Normal dispersion supercontinuum reaching mid-infrared in silica microstructured optical fibers

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Abstract

Since the first observation of supercontinuum (SC) generation in borosilicate glass in 1970 [1], this process has been thoroughly investigated. It was shown that the large spectra broadening is obtained by pumping microstructured optical fiber close to zero dispersion wavelength [2]. Ultra-broad spectrum with uniform spectral energy density can be generated in an all-normal dispersion (ANDi) microstructured fiber [3]. However, to achieve effective supercontinuum generation in ANDi regime, it is beneficial to match the pump wavelength and the local maximum of dispersion curve [4]. The possibility of obtaining a generation of ANDi SC was analyzed by Hartung et al.[4], who showed that photonic fibers are characterized by high flexibility in modeling the location of the maximum dispersion. It was shown recently [5, 6], that a design combining microstructured silica cladding with Ge-doped silica core allows to generate a supercontinuum extending beyond 2.5 µm. The great advantage of this design is compatibily with telecommunication technology.
In this work we determine the optimal pumping conditions such as pulse peak power, central wavelength and duration for optimized microstructured fibers proposed in [7]. To study the influence of pumping parameters on the SC characteristics (its width and flatness) we use a self-developed software solving the generalized nonlinear Schrödinger equation (GNLSE) with the fourth-order Runge-Kutta in the Interaction Picture (RK4IP) method [8]. In the simulations, we assume the Raman response function as given by Stolen [9]. Additionally, we accounted for dispersion of effective mode area using the envelope normalization proposed by Laegsgaard [10] and loss. Our simulations show that ANDi SC generated in proposed fibers covers whole transparency window of silica glass.

Germanium doped silica MOFs

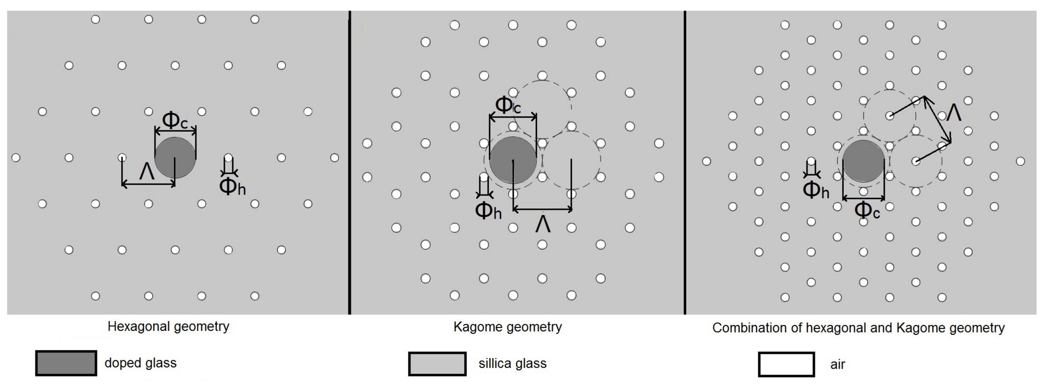

Figure 1. Cross-sections of the considered designs of microstrcutred silica fibers with germanium doped core surrounded of microsructured region of hexagonal symmetry, Kagome symmetry and combination of both [7].

Table 1. Optimal geometrical fibers' parameters assuring the broadest normal dispersion range [7]

core doping core diameter holes' layers N	hexagonal lattice		Kagome lattice		hybrid lattice	
	Λ [μm]	Φ_h [μm]	Λ [μm]	Φ_h [μm]	Λ [μm]	Φ_h [μm]
40 mol% $\Phi_c = 2.5$ μm $N = 3$	2.8	0.40	3.8	0.25	3.3	0.25
20 mol% $\Phi_c = 3$ μm $N = 3$	3.2	0.40	4.0	0.25	3.6	0.20

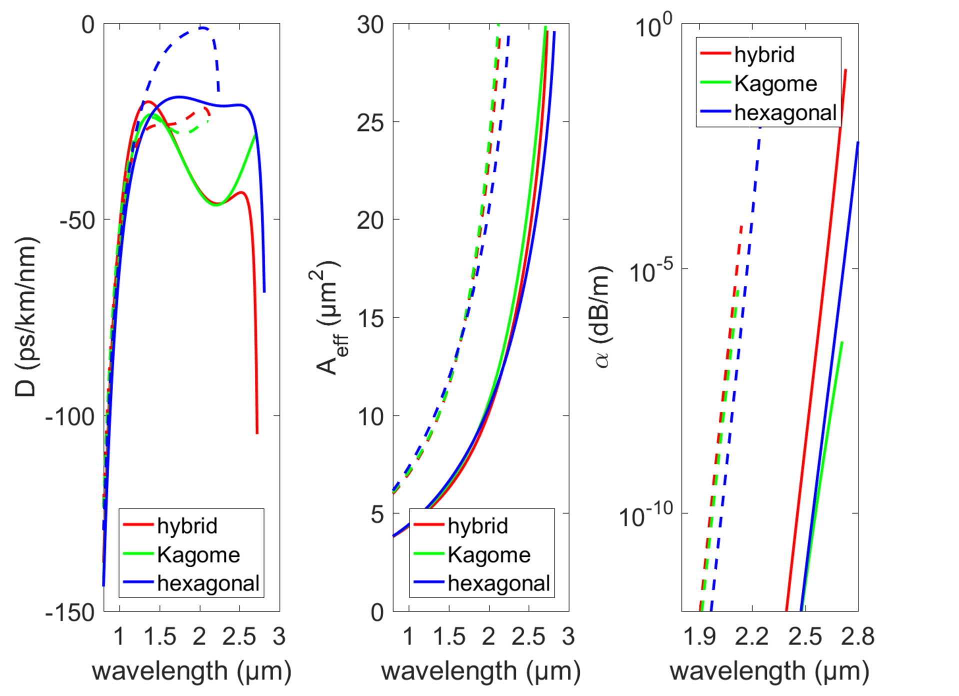

Figure 2. Calculated chromatic dispersion, effective mode area and confinement loss of optimized geometries for fixed doping level 20% mol (dashed) and 40% mol (solid) of GeO_2.

References

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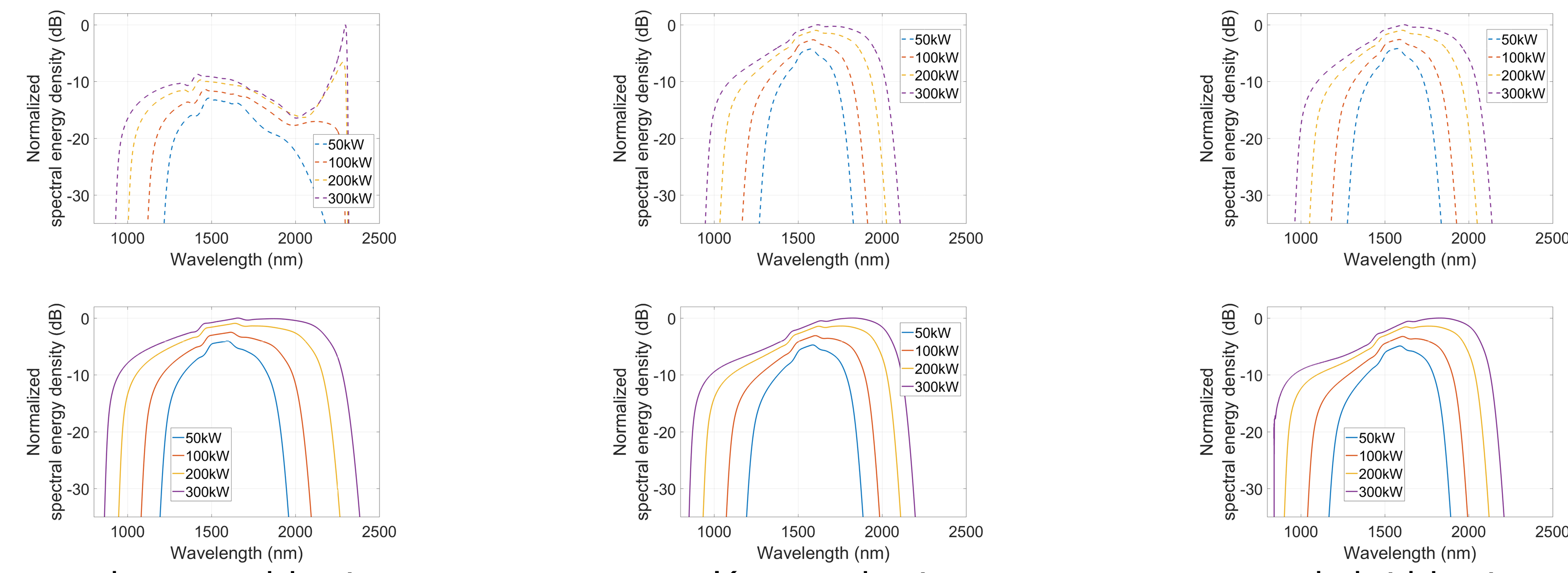
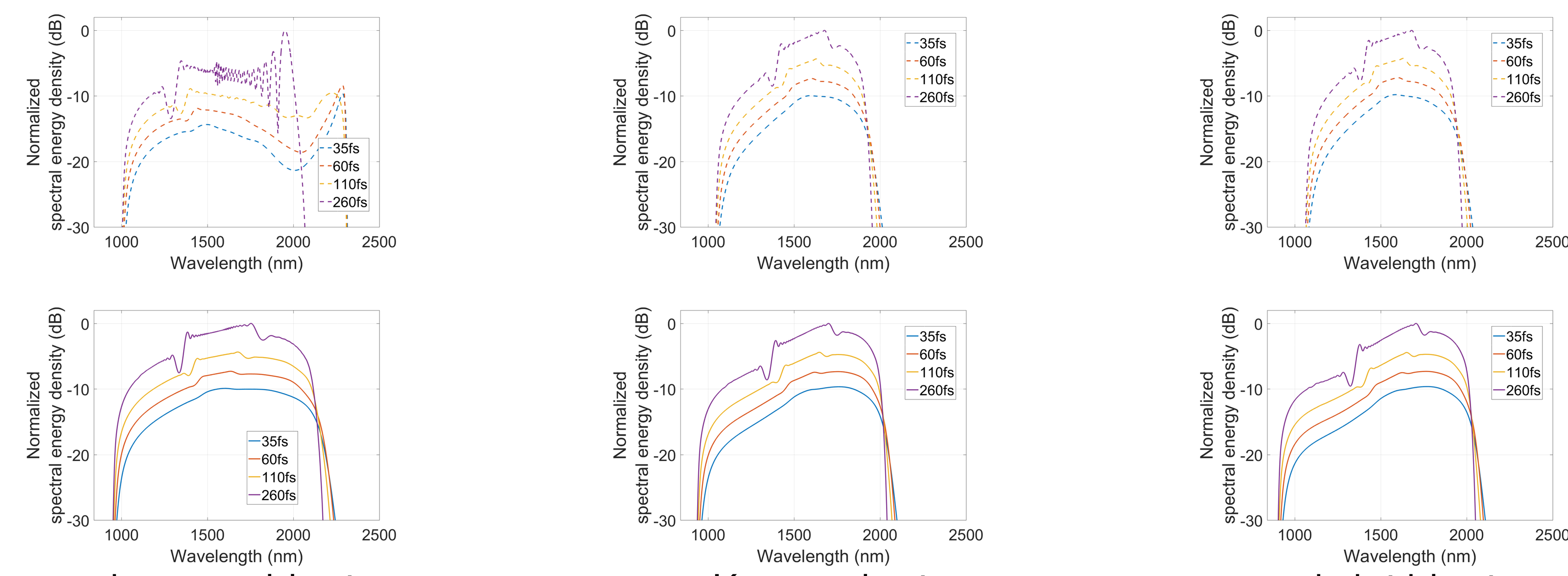
Supercontinuum generation – various pumping conditions



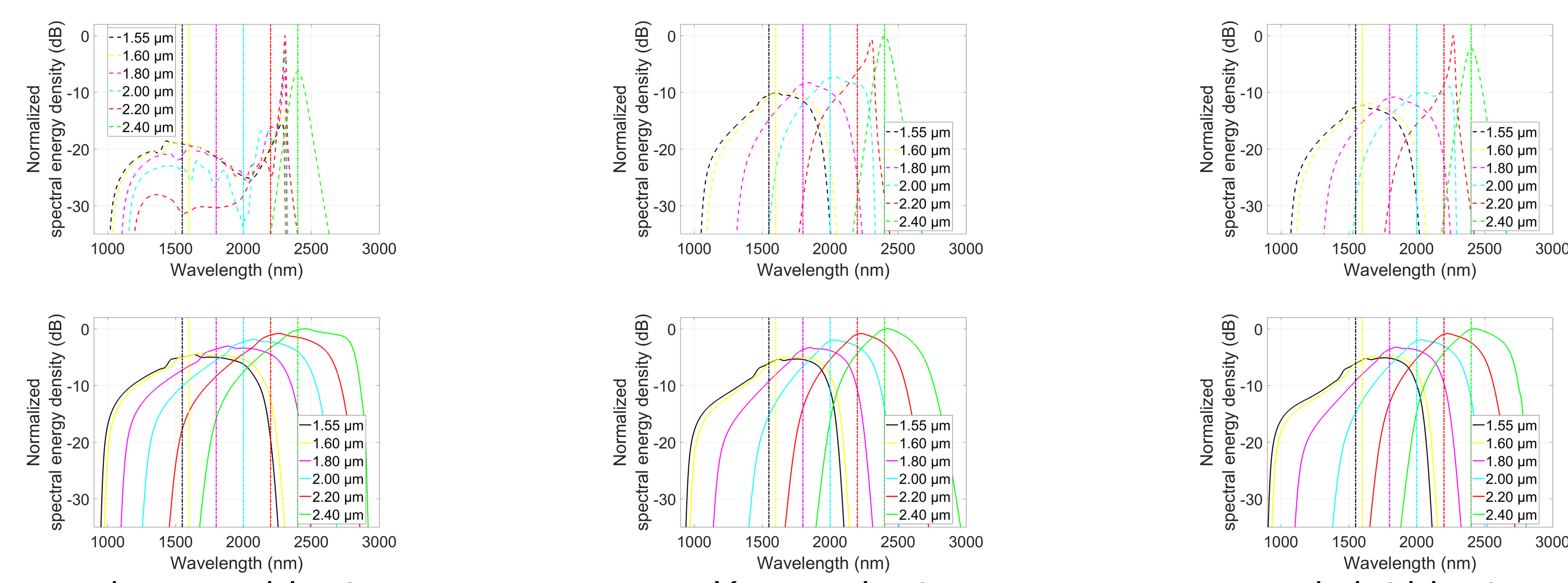
(a) hexagonal lattice (b) Kagome lattice (c) hybrid lattice

Figure 3. Normalized spectra for different initial pulse power P_{P} and duration $t_{\mathrm{FWHM}} = 65$ fs. SC was generated in the 20 cm long fiber with germanium doped core for fixed doping level 20% mol (dashed) and 40% mol (solid) surrounded by microstructured region of different symmetries.



(a) hexagonal lattice (b) Kagome lattice (c) hybrid lattice

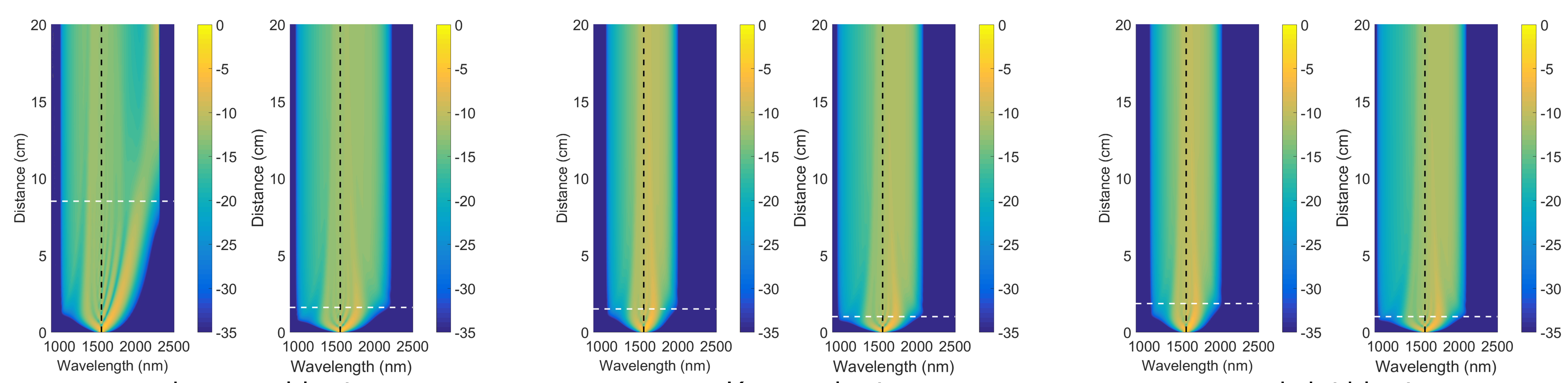
Figure 4. Normalized spectra for different initial pulse duration t_{FWHM} and peak power $P_{\mathrm{P}} = 200$ kW. SC was generated in the 20 cm long fiber with germanium doped core for fixed doping level 20% mol (dashed) and 40% mol (solid) surrounded by microstructured region of different symmetries.



(a) hexagonal lattice (b) Kagome lattice (c) hybrid lattice

Figure 5. Normalized spectra for different pump wavelength (indicated by vertical lines in corresponding colors). Simulation peak power is $P_{\mathrm{P}} = 200$ kW and duration $t_{\mathrm{FWHM}} = 65$ fs. SC was generated in the 20 cm long fiber with germanium doped core for fixed doping level 20% mol (dashed) and 40% mol (solid) surrounded by microstructured region of different symmetries.

Supercontinuum generation – spectral evolution over propagation distance



(a) hexagonal lattice (b) Kagome lattice (c) hybrid lattice

Figure 6. Simulated SC spectral evolution over propagation distance for different designs of microsructured region: hexagonal symmetry, Kagome symmetry and combination of both. Black dashed lines denote pumping wavelength and white dashed lines denote distances at which maximum spectral broadening is reached.