Optica Applicata, Vol. XXIV, No. 4, 1994

Limiting efficiency of self-organized second-harmonic generation in doped-glass fibres by self-saturation

P. CHMELA, J. PETRÁČEK

Institute of Physical Engineering, Technical University of Brno, Technická 2, 616 69 Brno, Czech Republic.

The self-saturation of self-organized second-harmonic generation in optical fibres, predicted by the directional photoionization model and the phenomenological cumulative local-response model, was verified by calculating the saturation value of the ratio $I_{2\omega}/I_{\omega}^2$ using experimental data of some previous experiments. It was found that the experimentally determined value of $(I_{2\omega}/I_{\omega}^2)_{sat}$ ranges from 0.2×10^{-16} to 2×10^{-16} m²/W, which is in a reasonable agreement with the predictions of the directional photoionization model.

The self-saturation of self-organized second-harmonic generation (SHG) in doped-glass fibres [1]–[3] has first been predicted by the directional photoionization model by ANDERSON *et al.* [4]. Though the directional photoionization model was found to be in a strong disagreement with the experiments on preparing optical fibres with the third exciting radiation [5], [6] and it also gives wrong predictions concerning the growth rate of self-organized SHG [7], [8], which is a consequence of the fact that it does not involve any memory mechanism [8], this model yields good predictions as for the saturation of the ratio $I_{2\omega}/I_{\omega}^2$ (I_{ω} and $I_{2\omega}$ being the light intensities of fundamental and second-harmonic radiation, respectively) [8]–[10].

The directional photoionization model is based on a spatially anisotropic ionizing transition rate that depends on the relative phase of fundamental and second-harmonic interacting fields. Considering two-, three-, and four-photon ionizing interference ANDERSON *et al.* [4] derived a new formula for the optically induced steady-state dc electric field in the picture of anisotropic excitation process. For the saturation value of the ratio $I_{2\omega}/I_{\omega}^2$ it follows from the directional photoionization model that

$$\left[\frac{I_{2\omega}}{I_{\omega}^2}\right]_{sat} = \left[\frac{\mu_0}{\varepsilon_0}\right]\frac{16 n_{2\omega} e^2 \varkappa}{n_{\omega}^2 \hbar \omega^3 m_e} \leqslant 10^{-16}\ \mathrm{m^2/W} \tag{1}$$

where ε_0 is the electric permittivity and μ_0 – magnetic permeability in SI units, n_{ω} and $n_{2\omega}$ are the refractive indices of fundamental and second-harmonic waves, ω is the frequency of fundamental field, e and m_e are the elementary charge and mass of the electron, respectively, $\hbar$ is the reduced Planck constant, and $\varkappa$ is a factor related to the ionized electron momentum which is less but of the order of unity.

The saturation of $I_{2\omega}/I_{\omega}^2$ has been predicted by the cumulative local-response phenomenological model [8] as well. It has been derived that

$$\left[\frac{I_{2\omega}}{I_{\omega}^{2}}\right]_{\mathrm{sat}}=\left[\frac{\mu_0}{\varepsilon_0}\right]^{1/2}\frac{2n_{2\omega}\chi_{\mathrm{sat}}^{(3)\mathrm{ind}}}{n_{\omega}^{2}\chi_{\mathrm{sat}}^{(1)\mathrm{ind}}}, \tag{2}$$

where $\chi_{\mathrm{sat}}^{(3)\mathrm{ind}}$ and $\chi_{\mathrm{sat}}^{(1)\mathrm{ind}}$ represent the optically induced third- and first-order effective susceptibilities in the saturation state describing the instantaneous two-photon absorption of fundamental radiation and one-photon emission of second-harmonic radiation, respectively. In fact, Eq. (2) implies nothing else than the energy conservation between two-photon absorption of fundamental radiation and one-photon emission of second-harmonic radiation in the saturation state. The numerical value of $(I_{2\omega}/I_{\omega}^{2})_{\mathrm{sat}}$ given by Eq. (1) can be revealed when considering a phenomenological analogy to the directional photoionization model [8].

The first attempt to verify experimentally the self-saturation of self-organized SHG, predicted by the directional photoionization model, was undertaken by DEMOUCHY and BOYER [9], who prepared Ge-doped and Er^{3+}-co-doped optical fibres with fundamental infrared and second-harmonic green seeding pulses of different powers and pulse durations. The saturation values of $I_{2\omega}/I_{\omega}^{2}$ reported by the authors of [9] are of the order from 10^{-7} to 10^{-5}. However, the units are not mentioned. Provided the authors used SI unit system, their experimentally measured values would be absurdly high. We are of the opinion that light intensities were confused with powers. If it were the case, it would be necessary to multiply the presented values by an effective cross-section area S_{eff}. Taking roughly $S_{\mathrm{eff}} \approx 10^{-11}$ m^2 we arrive at $(I_{2\omega}/I_{\omega}^{2})_{\mathrm{sat}} \approx 10^{-18}-10^{-16}$ m^2/W, which seems to be in a reasonable agreement with Eq. (1). Unfortunately, the contribution of second-harmonic seeding intensity to the total second-harmonic saturation light intensity was neglected. We are of the opinion that if the seeding intensities were included, a much better agreement of experimental results with Eq. (1) would be discovered.

In order to verify the saturation of the self-organized SHG, predicted by the theoretical models [4], [8], the saturation values of $I_{2\omega}/I_{\omega}^{2}$ for some former experiments on self-organized SHG with self-seeding and external seeding [1], [2], [11]–[14] were calculated in [10]. The calculated values of $(I_{2\omega}/I_{\omega}^{2})_{\mathrm{sat}}$ range from about 0.2×10^{-16} to 2×10^{-16} m^2/W. In our view the uncertainty within one order of the results obtained is dominantly caused by the inaccuracy of experimental data, especially of the radiation power propagating in the fibre core and the mode structure of interacting radiation. Maybe the saturation had not been reached in some experiments considered. We are of the opinion that more careful measurements will bring a better specification of the saturation value of $I_{2\omega}/I_{\omega}^{2}$. Anyhow, the obtained results manifest the saturation of self-organized SHG predicted by Eq. (1) clearly enough.

It seems that the self-saturation is a general feature of self-organized SHG in doped glass. The ratio $I_{2\omega}/I_{\omega}^{2}$ saturates almost at the same value being of the order 10^{-16} m^2/W irrespective of the light intensities of pump and second-harmonic seeding radiation, and even of the effective fibre length, which might substantially affect the further evolution of the research on self-organized nonlinear optical phenomena towards the parametric down conversion effects for example.

References

[1] ÖSTERBERG U., MARGULIS W., Opt. Lett. **11** (1986), 516; **12** (1987), 57.
[2] STOLEN R. H., TOM H. W. K., Opt. Lett. **12** (1987), 585.
[3] CHMELA P., [In] *Modern Nonlinear Optics*, Part 1, [Eds] M. W. Evans and S. Kielich, Wiley, New York 1993, p. 249.
[4] ANDERSON D. Z., MIZRAHI V., SPIE J. E., Opt. Lett. **16** (1991), 796.
[5] MARGULIS W., CARVALHO I. C. S., LESCHE B., Opt. Lett. **16** (1991), 1487.
[6] LAWANDY N. M., DRISCOL T. J., ADLER C. L., IEE Proc. J. **139** (1992), 133.
[7] DOMINIC V., FEINBERG J., Opt. Lett. **17** (1992), 1761.
[8] CHMELA P., PETRÁČEK J., ROMOLINI A., PASCUCCI T., FALCIAI R., Opt. Commun., to be published.
[9] DEMOUCHY G., BOYER G. R., Opt. Commun. **101** (1993), 385.
[10] CHMELA P., ROMOLINI A., PASCUCCI T., FALCIAI R., Opt. Lett., to be published.
[11] FARRIES M. C., RUSSEL P. S., PAYNE D. N., Electron. Lett. **23** (1987), 322.
[12] GABRIGUES J. M., FÉVRIER H., Opt. Lett. **12** (1987), 720.
[13] BATDORF B., KRAUTSCHIK C., ÖSTERBERG U., STEGEMAN G., LEITCH J. W., ROTGÉ J. R., MORSE T. F., Opt. Commun. **73** (1989), 393.
[14] DIANOV E. M., KORNIENKO L. S., RYBALTOVSKY A. O., CHERNOV R. V., YATSENKO YU. P., Opt. Lett. **19** (1994), 439.