# Observation of polychromatic gap solitons generated by supercontinuum light

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We present the first observation of simultaneous spatio-spectral localization and formation of a supercontinuum gap soliton in an optical waveguide array, demonstrating new possibilities for tunable reshaping of polychromatic light in nonlinear periodic photonic structures.

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Advances in the generation of light with supercontinuum spectra in photonic-crystal fibers open new possibilities for a wide range of applications including spectroscopy, tomography, and optical sensing[1]. High coherence and spectral brightness of the supercontinuum radiation makes it an attractive tool for characterizing the spectral properties of different bandgap structures including photonic crystals[2], where the material spectral dispersion is substantially modified by the periodicity. Furthermore, the high-peak intensity and average power of the supercontinuum radiation, not achievable with any other light source, enables enhanced light-matter interactions in the nonlinear regime[3].

In this work, we demonstrate experimentally novel possibilities for all-optical spatial switching and simultaneous spectral reshaping of supercontinuum light beams by the combined effect of material periodicity and nonlinear interaction of multiple colors in a nonlinear waveguide array. For the first time to our knowledge, we observe the simultaneous spatio-spectral localization of supercontinuum light and the formation of supercontinuum gap solitons. Our results provide a novel scheme for tunable reshaping of polychromatic beams by periodic photonic structures.

In our experiments, we generate supercontinuum light of ultra-broad spectrum [Fig. 1(a)] in a photonic-crystal fiber. The supercontinuum beam is then focused into a single channel of an array of optical waveguides (period $10\,\mu$m) [Fig. 1(b)] fabricated by Titanium indiffusion in a X-cut 55 mm long mono-crystal Lithium Niobate wafer. 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. The rate of diffraction is inversely proportional to the coupling length between the neighboring waveguides which varies in our experimental sample from 2.5 cm for blue to less than 1 cm for red spectral regions. As a result, the individual spectral components become redistributed among different channels of the array as shown in numerical simulations [Fig. 1(c)]. Experimentally registered diffracted light is shown in Fig. 2(a), and the corresponding spectrally resolved intensity distribution in each output channel (measured by a spectrometer) is shown in Fig. 2(e). We observe that the red components dominate in the wings of the beam, while the blue components are dominant in the central region of the beam. This effect is somewhat analogous to the superprism phenomena observed in photonic crystals.

At high laser powers, the spectral components start to interact with each other due to the intensity-dependent

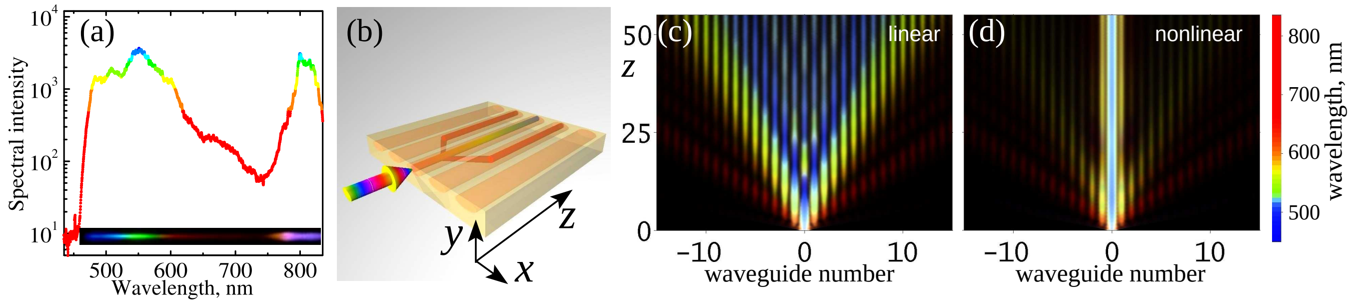

Fig. 1. (a) Spectrum of the generated supercontinuum. (b) Schematic of coupling of the supercontinuum to an array of optical waveguides. (c,d) Numerically calculated beam reshaping in the waveguide array: (c) polychromatic discrete diffraction in the linear regime, and (d) nonlinear self-trapping and the formation of a polychromatic gap soliton.

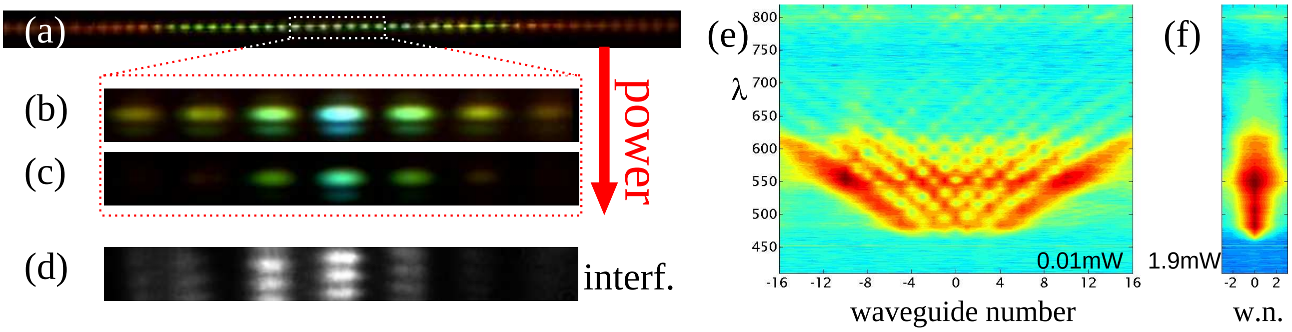

Fig. 2. Experimental observation of spatio-spectral supercontinuum beam reshaping in the nonlinear waveguide array: (a-c) Real-color CCD camera images of the output beam intensity profile: (a) Diffraction profile at low power; (b,c) Nonlinear localization with increasing supercontinuum power and formation of polychromatic gap soliton (c). (d) Interferogram of the output beam profile (c) and a reference supercontinuum beam, integrated over all spectral components. (e,f) Spectrally resolved measurements of the profiles (a) and (c), respectively.

change of the optical refractive index[4] through the photovoltaic effect. An important characteristic of the photovoltaic nonlinearity in Lithium Niobate is that an increase of the beam intensity leads to a local decrease of the material refractive index. Although such a negative nonlinear response would result in self-defocusing and accelerated beam broadening in bulk media, we show that the polychromatic beam can experience self-trapping in periodic waveguide arrays, as shown in the numerical simulations of Fig. 1(d). The formation of such self-localized beams becomes possible solely due to the Bragg scattering from the periodic modulations and the simultaneous localization of all spectral components in the photonic bandgap[5]. Hence, such localisation represents a uniquely different physical picture compared to the theoretically studied white-light solitons in lattices supported by a focusing nonlinearity[6].

We observe experimentally simultaneous dynamic spatio-spectral reshaping of the supercontinuum light as its input power is increased [Figs. 2(a-c)]. At certain input power the beam forms a polychromatic soliton which is localised into a single waveguide of the array when the power is high enough [Fig. 2(c)]. The important characteristic of this localization process is the fact that it combines all white-light wavelength components (from the blue to red) of the supercontinuum spectrum [Fig. 2(f)] and as such achieves suppression of the spatial dispersion in the nonlinear regime through the formation of a *polychromatic gap soliton*. We note that the existence of spatial gap solitons excited by monochromatic light relies on a special staggered phase structure[7] required for the efficient Bragg scattering. Taking advantage of high coherence of the supercontinuum light, we performed white-light interferometric measurement of the localized output profile. The observed interference pattern [Fig. 2(d)] reveals that the dominating spectral components in the adjacent waveguides are out-of-phase, providing an additional confirmation that the localized beam is indeed a *polychromatic gap soliton*.

The development of the well-defined staggered phase structure in different spectral components demonstrates an opportunity for nontrivial phase control of supercontinuum radiation, and distinguishes such nonlinear processes from the localisation of spatially incoherent sources[6]. This allows one to perform optically-tunable separation and mutual localization of different spectral components in a broad region. In particular, spatial phase correlations of the supercontinuum light become important when light is coupled close to a defect waveguide of the array. Experimentally, we induce a negative defect by forming a polychromatic gap soliton localised at a single waveguide. The defect can remain in the structure for a long period of time, which can be used to realize power-controlled filtering of the supercontinuum spectrum.

In conclusion, we have presented the first observation of polychromatic gap solitons in periodic photonic structures with defocusing nonlinearity. Such solitons form due to simultaneous spatio-spectral localization of supercontinuum radiation inside the photonic bandgaps. We anticipate that the demonstrated effects can be applied for tunable control of the wavelength dispersion for ultra-broad spectrum pulses offering additional functionality for laser mode-locking.

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