Mid-infrared supercontinuum generation in a SiN waveguide pumped at 1.55 micron

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Abstract: We report supercontinuum generation extending to 3.6 micron in silicon-nitride waveguides pumped by a commercial source at 1.55 micron. The span is a bandwidth record for the platform and demonstrates its potential as mid-infrared source.

OCIS codes: (190.4390) Nonlinear optics, integrated optics; (320.6629) Supercontinuum generation

Introduction

The recent development of supercontinuum (SC) sources have confirmed their potential as light sources in the mid-infrared region, where a number of molecules, relevant for sensing and spectroscopy, have their characteristic signatures. Efficient SC generation has been achieved in highly nonlinear and microstructures silica fibers [1]. However silica is not suitable for generation beyond 2.4 μm due to its excessive attenuation. To overcome this drawback, fluoride and chalcogenide fibers have been investigated [2,3]. Miniaturizing SC sources in integrated platforms represents a valuable approach to achieve very high mode confinement and nonlinearities, together with great flexibility in dispersion engineering. Pulsed laser broadening has been shown in different waveguide materials [4,5]. In particular, several demonstrations of incoherent and coherent SC generation based on low energy pulses have already been reported using ad hoc pump sources in SiN [6-9] which, among CMOS compatible devices, features the widest transparency region. Here, we report the generation of an extremely broad SC in a SiN waveguide extending over 400 THz from the visible to 3.6 μm. Pumped by a turn-key, commercial pulsed fiber source at telecom wavelengths the system not only represents, to the best of our knowledge, a record spectral broadening, but it demonstrates the great potential of SiN waveguides for broadband, high brightness mid-infrared sources based on compact and cost-effective components.

Experimental results and numerical simulations

The fully oxide cladded waveguide core is made of stoichiometric Si_3N_4, deposited via low-pressure vapor deposition, following the process flow described in [10]. The chip is 4.8 mm long, with inverse taper mode converters at both ends. The waveguide cross section is approximately rectangular, featuring a 1.7 μm width and a 0.87 μm height. The photonic Damascene process used here guarantees a crack-free thick nitride layer deposition and excellent core-cladding interfaces, resulting in low propagation losses, of the order of 0.2 dB/cm.

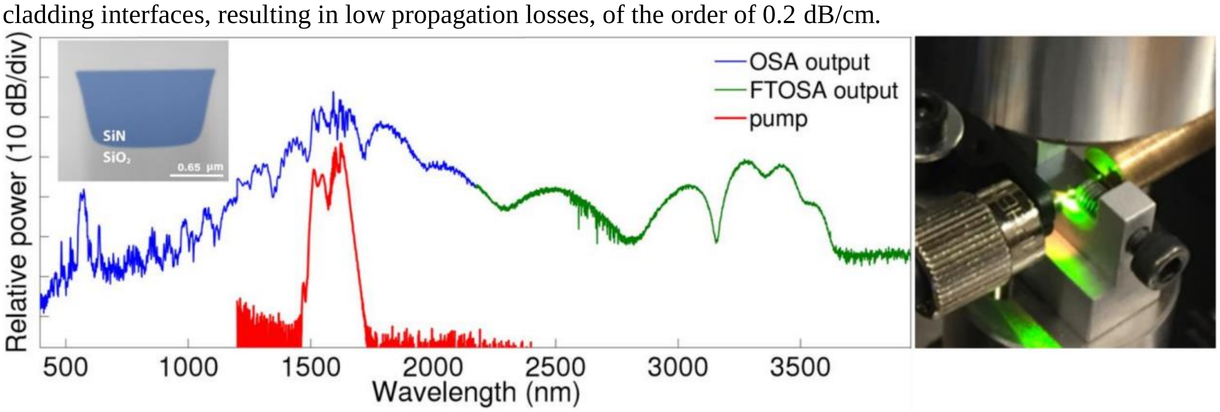

Fig. 1. Left: spectrum of the SC after the waveguide recorded with the OSAs and FTOSA, and spectrum of the pump at the input. The inset shows a SEM cross section of the waveguide. Right: picture of the setup during operation, showing the lensed fiber on the right side and the fluoride fiber on the left side.

The pump laser is a femtosecond erbium-doped fiber oscillator (ELMO from Menlo Systems), injected into the chip via a lensed fiber with a 50% coupling efficiency. A fiber polarization controller is used to launch the pump into the TM mode. The pulse train at the waveguide input has 100 MHz repetition rate, 130 fs duration at half maximum and an average power of 118 mW. Assuming a Gaussian pulse, a pulse energy of 0.6 nJ and a peak power of 4.2 kW are launched into the waveguide. At the chip output, light is collected by a polished, multimode fluoride fiber with a core diameter of 100 μm, a numerical aperture of 0.26 and a transparency window from 0.3 to 5.5 μm, providing 4 dB of out-coupling losses. The analysis of the SC is done via two optical spectrum analyzers (OSA) covering the 0.35-2.4 μm wavelength range, and a Fourier transform OSA (FTOSA) to resolve longer wavelengths.

The overall recorded spectrum is shown on Fig. 1(a) while the attenuated input laser spectrum is also shown (red). A total power of 16 mW is measured at the output of the fluoride fiber using a thermal power-meter. A significant broadening of the 1550 nm input pulse is observed, together with light generation up to -15 dB with respect to the pump level in the 3-3.5 μm range, and up to -25 dB in the green (530 nm). Water absorption lines are visible around 2.7 μm as the FTOSA was not purged for the experiment. Fig. 1(b) displays a picture of the actual transmission set-up, strong green and yellow light scattering is clearly visible under pumping operation. In order to determine the processes at play in this SC generation, numerical simulations were performed. The dispersion and confinement of the excited fundamental TM mode, shown in Fig. 2(a), are simulated using a FEM solver. Based on these values and the pulse properties specified above, the pulse spectral broadening is then simulated using a split-step Fourier solver of the nonlinear Schrödinger equation without including Raman terms. The results are shown in Fig. 2(b), from which one can infer that initially, the pulse broadening is solely based on self-phase modulation. Then, the pulse undergoes soliton fission. A soliton number larger than 30 is estimated, indicating incoherent broadening. The simulated short-wavelength dispersive wave explains well the experimentally observed spectral peaks around 530nm, and causes the spectral recoil of the main pulse. No second dispersive wave feature at longer wavelengths is observed, suggesting that the SC extension to the mid-infrared is not limited by dispersion. Moreover the simulated effective mode area beyond 3 μm (more than 6 μm^2) indicates that low confinement and substrate leakage, instead of dispersion and material losses, could be the limiting factors of the presented device.

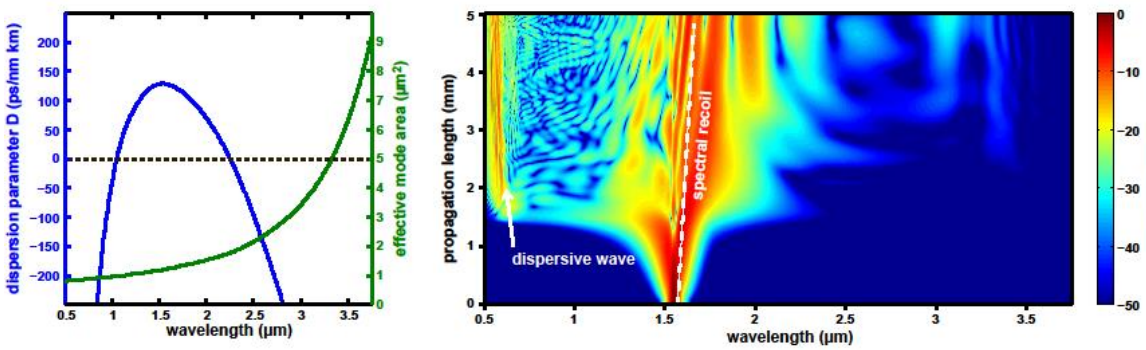

Fig. 2. Left: dispersion (blue) and effective area (green) as a function of wavelength for the fundamental TM mode. Right: evolution of the SC spectrum over the propagation distance.

These results demonstrate that extremely broad continuum extending deep into the MIR can be generated in very short, mass producible waveguides, pumped by a commercial, compact femtosecond laser at telecom wavelength. In the future, advanced waveguide designs offering higher confinement could enable further extension of the supercontinuum up to the material absorption limits.

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