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Low-noise mid-infrared supercontinuum generation in a silicon-based chip

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Abstract: We report the first mid-infrared octave-spanning supercontinuum in an all-normal dispersion silicon-based chip. We generated coherent supercontinuum from 2.8 to 5.7 μm in a silicon-germanium waveguide pumped at 4 μm with 200 fs pulses. © 2020 The Author(s)

Many important molecules, in particular organic species, have sharp absorption lines in the mid-infrared (mid-IR, 3 – 15 μm), allowing for sensing applications in air quality and environmental monitoring [1]. Despite recent progress, mid-IR technologies are still limited in their range of applications, largely due to the size of the devices and the prohibitive costs of the instruments. Achieving a small footprint low-cost sensing platform, with an integrated supercontinuum (SC) source, is a long desired objective in the mid-IR silicon photonics community [2, 3]. Silicon germanium-on-silicon (SiGe-on-Si) is a particularly appealing Si-based platform as SiGe with reasonably nonlinear, and low-loss waveguides in the mid-IR [4]. In this platform, we managed to demonstrate SC from 3 to 8.5 μm experimentally [5]. More recently, we reported high coherence of an SC spanning from 2.6 to 6.2 μm at frequencies separated by an octave, as required for f to $2f$ self-referencing schemes used to stabilize pulse [6].

SC generation in all-normal dispersion (ANDi) regime is a low-noise process that maintains a single pulse, allowing for high-precision spectroscopy [7]. So far, SC generation in the ANDi regime was reported in various fiber platforms [8-11] and in a chalcogenide waveguide [12], without any discussion about the phase spectral coherence properties. Recently, we demonstrated a post-fabrication technique used for trimming dispersion from anomalous to all-normal [13]. In this work, we report what we believe to be the first octave-spanning fully coherent supercontinuum in an ANDi waveguide on a silicon-based chip in the mid-infrared.

Our SiGe (40% Ge in alloy) waveguides, with 5.0 $\mu\text{m} \times 2.7 \mu\text{m}$ cross-section were fabricated at CEA Leti. A SiGe layer was epitaxially grown on the Si substrate. The waveguides were patterned using deep-UV lithography, and finally formed by deep reactive-ion etching. Fig. 1a shows an SEM image of the fabricated waveguide. We designed the waveguides to operate in the ANDi regime with low group-velocity dispersion ($\text{GVD} < 100 \text{ ps}^2/\text{nm}/\text{km}$) across an octave bandwidth between 3 and 6 μm in TM polarization (see Fig. 1a, bottom).

We characterized our waveguides using a standard butt-coupling setup. We used a 7.5 pico-second laser tunable from 3 to 6 μm for propagation loss measurements. 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 200 femtoseconds, 63 MHz repetition rate pulses delivered by a Miropa-fs OPA operating at 4 μm . Fig. 1b shows the measured output spectra obtained by pumping the waveguide with low (blue solid curve) and high (black solid curve) input power. In the latter case, a SC spanning over an octave from 2.8 to 5.7 μm was obtained with 40 mW (5.7 kW) coupled average (peak) power. Our simulations (dash-dotted curves in Fig. 1b) are in good agreement with the experimentally generated spectra. We calculated the

degree of first-order coherence g_{12} of the high power spectrum from 50 independent simulations. The calculated coherence is high, with g_{12} equal to unity over the entire bandwidth (red curve in Fig. 1b).

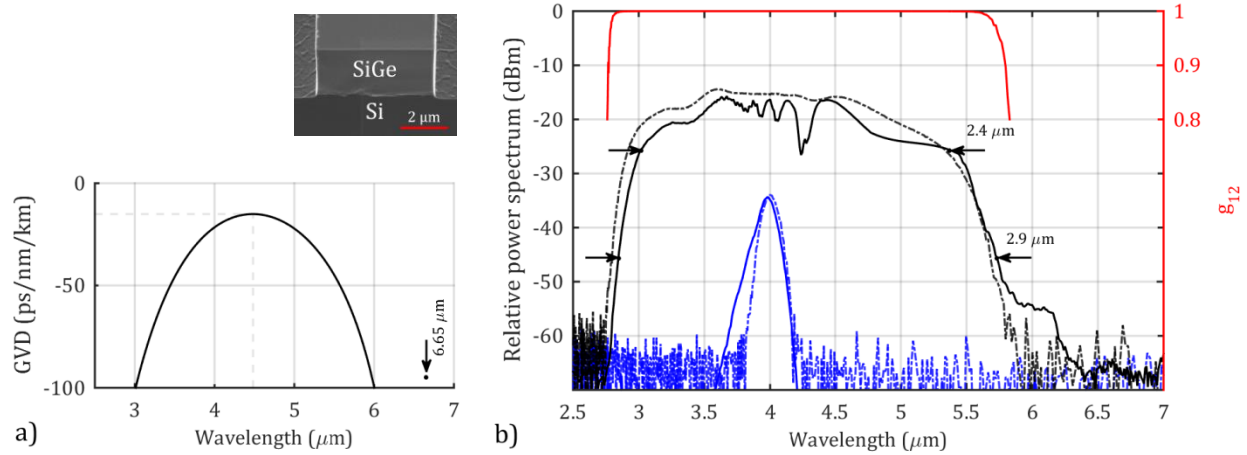


Fig. 1 a) Calculated group velocity dispersion GVD for $5.0 \mu\text{m} \times 2.7 \mu\text{m}$ cross-section air-clad $\text{Si}_{0.6}\text{Ge}_{0.4}/\text{Si}$ waveguide. The SEM image of the waveguide is provided on top, **b)** Measured (solid) and simulated (dash-dotted) low-power (blue) and SC (black) spectra in the TM polarization. The top red curve shows the calculated coherence of the SC spectrum.

SC in all-normal dispersion waveguides does not suffer from polarization noise as in optical fibers [14]. Moreover, when compared to SC in anomalous dispersion waveguides, the noise due to the modulation instability is inhibited. Thus, the SC in ANDi waveguides can enable an ultra-low noise source.

In conclusion, we have demonstrated a fully coherent octave-spanning supercontinuum in an all-normal dispersion 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 SC covers the critical 3 to 5 μm molecule vibration absorptions region, and thanks to its flat spectrum with low noise can enable high-precision on-chip spectroscopy.

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