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# Bright on-chip mid-IR supercontinuum generation to 7.7 $\mu\text{m}$ in silicon germanium-on-silicon platform

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**Abstract:** We report mid-IR supercontinuum generation, from 2.9 to 7.7 $\mu\text{m}$ , in a CMOS compatible silicon-germanium waveguide. This 1.3 octave bright supercontinuum has been achieved in a low loss dispersion engineered air-clad  $\text{Si}_{0.6}\text{Ge}_{0.4}/\text{Si}$  waveguide.

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

## 1. Introduction

The generation in a CMOS compatible platform of a spectrally bright supercontinuum covering the mid-wavelength infrared band (MWIR – at 3 – 8 $\mu\text{m}$ ) is a technological challenge that is promising to have a strong impact on molecular detection, as most chemical and biological compounds exhibit strong and unique absorption features in this spectral region [1]. The miniaturization of broadband octave-spanning sources (SCG) in the mid-IR has been already demonstrated on a chalcogenide chip [2]. Yet, these materials do not allow exploiting the advantages of the CMOS fabrication technologies in terms of reliability, mass manufacturing and cost. On the other hand, a mid-IR supercontinuum generation in group IV materials based platforms remains challenging. Although supercontinuum generation has been demonstrated in CMOS compatible platforms like silicon nitride-on-insulator [3, 4], silicon-on-insulator [5, 6], silicon-germanium-on-insulator [7] and silicon-on sapphire [8], these sources are limited to 3.5 $\mu\text{m}$  and 6 $\mu\text{m}$ , due to the absorption in the silica and sapphire substrates, respectively. By taking advantage of the wider transparency window of the silicon substrate, the recently proposed silicon germanium-on-silicon platform is promising to overcome these limitations [9-11], potentially extending the spectral region of integrated sources at least up to 8 $\mu\text{m}$  [12].

## 2. Waveguide design and experiments

We just reported the generation of an octave spanning supercontinuum from 3 to 8.5 $\mu\text{m}$  in TE polarization in a silicon germanium-on-silicon waveguide [11]. Here, we demonstrate the generation of 1.3 octave spanning supercontinuum in the MWIR from 2.9 to 7.7 $\mu\text{m}$  in TM polarization, with a useful on-chip average power greater than 7mW by pumping dispersion engineered silicon germanium-on-silicon waveguide [9, 10]. Our waveguide consists of a 4.2 $\mu\text{m}$  thick and 4.5 $\mu\text{m}$  wide  $\text{Si}_{0.6}\text{Ge}_{0.4}$  ridge with a top air cladding that seats on a silicon substrate (see inset Fig. 1a). The air clad design with a large SiGe cross-section (effective area of  $\sim 10.5\mu\text{m}^2$ ) results in low anomalous dispersion across a large bandwidth (see figure 1a), a cut-off wavelength of 8.2 $\mu\text{m}$ , a strong mode confinement in the waveguide core material (>98 % at 4.15 $\mu\text{m}$ ) and a reduction of the contribution from surface roughness to the propagation loss.

Waveguide propagation losses were measured to be between 0.3 and 0.4dB/cm in the 4 – 5 $\mu\text{m}$  wavelength range with the minimum value being 0.32dB/cm at 5 $\mu\text{m}$ .

Supercontinuum was then achieved by pumping the waveguide with  $\sim 200\text{fs}$  pulses delivered from a mid-infrared MIROPA-fs optical parametric amplifier at a repetition rate of 63MHz. Using a 7cm long waveguide pumped at 4.15 $\mu\text{m}$  close to the first zero-dispersion wavelength, we obtained the spectra shown in Fig. 1b for average coupled powers increasing from  $\sim 1\text{mW}$  to 21mW. At 21.1mW coupled average power ( $\sim 3\text{kW}$  coupled peak power), we measured a supercontinuum spanning 1.3 octaves, from 2.9 to 7.7 $\mu\text{m}$  at the -30 dB level was achieved. Besides, the output spectrum is relatively smooth with a large -10dB bandwidth from 3.0 – 7.4 $\mu\text{m}$ .

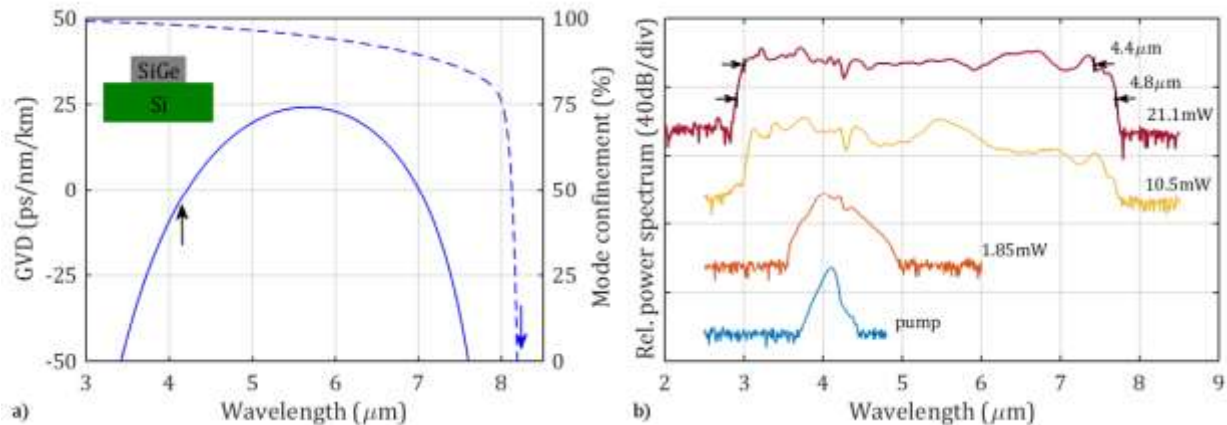


Figure 1 a) Calculated group velocity dispersion (GVD) and confinement of the mode field in the waveguide core (dashed lines), black arrow indicate pump wavelength, blue arrow indicates the cut-off wavelength, schematic of an air clad SiGe waveguide as an insert, b) Output spectra measured at different average coupled power. Coupled average power is calculated assuming 4.5dB coupling loss.

### 3. Conclusion

In summary, we report supercontinuum generation in TM polarization from a silicon germanium-on-silicon platform covering almost the whole mid-wavelength infrared, where most molecules in atmosphere have relevant fingerprints. The generated on-chip supercontinuum MWIR power and bandwidth exceed that produced so far by other Si-based platforms that are intrinsically limited by the silica or sapphire substrate absorption. This establishes silicon germanium-on-silicon as a promising platform for integrated nonlinear photonics in MWIR, with the potential to extend the operating range beyond 8 $\mu$ m.

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