Distribution in channels for frequency doubling of laser radiation upon volumetric optical poling

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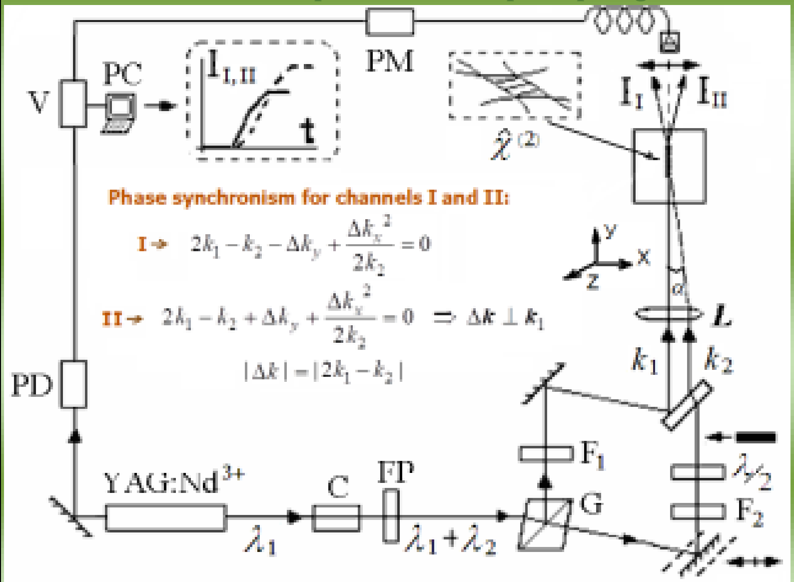
Different channel optical sources are important for studies of micro-objects and for applications in areas of the modern optoelectronics and bio-photonics. As a rule, various light micro-sources are necessary both for observe the sufficiently high spatial resolutions and also for the steady-stable coherent control in real-time during the process of organization of the high-ordered molecular systems. Experimental technique of the volumetric optical poling wherein gives possibilities for organization in isotropic mediums of the optically micro-structured elements with various properties which can be used for transformations and redistributions of pulsed light signals. In this work using the example of considering the nonlinear optical process of doubling the frequency of the pulsed laser radiation in case of the volumetric optical poling of isotropic medium it's shown the possibility for the simultaneous and phase-matched separation of output signals of light over the paired distribution channels. Optimal conditions for selection of beams of the light signals are analyzed and the spatial and other characteristics of the channel-by-channel transformation are investigated. The work was made as part of Russian State Project FWGW-2025-0012.

Set-up for investigations of per-channel frequency doubling of laser radiation upon volumetric optical poling



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

In experimental scheme there are the possibilities for observing of signals of the optical frequency doubling on the photo-induced micro-structures of the second-order susceptibility of χ(2) in two variants. In first case the signal is observed independently in channel I, and the phase-matched condition for synchronism exists automatically. In second case the signals can be observed simultaneously in channels I and II, and there is the phase-matched condition for synchronism also for channel II. The theoretical calculations have been made and corresponding characteristics have been obtained.

1. *Balakirev M.K., Kityk I.V., Smirnov V.A., Vostrikova L.I., Ebothe J. // Phys. Rev. A. 2003. V. 67. P. 023806-8.*
2. *Hickstein D.D., Carlson D.R., Kowligy A. et al.* // Nature Photonics. 2019. V. 13. P. 494.
3. *Vostrikova L.I., Kartashev I.A.* // Bull. Russ. Acad. Sci. Phys. 2024. V. 88. № 7. P. 1055.

Calculated equation for per-channel signals of optical fields of frequency doubled radiations upon volumetric optical poling

$$\boldsymbol{E}_{I,II}(\boldsymbol{r}) = \frac{\boldsymbol{A}\exp[-d_1\{2k_1 - k_2 \mp \Delta k_y + \Delta k_x^2/(2k_2)\}^2]}{\sqrt{f_1 f_2}\sqrt[4]{(1+D_1^2)(1+D_2^2)}}\exp[ik_2\gamma]\exp[-\frac{z^2}{4f_1(1+D_1^2)} - \frac{\tau^2}{4f_2(1+D_2^2)}]\times$$

$$\times\exp[-\frac{\tau(\gamma \pm \tau\Delta k_x/k_2)(f_3/f_2) + f_3^2 k_2^2}{4f_2(1+D_2^2)}]\exp[-ik_2\{\frac{\tau f_3/(2f_2) + (\gamma \pm \tau\Delta k_x/k_2)f_3^2/(8f_2^2)}{1+D_2^2}\}]\times$$

$$\times\exp[\frac{iz^2 D_1}{4f_1(1+D_1^2)} + \frac{i\tau^2 D_2}{4f_2(1+D_2^2)}]\exp[-i\,\mathrm{arctg}\{\frac{\sqrt{(1+D_1^2)(1+D_2^2)} + D_1 D_2 - 1}{D_1 + D_2}\}],$$

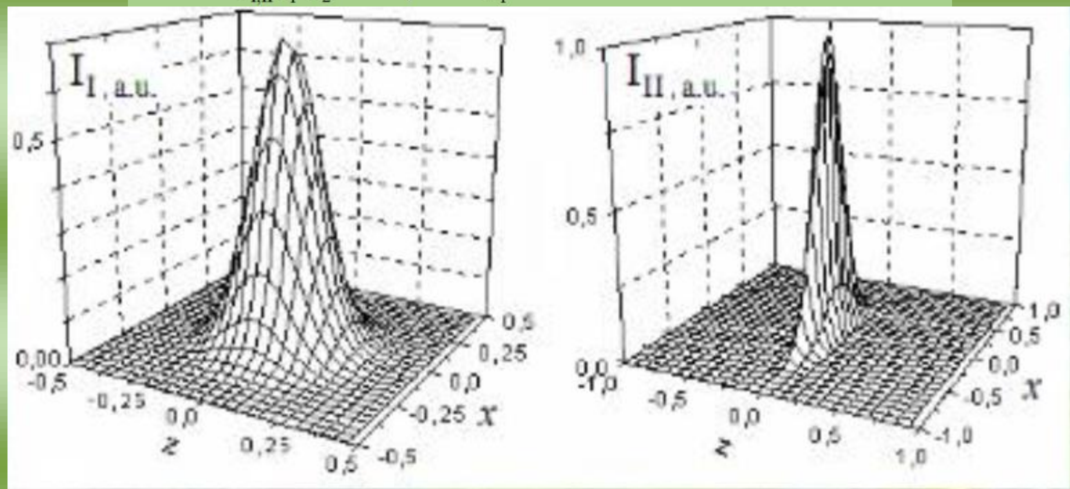
$$\boldsymbol{A} = \frac{(\chi_{ijk}^{(2)} \cdot\cdot \boldsymbol{E}_1\boldsymbol{E}_1) i k_2 \pi^2 a_1^3 e^{i\Delta\phi}}{2\sqrt{6\pi}\varepsilon_2 \sin\alpha},\quad f_1 = \frac{a_1^2}{12} + \frac{d_1}{k_2}(2k_1 - k_2 \mp \Delta k_y + \frac{\Delta k_x^2}{2k_2}),\quad f_2 = f_1 + d_1(d_2 \mp \frac{\Delta k_x}{k_2})^2,$$

$$f_3 = \frac{2d_1}{k_2}(d_2 \mp \frac{\Delta k_x}{k_2})(2k_1 - k_2 \mp \Delta k_y + \frac{\Delta k_x^2}{2k_2}),\ D_1 = \frac{y}{2k_2 f_1},\ D_2 = \frac{y}{2k_2 f_2},\ d_1 = \frac{3a_1^2}{8\sin^2\alpha},\ d_2 = \frac{\sin\alpha}{3},$$

$$\gamma = y(1 - \frac{\Delta k_x^2}{2k_2^2} - \frac{\Delta k_x^4}{8k_2^4}) \mp x\frac{\Delta k_x}{k_2},\quad \tau \approx x(1 - \frac{\Delta k_x^2}{2k_2^2}) \pm y\frac{\Delta k_x}{k_2},\quad \chi_{ijk}^{(2)} = \chi^{(3)}(\mathrm{E}_i\delta_{jk} + 2\mathrm{E}_k\delta_{ij}).$$

Nonlinear conversion efficiency for channels I and II:

$$\eta_{I,II} \approx \frac{24\pi^5}{b_{I,II} n_1^2 n_2}\frac{1}{c}(\frac{\chi^{(3)}E}{\lambda_1}L)^2\frac{P_1}{a_1^2},\quad b_I = \sqrt{3},\ b_{II} = 3,\ L \approx \frac{a_1(\sqrt{2}+2)}{\sin\alpha}.$$



Distributions of beam signals in channels I and II:

Exp. results: signal in channel II has more big value but 2D-distribution has asymmetrical view, tensoral characteristics are coincident with theory.

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