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Bright on-chip mid-IR supercontinuum generation to 7.7 μm in silicon germanium-on-silicon platform

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Abstract: We report mid-IR supercontinuum generation, from 2.9 to 7.7 μm , 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 μm) 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 μm and 6 μm , 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 μm [12].

2. Waveguide design and experiments

We just reported the generation of an octave spanning supercontinuum from 3 to 8.5 μm 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 μm 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 μm thick and 4.5 μm 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 μm , a strong mode confinement in the waveguide core material (>98 % at 4.15 μm) 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 μm wavelength range with the minimum value being 0.32dB/cm at 5 μm .

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 μm 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 μm at the -30 dB level was achieved. Besides, the output spectrum is relatively smooth with a large -10dB bandwidth from 3.0 – 7.4 μm .

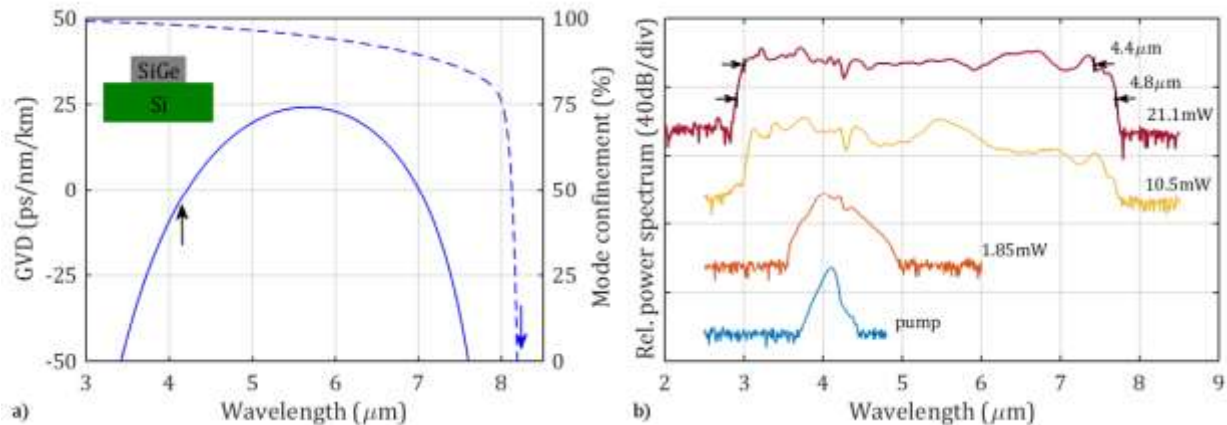


Figure 1 a) Calculated group velocity dispersion (GVD) and confinement of the mode field in the waveguide core (dashed lines), black arrow indicate pump wavelength, blue arrow indicates the cut-off wavelength, schematic of an air clad SiGe waveguide as an insert, b) Output spectra measured at different 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 μ m.

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