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Coherent mid-infrared supercontinuum generation for pulse compression in a silicon-based chip

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Abstract: We report coherent supercontinuum generation spanning from 2.8 to 5.7 μm in an all-normal dispersion SiGe-on-Si waveguide pumped with 205 fs pulses at 4 μm . We demonstrate by simulations pulse compression to around 22 fs. © 2020 The Author(s)

OCIS codes: (320.6629) Supercontinuum generation; (190.4390) Nonlinear optics, integrated optics; (140.3070) Infrared and far-infrared lasers.

Many fundamental molecules have sharp absorption lines in the mid-infrared (mid-IR, 2.5 – 15 μm), allowing for air quality and environmental monitoring applications [1]. However, mid-IR technologies are still limited in their range of applications, primarily due to devices' size and prohibitive costs [2, 3]. In this context, we aim to achieve a small footprint low-cost sensing platform with an integrated supercontinuum (SC) source. In the silicon germanium-on-silicon (SiGe-on-Si) platform we managed to experimentally demonstrate SC from 3 to 8.5 μm [4]. Furthermore, we demonstrated a post-fabrication technique for trimming dispersion [5], and we reported high coherence of an SC at frequencies separated by an octave [6].

High-precision ultrafast spectroscopy requires coherent SC with ultrashort pulses. SC generation in all-normal dispersion (ANDi) regime is a coherent process maintaining a single pulse allowing for pulse compression [7]. Following the SC generation reports in the ANDi regime in various fiber platforms [8-11], a chalcogenide chip [12], we report what we believe to be the first octave-spanning mid-infrared SC in an ANDi waveguide in a silicon-based chip [13].

We designed our SiGe (40% Ge in alloy) waveguides, with 5.0 μm \times 2.7 μm cross-section, to operate in the ANDi regime with low group-velocity dispersion (GVD < 100 ps/nm/km) across an octave bandwidth between 3 and 6 μm in TM polarization (see Fig. 1c).

We characterized our waveguides using a standard free-space butt-coupling setup. Using a cut-back method and a 7.5 pico-second laser, we measured losses as low as 0.3 dB/cm between 4 and 5 μm in TM polarization. We then performed SC spectrum measurements by pumping a 2 cm long waveguide with 205 fs, 63 MHz repetition rate pulses at 4 μm . The Fig. 1a shows the measured output spectra, spanning over an octave from 2.8 to 5.7 μm , obtained by pumping the waveguide with 40 mW (5.7 kW) coupled average (peak) power [13].

Our simulations are in good agreement with the experimentally generated spectra (see Fig. 1a). We calculated the degree of first-order coherence g_{12} from 50 independent simulations showing a high-degree of coherence g_{12} equal to unity over the entire bandwidth (red curve in Fig. 1a). Such a fully coherent SC with a single pulse in time-domain can be compressed to a few-cycle limit after compensating the second- and third-order dispersion [14]. In Fig. 1b, we show the simulated spectrograms of the numerically generated SC at the waveguide output (left) and the compressed pulse (right). Our simulations show that it is possible, in principle, to exploit our SC to compress the 205 fs pump pulses down to 22 fs.

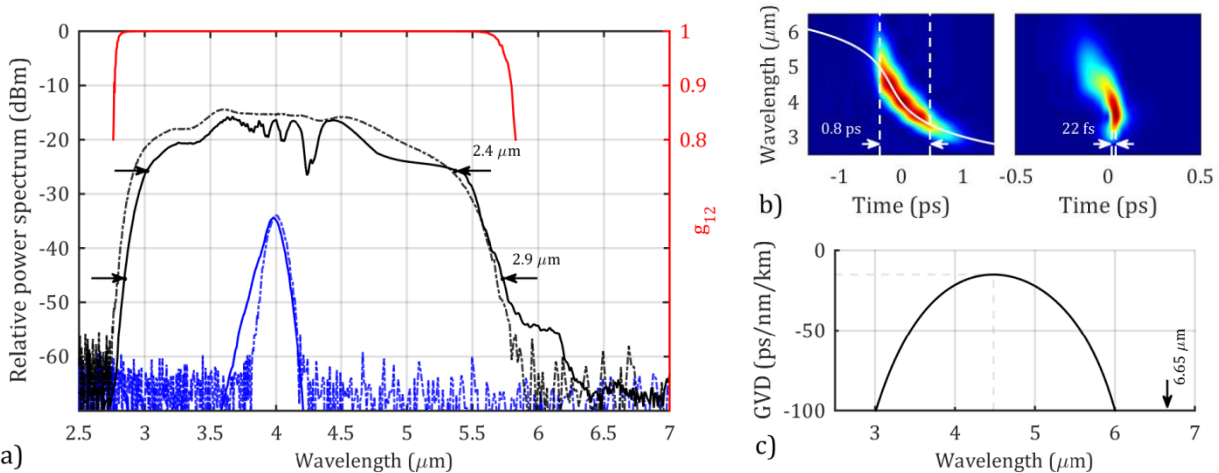


Fig. 1 a) Measured (solid) and simulated (dash-dotted) low-power (blue) and SC (black) spectra in the TM polarization. The top red curve shows the calculated coherence of the SC spectrum. b) Simulated pulse spectrograms for at the output (left) and compressed SC (right) at the 4 kW pump. White dashed lines give FWHM pulse durations. c) Calculated group velocity dispersion GVD for $5.0 \mu\text{m} \times 2.7 \mu\text{m}$ cross-section air-clad SiGe-on-Si waveguide.

In conclusion, we have demonstrated a fully coherent octave-spanning SC in an ANDi SiGe-on-Si waveguide. We found good agreement between measurements and simulations, allowing us to numerically confirm the full coherence of the generated SC across its entire bandwidth. The fully coherent SC achieved in this regime is suitable for efficient on-chip pulse compression schemes.

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