Visible to Mid-infrared Supercontinuum Generation in 4H-Silicon-Carbide Nanophotonic Waveguides

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Abstract: Dispersion-engineered silicon-carbide waveguides generate dispersive waves at visible and mid-infrared wavelengths as long as 4 µm. The energy of the seed 70-fs pulses centered at 1.5-µm can be as low as 200 pJ.

1. Introduction

Silicon carbide (SiC) on insulator has emerged as a powerful platform for integrated nonlinear optics owing to its broad transparency window, its high refractive index, its large second- and third-order optical nonlinearity and propagation loss as low as 0.08 dB/cm [1,2].

Laser frequency combs spanning over the visible to the mid-infrared region are key to new approaches to spectroscopy. Spectral broadening of combs through supercontinuum generation makes it possible to reach regions where direct emission of femtosecond oscillators is not possible or still challenging. Soliton-induced dispersive wave generation in silicon nitride [3] and aluminum nitride [4] waveguides under seeding at telecommunication wavelengths (1.5 µm) has shown visible and mid-infrared up to 4.0 µm with pulse energies of 0.6 nJ [3] and 0.7 nJ [4], respectively. Here we investigate the formation of visible and mid-IR dispersive waves in SiC waveguides. Owing to the strong optical nonlinearity of SiC, pulse energies as low as 200 pJ are sufficient to generate a broad spectrum centered in the 3-4 µm range, region of the fundamental CH, NH, OH stretches in molecules. Low seeding powers open up the prospect of fully on-chip devices including ultrashort-pulse seed source, broadening waveguides and even of integrated spectrometers for trace gas sensing.

2. Experiments and results

4H-SiC-on-insulator waveguides have been fabricated for the generation of lithographically-engineered dispersive waves at visible and mid-infrared wavelengths, when seeded at 1.5 µm. The dispersive-wave center frequencies can be approximated from the zeros of the integrated dispersion, defined as:

$$\beta_{int}(\omega) = \beta(\omega) - \beta(\omega_0) - \frac{d\beta(\omega)}{d(\omega)}(\omega - \omega_0) \quad (1)$$

where $\beta(\omega)$ is the effective change in spectral phase per unit length (wavenumber of light) at the angular frequency ω, and ω_0 is the seed angular frequency. The simulated TE00-mode integrated dispersion is exemplified in Fig.1, for waveguide cross-sections of 978×470 nm and 1233×470 nm. Changing the waveguide width from 978 nm to 1233 nm enables to translate the center wavelength of the visible dispersive-wave from 600 nm to 720 nm, and that of the mid-infrared from 3100 nm to 3500 nm. The short waveguides of a length of 4.1 mm maintain phase coherence of the frequency comb and the inverse tapers at their ends ensure efficient coupling of the fundamental TE spatial mode.

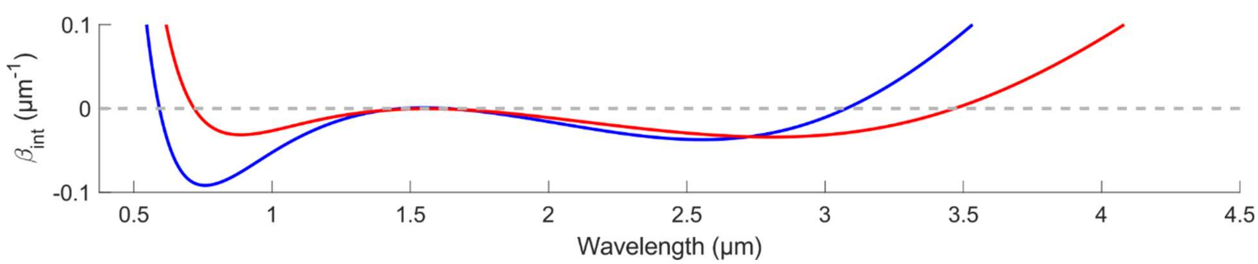

Fig. 1. Calculated integrated dispersion of the 978×470 nm (blue), and 1233×470 nm (red) waveguides fundamental TE mode. Dispersive waves are expected near the zero-crossing points when the waveguide is seeded by pulses centered around 1550 nm.

An erbium-doped mode-locked laser is used as a seed source. Pulses of a duration of 70 fs are emitted at a repetition frequency of 100 MHz and an average power up to 300 mW. Their spectrum is centered at 1570 nm. The beam is polarized and focused onto the chip to excite the fundamental TE mode of the waveguides. The visible and near-infrared part of the spectrum (350-2400 nm) is measured with dispersive optical spectrum analyzers, while the mid-infrared part of the spectrum (2400-3500 nm) is recorded with a Fourier-transform spectrometer. Fig. 2 provides examples of two spectra in different waveguides at an on-chip pulse energy of 0.2 nJ. Visible dispersive waves spanning about 100 nm and mid-infrared dispersive waves spanning about 500 nm are measured close to the expected wavelengths.

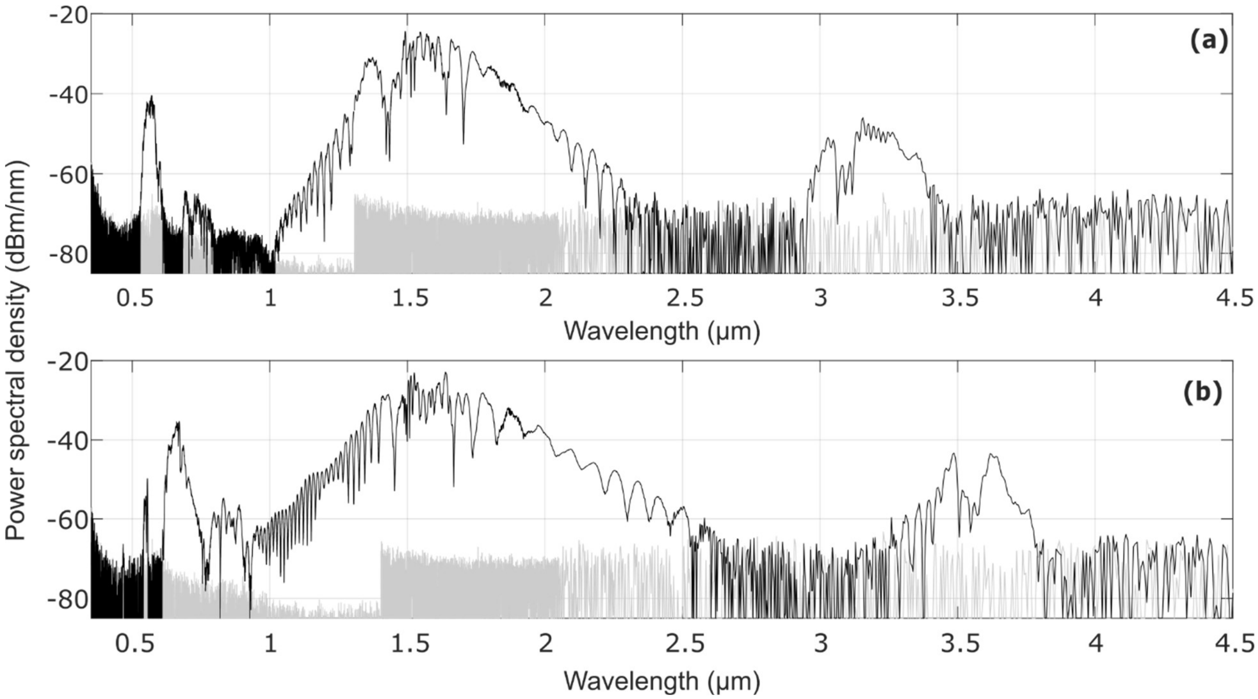

Fig. 2. Supercontinua measured on the spectrum analyzers / spectrometer, after the (a) 978×470 nm and (b) 1233×470 nm SiC waveguides, under an on-chip seed-pulse energy of 200 pJ (black curves). Noise floors of the spectrometers are represented in light grey.

Nonlinear optics with the SiC-on-insulator platform enables 3-µm mid-infrared dispersive-wave generation at pulse energies as low as 0.2 nJ. A remarkable feature of 4H-SiC is its strong second-order nonlinearity, which will be leveraged for second harmonic generation and, with overlap to the visible dispersive wave, self-referencing of the frequency comb at low pulse energy. New tools for precision mid-infrared frequency-comb spectroscopy are within reach and they establish novel strategies for compact or even integrated devices. Results will be discussed at the conference.

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3. References

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