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Experimental Mid-Infrared Supercontinuum Generation in a Germanium on Silicon Waveguide

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Abstract: We report the first experimental supercontinuum generation in a germanium waveguide. By pumping a low-loss germanium on silicon waveguide with ≈ 200 fs pulses at 4.6 μm , we generated a supercontinuum extending from 3.53 to 5.83 μm .

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1. Introduction

In the last two decades, germanium has played a key role in group IV photonics. The first applications of germanium in integrated photonics were addressed to devices operating in the near-infrared [1,2]. More recently, however, the wide transparency window up to 15 μm [3] and its theoretically anticipated attractive nonlinear properties [4] have led to high expectations for germanium to become a promising material for (from 3 to 13 μm) photonics. In terms of fabrication, tremendous progress has been made in the last years, with several demonstration of low-loss germanium on silicon waveguides in the mid-infrared region [1].

Photonics in the mid-infrared 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 [3]. A broadband source, such as a supercontinuum, is a fundamental element for integrated sensing platforms since it allows for parallel detection of multiple gas species [5]. On-chip mid-infrared supercontinuum generation has been demonstrated in several group IV platforms [5-8]. Supercontinuum generation up to 8.5 μm has been demonstrated by our group in silicon-germanium on silicon waveguides, reaching the onset of the absorption from the silicon substrate [7]. In this latter platform, we have also demonstrated the possibility of precisely controlling the supercontinuum coherence properties [9,10]. Due to its a priori wider transparency window [11], pure germanium on silicon waveguides are anticipated to overcome the current limits of the other group IV platforms. So far, however, supercontinuum generation in germanium waveguides has been limited to numerical demonstrations.

Here we report the first experimental demonstration of supercontinuum generation in a germanium waveguide. We pumped a 4.46 μm x 2.57 μm cross-section germanium on silicon air-clad waveguide with ≈ 200 fs pulses at 4.6 μm , generating a supercontinuum extending from 3.53 to 5.83 μm . Owing to the transparency of atmosphere between 3 and 5 μm and to the strong absorption of hazardous and greenhouse gases such as CO (~ 4.5 μm), CO₂ (4.2, 4.3 μm) and CH₄ (3.45 μm) [12], our source has potential applications in free-space communications and environmental monitoring.

2. Supercontinuum Generation

A 4.46 μm wide, 2.57 μm thick air-clad germanium on silicon waveguide (fig. 1a inset) was designed to have low dispersion beyond 4 μm (fig. 1a). We measured propagation loss of ≈ 1.25 dB/cm between 3.5 and 4.5 μm . Supercontinuum generation is achieved by pumping the waveguide with ≈ 200 fs TE polarized pulses from a mid-infrared MIROPA-fs optical parametric amplifier at a repetition rate of 63MHz. By pumping at 4.6 μm in the normal dispersion regime we obtain the spectra shown in Fig 1b. When pumped with 82mW coupled average pump power (corresponding to 3.46 kW coupled peak power), a 2.3 μm bandwidth (3.53–5.83 μm) at -30dB level is achieved. Our modeling work shows that this long wavelength boundary is mainly limited by the high free-carrier absorption beyond 6 μm [13]. Yet, our supercontinuum covers the 3-5 μm atmospheric transparency window, already making it particularly interesting for free-space communications and environmental monitoring.

Fig. 1: (a) Dispersion parameter of the $4.46\mu\text{m} \times 2.57\mu\text{m}$ cross-section germanium on silicon waveguide. A Scanning Electron Microscope image of the waveguide is shown in the inset. (b) Output spectra measured at different coupled average powers.

3. Conclusion

In conclusion, we have demonstrated the first experimental supercontinuum generation in a germanium waveguide. The supercontinuum covers the $3.53\text{--}5.83\mu\text{m}$ band. The multiphoton absorption and therefore the generation of free-carriers could be reduced by pumping at longer wavelengths [14], potentially allowing to fully exploit the transparency up to $12\mu\text{m}$ [11] of the germanium on silicon platform.

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