Supercontinuum spatial gap solitons

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Advances in the generation of light with supercontinuum spectra in photonic-crystal fibers (PCFs) open new possibilities for a wide range of applications. PCFs allow for engineering of the spectral dispersion and confinement of light through the underlying periodicity of their structure. Periodic photonic structures also find applications for spatial beam control, however their use is primarily optimized for beam shaping and deflection in a narrow-frequency range. In this work, we predict theoretically and demonstrate experimentally novel possibilities for active control of supercontinuum light beams in nonlinear waveguide arrays. Whereas different colors are separated in the linear regime due to the strong spectral dispersion, we show that nonlinear interactions enable collective manipulation of amplitude and phase states of all spectral components through the formation of supercontinuum spatial gap solitons.

Fig. 1. (a-c) Calculated real-color intensity plots of supercontinuum light beams: (a) linear diffraction inside the waveguide array; (b) output beam profile vs. the input power; (c) soliton formation at high input power. (d) Output phase structure of individual frequency components corresponding to (c).

In the linear regime (at low optical powers), each spectral component exhibits typical discrete diffraction where most of the light is concentrated into the wings of the beam rather than in its center. Spectral dispersion leads to the separation of various colors among different channels of the waveguide array, as shown in Figs. 1(a) and 2(a). We demonstrate that collective manipulation of all colors becomes possible when spectral dispersion is compensated by nonlinear incoherent interactions between spectral components in photorefractive media through the optically-induced decreased of the optical refractive index. Although such a negative nonlinear response would result in self-defocusing and accelerated beam broadening in bulk media, the supercontinuum beam experiences sharp transition to self-trapping in a periodic waveguide array above a critical power level [Fig. 1(b)]. The formation of such self-localized gap solitons [Fig. 1(c) and 2(c)] becomes possible due to localization in the photonic bandgap\(^1\), when the dominating spectral components in the adjacent waveguides are out-of-phase [Fig. 1(d) and 2(d)], demonstrating nontrivial phase control of supercontinuum radiation. This represents a uniquely different phenomenon compared to the theoretically studied white-light lattice solitons in self-focusing media\(^2\).

References