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Coherent supercontinuum generation in a silicon-germanium waveguide in the mid infrared

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Abstract: We report high brightness coherent supercontinuum extending from 2.8 to 5.0 μm in an air cladded $\text{Si}_{0.6}\text{Ge}_{0.4}/\text{Si}$ waveguide with all-normal dispersion. Supercontinuum is generated by pumping with $\sim 200\text{fs}$ pulses at 3.8 μm . Dispersion engineering and low propagation loss ($\sim 0.5\text{dB/cm}$ at 3.8 μm) allowed us to achieve more than 5mW useful on-chip average power.

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

Photonics in the mid infrared (mid-IR – at 3–20 μm) has a large number of applications based on the optical detection of molecules that can be readily identified through measuring their strong fundamental absorption lines in this band [1, 2]. To perform this measurement, supercontinuum (SC) sources are particularly well-suited, since they allow for reliable molecule detection by accessing in parallel their distinct absorption lines. Broad mid-IR supercontinuum is traditionally generated via soliton fission, as obtained by pumping a nonlinear waveguide with an anomalous dispersion, close to the zero dispersion wavelength (ZDW) [3, 4]. Although these sources have a large spectral power density across a wide wavelength band and a relatively good power budget, the soliton fission process is triggered by noise seeded modulation instability, which degrades the coherence of the related source. However, many applications such as optical coherence tomography, coherent Raman and anti-stokes Raman spectroscopy, broadband time-resolved pump-probe spectroscopy or ultra-short pulse generation, require a broadband phase coherent source [5-7].

Stable and coherent SC generation can be achieved by exploiting coherent self-phase modulation and optical wave breaking effects in a waveguide with low all-normal dispersion [5]. The required pump power however tends to be larger in this dispersion regime, which has precluded its widespread use in applications. In this work, we report SC in the mid-IR spanning from 2.78 – 5.05 μm by launching 18.3mW pump power into a dispersion-engineered low-loss “air clad” $\text{Si}_{0.6}\text{Ge}_{0.4}$ waveguide with all-normal group velocity dispersion (Fig1b – inset). The waveguide consists of a 2.7 μm thick and 3.5 μm wide $\text{Si}_{0.6}\text{Ge}_{0.4}$ ridge on a silicon substrate. It was engineered to have single-mode operation and low normal dispersion with low effective area and strong mode confinement ($>94\%$ at 3.8 μm , see Fig1b – inset). Although being air-clad, a propagation loss as low as 0.4dB/cm in the broad range from 3.8 to 5.0 μm , has been reported in these waveguides [8].

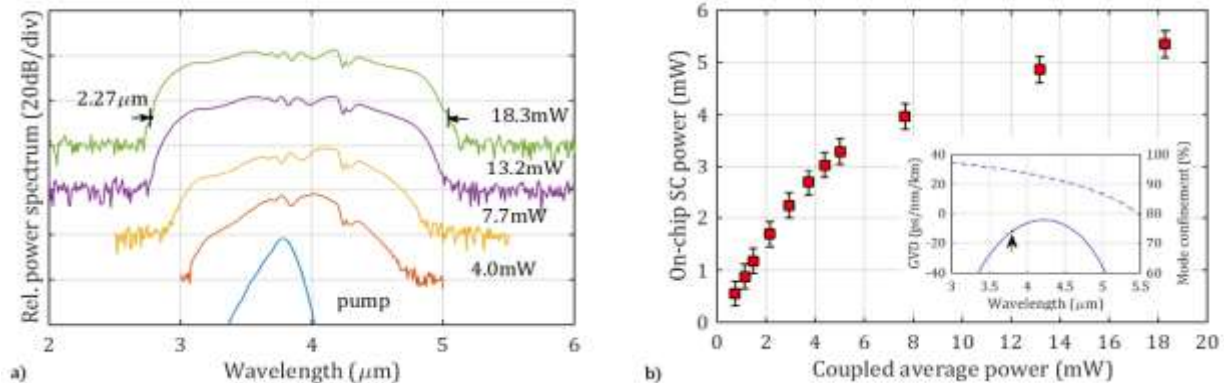


Figure 1 a) Output spectra measured at different coupled power, b) Measured on-chip SC power versus coupled power. Calculated group velocity dispersion (solid blue line) and mode confinement (dashed blue line) are shown in the inset.

Supercontinuum generation is achieved by pumping the waveguide with ≈ 200 fs TM polarized pulses from a mid-infrared MIROPA-fs optical parametric amplifier at a repetition rate of 63MHz. Using a 2cm long waveguide pumped at 3.8 μ m in the normal dispersion regime we obtain the spectra shown in Fig 1a. The supercontinuum spectra achieved here are smoother than that traditionally obtained in the anomalous dispersion regime, and the remaining fluctuations observed on Fig. 1a are typical from self-phase modulation. When pumped with 18.3mW coupled average pump power, a 2.27 μ m bandwidth at -30dB (2.78–5.05 μ m) and a 1.84 μ m bandwidth at -10dB level are achieved. The lower propagation losses achieved here compared with previous results [9, 10], enabled us to generate SC at much reduced pump intensity, thereby limiting the impact of high-order nonlinear absorption (Fig 1b), resulting in an increased SC on-chip power (>5mW).

In summary, we report the first supercontinuum generated in all-normal dispersion regime in any CMOS compatible platform. Supercontinuum is spanning across the relevant mid-IR wavelength range from 3 - 5 μ m, where most molecules have fingerprints, enabling coherent spectroscopy applications. The generated average mid-IR power exceeds that produced so far by other Si-based platforms. This establishes silicon germanium-on-silicon as a promising platform for integrated nonlinear photonics in the mid-IR.

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