Technical University of Denmark

Dispersive waves in fs cascaded second-harmonic generation

Bache, Morten; Bang, Ole; Krolikowski, Wieslaw; Wise, Frank W.

Published in:
Conference abstract series, CLEO/Europe - EQEC

Link to article, DOI:
10.1109/CLEOE-EQEC.2009.5196402

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

Dispersive waves in fs cascaded second-harmonic generation

Morten Bache[1], Ole Bang[1], Wieslaw Krolikowski[1,2] and Frank W. Wise[3]

1. DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

2. Research School of Physical Sciences and Engineering, Australian National University, Canberra ACT 0200, Australia

3. Department of Applied and Engineering Physics, Cornell University, Ithaca, New York 14853, USA

Optical solitons are nondispersive nonlinear waves that are supported through a balance between group-velocity dispersion (GVD) and nonlinearity. The so-called *dispersive waves* are linear waves phase-matched to these solitons, and are often found in supercontimuum generation [1, 2]. The dispersive wave wavelength can be predicted from a phase-matching condition to the solitonic wave [3]. This phase-matching point is often interpreted as being located where solitons are no longer supported, i.e. where the GVD changes sign. However, in reality the dispersive wave is found at the wavelength where the total dispersion of the generated soliton is changing sign.

Recently, we studied cascaded second-harmonic generation (SHG) for soliton compression of fs pulses and found numerical evidence of dispersive-wave formation [4]. For the setup used (a β-barium borate, BBO, nonlinear crystal set up for type I SHG pumped at $\lambda_1 = 1.06\ \mu$m) the dispersive waves were strongly red-shifted compared to the compressed ultra-short near-IR soliton, and this probably explains why they have not been observed before. We noted that they appeared around the wavelength where the total dispersion of the pump wave changed sign.

Here we study this phenomenon in further detail by modelling an intense fs pulse propagating in a quadratic nonlinear crystal, where phase mismatched (cascaded) SHG takes place. As the pump pulse propagates, a huge nonlinear phase shift – and thus a chirp – is created on it due to cascaded SHG. In presence of proper dispersion this strongly chirped pulse can through the soliton effect be compressed using to a duration of just a few cycles [4, 5]. The physics behind this is that the pump pulse may propagate as a Kerr-like soliton: if the cascaded SHG process has a negative phase mismatch $\Delta k = k_2 - 2k_1 < 0$, where $k_j = n_j(\omega)\omega/c$, then a self-focusing Kerr-like nonlinearity is created and solitons are therefore supported with anomalous GVD. However, if $\Delta k > 0$ the pump feels the cascaded SHG as a self-defocusing Kerr-like nonlinearity and solitons are supported with normal GVD.

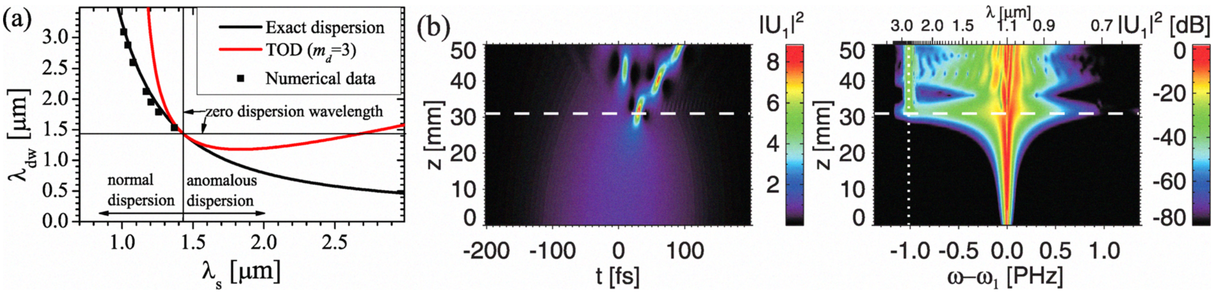

Fig. 1. (a) The calculated phase-matching curve showing the wavelength of the dispersive wave $\lambda_{\rm dw}$ vs. the soliton $\lambda_{\rm s}$ in a BBO nonlinear crystal. The effect of including only up to 3rd order dispersion is also shown. (b) Numerical simulation ($\lambda_1 = 1.1\ \mu$m, $T_{\rm in} = 200$ fs FWHM, $I_{\rm in} = 78\ {\rm GW/cm^2}$ and $\Delta k = 60\ {\rm mm^{-1}}$): the pulse compresses to 7.0 fs at the dashed line, and a dispersive wave appears close to the predicted wavelength (dotted line). The result of this and other numerical simulations with $\lambda_1 \in [1.03 - 1.40]\ \mu$m are shown in (a).

A dispersive wave can get phase matched to the compressed soliton at a wavelength determined by the zero point in frequency domain of the dispersion operator for the fundamental wave: $\sum_{m=2}^{m_d} \frac{(\omega-\omega_s)^m}{m!} \left(\frac{\partial^m k_1}{\partial \omega^m}\right)_{\omega=\omega_s}$, where m_d is the dispersion order. We plot this phase-matching condition for exact dispersion ($m_d = \infty$) and 3rd order dispersion ($m_d = 3$) in Fig. 1(a). It is evidently crucial to use exact dispersion. We also show the results of numerical simulations of a plane-wave model [4] with exact dispersion. We found dispersive waves phase-matched to the compressed few-cycle solitons with normal GVD ($\lambda_1 < 1.45\ \mu$m). These results confirm the analytical calculations. A simulation example is shown in (b), where a $\lambda_1 = 1.1\ \mu$m few-cycle soliton is generated after propagating 30 mm and then a dispersive wave appears close to the predicted $\lambda_{\rm dw} \simeq 2.70\ \mu$m. For $\lambda_1 > 1.45\ \mu$m the GVD of BBO is anomalous and solitons are therefore of the self-focusing kind. Such solitons would show highly distorted beam profiles due to self-focusing effects, and cannot be described by our plane-wave model.

References

[1] J. Herrmann *et al.*, "Experimental Evidence for Supercontinuum Generation by Fission of Higher-Order Solitons in Photonic Fibers," Phys. Rev. Lett. **88,** 173901 (2002).

[2] D. V. Skryabin *et al.*, "Soliton Self-Frequency Shift Cancellation in Photonic Crystal Fibers," Science **301,** 1705–1708 (2003).

[3] N. Akhmediev and M. Karlsson, "Cherenkov radiation emitted by solitons in optical fibers," Phys. Rev. A **51,** 2602–2607 (1995).

[4] M. Bache *et al.*, "Limits to compression with cascaded quadratic soliton compressors," Opt. Express **16,** 3273–3287 (2008).

[5] J. Moses and F. W. Wise, "Soliton compression in quadratic media: high-energy few-cycle pulses with a frequency-doubling crystal," Opt. Lett. **31,** 1881–1883 (2006).

978-1-4244-4080-1/09/$25.00 ©2009 IEEE