이중 펄스의 XPM 효과를 이용한 초연속스펙트럼 조절
Spectral Modulation of the Supercontinuum by the XPM Effect of Double Pulses

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Photonic crystal fibers (PCFs), whose cladding consists of a periodic array of air holes have been studied extensively for their unique properties and wide variety of applications over a decade(1). A high index contrast between the core and cladding of solid core PCFs , allowing for tighter mode confinement and higher optical intensity and the design freedom of PCFs, extending the range of optical parameters like dispersion and nonlinearity make it possible to generate supercontinuum (SC), which is characterized by the dramatic spectral broadening over an octave of intense light pulses. The extensive investigations of physical mechanism leading to SC generation for various input pulses and PCFs have been carried out experimentally and numerically. The SC light sources have found important applications in areas such as coherent Raman spectroscopy, frequency metrology, optical coherence tomography (OCT), and so on. Especially controlling the continuum generation to simultaneously achieve high power and broad bandwidth with small spectral modulation and low amplitude noise is of primary interest for OCT. Although the fs pulse is required to make broad spectrum, the output spectrum has large spectral modulation.

In this paper, we describe the simulation result of the supercontinuum with small spectral- modulation by the benefit of XPM-induced components between two same pulses with 0.5 ps temporal delay. The newly-born spectral components due to XPM effect fill the spectral gap in the spectrum to make spectrum smooth.

To study the role of the XPM effect of input pulses, we have numerically solved the generalized nonlinear Schrödinger equation (GNLSE)(2)

$$\frac{\partial A}{\partial z} = i\sum_{m\geq 2}\frac{i^m\beta_m}{m!}\frac{\partial^m A}{\partial t} + i\gamma\left[1+\frac{i}{\omega_0}\frac{\partial}{\partial t}\right]\left[A(z,t)\int_{-\infty}^{t}R(t')|A(z,t-t')|^2dt'\right] \quad (1)$$

, where $A(z,t)$ is the pulse envelope in a retarded time frame t moving with the group velocity of the pump pulse along the fiber axis z. The dispersion parameters β_m are estimated from a polynomial fit to the fiber dispersion profile, γ is the nonlinear parameter, ω_0 is the center angular frequency of the pump pulse, and $R(t')$ is the Raman response function. We consider an input pulse having a central angular frequency ω_0 and Gaussian shape : $A(0,T)=\sqrt{P_0}\exp(-\frac{T^2}{2T_0^2})$, $T=t-\frac{z}{v_g(\omega_0)}$

, where P_0 is the pulse peak power, $T_0 = T_{FWHM}/1.65$ and v_g is the group velocity at frequency ω_0 . The concerned PCFs here are the standard highly nonlinear PCFs which have only one zero dispersion wavelength (ZDW) at 800 nm.

Generally, in the first step of propagation the initial strong self-phase modulation effect due to the small group velocity dispersion (GVD) near the ZDW splits the incident pulse into two major parts after a few mm propagation. Two split pulses are in different dispersion regimes, respectively. At second, the split pulse in the anomalous regime forms the soliton by shedding waves and the other split part in the normal dispersion regime is disperse. As they propagate, the resonant dispersive wave (DW) is generated at the frequency phase-matched with soliton.

Figure 1 shows the evolution of the input pulses with temporal delay 0.5ps (see Fig. 1 (a)). Two pulses which are apart temporally generate the soliton and the DW which delay in parabolic shape at the center of ZDW (800 nm). The DW of pulse 1 is disperse and the part of the DW which is low group velocity has catched up with the soliton of pulse 2 at around propagation length of 5.76 cm (see Fig. 1 (b)). The XPM effect of the soliton of pulse 2 and the DW of pulse 1 leads to energy transfer into a new resonance, with a wavelength (690nm) lying between the soliton and the DW. The spectral component at 600 nm is induced by the XPM effect between the soliton of pulse 1 and the DW of pulse 1. The soliton of pulse 2, which losses more energy than the soliton of pulse 1 experiences weak SSRS, therefore the its frequency downshifts less than that of pulse 1 (see Fig. 1 (c)).

In conclusion, the two input pulses propagating with very close temporal delay experience the XPM effect to generate supercontinuum from 500 nm to 1200 nm with very small spectral modulation.

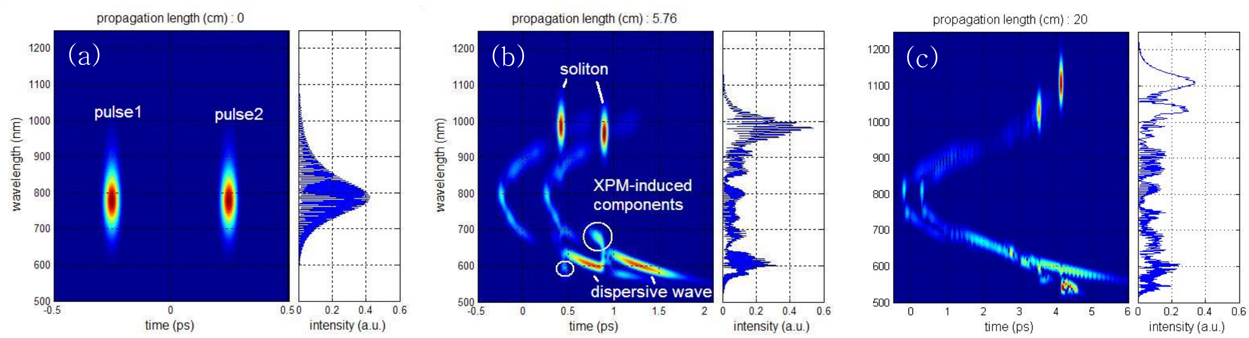

Fig. 1. Spectrograms of input pulses when P_0 = 38.3kW, T_{FWHM} = 10fs, ω_0=780nm, γ = 95[1/km·W], β_2 = 0.10 ps^2/km, β_3 = 10.4×10^{-2} ps^3/km, and β_4 = -1.18×10^{-6} ps^4/km .

1. J. C. Knight, T. A. Briks, P. St. J. Russell, D. M. Atkin, “All-silica single-mode optical fiber with photonic crystal cladding”, Opt. Lett. 21, 1547-1549 (1996).

2. G. P. Agrawal, “Nonlinear Fiber Optics”, 3rd ed. (Academic, San Diego, 2002).