Generation of ultra-compressed solitons with a high tunable wavelength shift in Raman-inactive hollow-core photonic crystal fibers

Rodislav Driben [1,2] and Boris. A. Malomed [1]

[1] Department of Physical Electronics, Faculty of Engineering, Tel Aviv University, Tel Aviv 69978, Israel

[2] Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

Abstract:

The fission of N-solitons is a key mechanism leading to the supercontinuum generation and creation of hyper-compressed pulses and solitons featuring strong wavelength tuning [1, 2]. Recent advances in manufacturing PCFs filled with Raman-inactive gases [3] provide a strong motivation to focus the studies on the fission driven by the third-order dispersion (TOD) [4], and potential applications of this setting to photonics. In the absence of the Raman-induced self-frequency shift and the Raman-associated noise, fission-produced strongly compressed solitons, once generated, may propagate keeping constant internal frequencies. A higher-order N-soliton, $u = N\sqrt{P_0}sech(T/T_0)$ is launched into the fiber,where T_0 and $P_0$are width and peak power of the corresponding fundamental soliton.If theTOD dispersion β_3 is very small, it can be considered as a perturbation added to the second-order dispersion, β_2. In this case, the peak power of each fundamental soliton emerging after the splitting of the N-soliton is given by the classical result, $P_j = P_0(2N-2j+1)^2$ [5]. If δ_3 is larger, it leads to a significant increase in the largest fundamental-soliton's peak power and compression degree, along with the increase of the wavelength shift. However, further increase of β_3 leads to a loss of the peak-power enhancement. For optimal pulse compression and wavelength conversion, universal optimal value of TOD strength parameter $\delta_3 \equiv \beta_3/(6\beta_2 t_0)$ was found. This optimal value is valid for any pulse duration, second- and third-order dispersion coefficients, depending solely on order N of the injected soliton . The optimal pulse-compression degree significantly exceeds the well-known analytical prediction [5].

On the contrary to the insensitivity of the solitons' peak powers to the signs of δ_3, the wavelength upshift and downshift significantly differ for the opposite signs of δ_3. The downshift of strongest solitons wavelength is opposed by the proximity to the zero dispersion point of PCF, beyond which solitons cannot propagate. The highest order in Fig.1 is N =15. For still larger N, one can achieve even higher peak-power ratio and wavelength shift, but, due to interaction between multiple generated solitons and trapped dispersive waves [6, 7], the control over parameters of the emerging solitons deteriorates. The physical mechanism beyond the phenomenon, which is valid also in the presence of the self-steepening effect, is the power and momentum absorption by the strongest newly born soliton in the course of inelastic interactions with weaker pulses after the decomposition of the initial N-soliton [4,8].

References:

1. G. P. Agrawal, Nonlinear Fiber Optics, 4th ed. (Academic Press, 2007).
2. J. M. Dudley, G. Gentry, and S. Coen, "Supercontinuum generation in photonic crystal fiber," Rev. Mod. Phys.78, 1135-1184 (2006).
3. J. C. Travers, W. Chang, J. Nold, N. Y. Joly, and P. St. J. Russell " Ultrafast nonlinear optics in gas-filled hollow-core photonic crystal fibers ", JOSA B, Vol. 28, Issue 12, pp. A11-A26 (2011)
4. R. Driben, B.A. Malomed, D. V. Skryabin, and A. V. Yulin "N-soliton fission under the action of higher order dispersion via a cradle made of optical soliton," submitted to Optics Letters.
5. J. Satsuma and N. Yajima (1974), "Initial value problems of one-dimensional selfmodulation of nonlinear waves in dispersive media," Progr. Theoret. Phys. Suppl. 55, 284-306.
6. A. Efimov, A.V. Yulin, D.V. Skryabin, J.C. Knight, N. Joly, F.G.Omenetto, A.J. Taylor, P. Russel, "Interaction of an optical soliton with a dispersive wave," Phys. Rev. Lett., 95, 213902 (2005).
7. R. Driben, F. Mitschke, and N. Zhavoronkov" Cascaded interactions between Raman induced solitons and dispersive waves in photonic crystal fibers at the advanced stage of supercontinuum generation" Optics Express Vol. 18, pp. 25993-25998 (2010)
8. B. J. Hong and C. C. Yang, "Interactions between femtosecond solitons in optical fibers," J. Opt. Soc. Am. B 8(5), 1114-1121 (1991).