 0,05	7 0,05	ML, QS*	10		10^{-8}
BS3	10 0,006	17 0,07	ML, QS	5		$5\cdot10^{-9}$
JS18	20 0,01	1 $2\cdot10^{-3}$	ML, QS	3	- 0,05 -	$5\cdot10^{-9}$
JS18	5 0,001	50 1,2	ML, QS	3		$2\cdot10^{-9}$
BS12	10 0,006	17 0,07	ML, QS	5		10^{-9}
GeO_2(10÷40%)PbO	50 0,05	7 0,05	ML, QS*	10		10^{-8}
GeO_2(10÷50%)PbO	4,5 0,001	30 0,06	ML, QS	10		10^{-11}
$SiO_2$40%PbO	50 0,05	7 0,05	ML, QS*	10		10^{-8}
$SiO_2$3%GeO_2+0,5%P	90 0,1	50 0,8	ML, QS	30		$2\cdot10^{-7}$
$SiO_2$20,5%PbO16%Na_2O	50 0,05	7 0,05	ML, QS*	10		10^{-6}
$Pb(PO_3)_2$-$R(PO_3)_2$; R=Ca, Sr, Ba; {5÷40%PbO}	10 0,01	25 0,04	PS	60	100 60 -	10^{-6}
$SiO_2$20,5%PbO16%Na_2O+ (7÷22%)TiO_2	50 0,05	7 0,05	ML, QS*	10		$5\cdot10^{-6}$
$Pb(PO_3)_2Ba(PO_3)_2$ +1,5%CeO_2; {16%PbO}	10 0,01	35 0,05	PS	40	10^4 60 -	10^{-5}
$SiO_2$20,5%PbO16%Na_2O+ 6%$TiO_2$1,7%CeO_2	50 0,05	7 0,05	ML, QS*	10		10^{-4}
76%$Pb(PO_3)_2$5,5%CeO_2; {38%PbO;4%P_2O_5}	10 0,01	35 0,05	PS	30		10^{-4}

d, L - diameter and length of all-optically induced $\chi^{(2)}$; I_ω, $I_{2\omega}$ - intensities of incident radiations ω and 2ω; t_w - $\chi^{(2)}$ writing time, t_d -time of $\chi^{(2)}$ dark relaxation, t_ω - relaxation time in presence of radiation ω, $t_{2\omega}$ - relaxation time in presence of radiation 2ω; η_g - efficiency of process of fully optical frequency doubling on $\chi^{(2)}$ (photoinduced second harmonic generation); PS - pulsed YAG: Nd-laser, τ=30÷50ns, f=10Hz (τ - pulse length, f - repetition frequency); ML,QS - pulsed YAG: Nd mode-locked and q-switched laser, τ=100÷600ps, f=76÷125 MHz, t=200÷300ns, F=1÷6кHz (t - duration of bending around a set of impulses, F - frequency of repetition of a set of impulses); ML,QS* - τ=30ps, f=76MHz, t=60ns, F=12,5Hz; PS* - τ=10ns, f=12,5Hz; BS3, BS4, BS7, BS8, BS12, JS4, JC18, JZS19, PS5 - plates from set of optical filters (GOST-9411-81); SK5, K8 - crons, F8 - flint.