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Tailoring the Dispersion of a Hybrid Chalcogenide/Silicon-Germanium Waveguide for Mid-Infrared Supercontinuum Generation

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Abstract: We report mid-infrared supercontinuum generation in a silicon germanium-on-silicon waveguide. We show that the dispersion properties of the waveguide can be precisely tuned by controlling the width of a chalcogenide cladding layer.

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

1. Introduction

On-chip mid-infrared (mid-IR, between 3 μm and 20 μm) supercontinuum (SC) generation is a technological challenge that is promising to have a strong impact in many different fields such as bio imaging, environmental sensors and security [1-5]. The prediction of great nonlinear properties, wide transparency window from 3 to 15 μm and CMOS compatibility of germanium have attracted a growing interest toward germanium-based platforms [6-9]. An octave spanning supercontinuum generation up to 8.5 μm has been already demonstrated by our group in a SiGe on Si waveguide [10]. The bandwidth and the coherence properties of the generated SC are mainly determined by the waveguide's dispersion profile. In general, the dispersive properties are set at the design stage and cannot be adjusted once the device has been fabricated. However, fabrication inaccuracies, surface roughness, surface contamination and the presence of defects may lead to a deviation from the targeted dispersion profile. Therefore, post-process tuning mechanisms are of great interest to post-trim the waveguide dispersion depending on the actual structure produced by fabrication. Here we demonstrate mid-IR supercontinuum generation in a highly nonlinear SiGe waveguide in both anomalous and normal dispersion. We show that it is possible to fine tune the dispersion profile a-posteriori by adding a chalcogenide cladding layer on top of the waveguide, introducing a simple post-processing tool to control the supercontinuum dynamics and its properties.

2. Supercontinuum Generation and dispersion tailoring

Supercontinuum generation was achieved in a 7 cm long $3.75 \times 2.7 \mu\text{m}^2$ cross-section air-clad silicon germanium-on-silicon waveguides (see fig.1 (a) for a schematic (top) and Scanning Electron Microscope image (bottom) of the waveguide). The waveguide operating in TE single mode, was pumped in anomalous dispersion (fig. 1(c), black continuous line) with ~ 200 fs pulses at 4 μm delivered from a MIROPA-fs optical parametric amplifier with 63 MHz repetition rate. A 1.26 μm thick coating layer of chalcogenide $\text{Ge}_{11.5}\text{As}_{24}\text{Se}_{64.5}$ was then deposited by thermal vapor deposition (see fig 1(b) for a schematic (top) and Scanning Electron Microscope image (bottom) of the waveguide). The chalcogenide clad waveguide was pumped in normal dispersion (fig 1(c), black dashed line) with pulses with the same parameters as before at 4.15 μm . Fig. 2 shows the experimental (blue) and simulated (red) output spectra obtained by pumping the air clad waveguide (fig. 2(a)) and the chalcogenide clad waveguide (fig. 2(b)) at 2.3 kW of coupled peak power. In the former case, the uneven amplitude across the spectrum (with a -30 dB bandwidth of 3.55 μm) is typical of SC generation in anomalous dispersion regime. In the latter case, the narrower and smoother spectrum (with a -30 dB bandwidth extending from 3.1 to 5.5 μm) is typical of SC generation in normal dispersion regime. The SC generation process was simulated by numerically solving the nonlinear Schrödinger equation using the split-step Fourier method. Nonlinearity of chalcogenide was neglected, as only 0.5% of the field is contained in the chalcogenide cladding. Experimental results are in good agreement with simulations. These results suggest that anomalous-to-normal dispersion shift occurs when the chalcogenide top cladding is added. We performed a numerical analysis to study the impact of the chalcogenide thickness on the group velocity dispersion.

Fig. 1 (c) shows the group velocity dispersion for different thicknesses of the chalcogenide layer. As the thickness increases, the dispersion gradually decreases, (shifting toward normal when depositing 500 nm of chalcogenide) flattening out the dispersion profile. The dispersion profile converges as the chalcogenide thickness approaches 1 μm . The possibility of controlling the dispersion profile by simply changing the thickness of the chalcogenide layer is a convenient post-processing tool to trim the group velocity dispersion depending on the actual structure produced by fabrication.

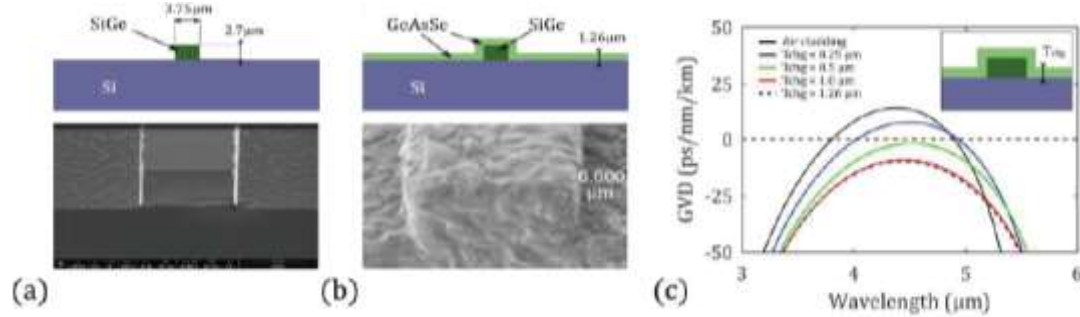


Fig. 1. Schematic (top) and Scanning Electron Microscope image (bottom) of the air clad (a) and the chalcogenide clad (b) waveguide. (c) Calculated group velocity dispersion for different thicknesses of the chalcogenide layer. The dashed black line indicates the zero dispersion. The inset shows a schematic of the waveguides.

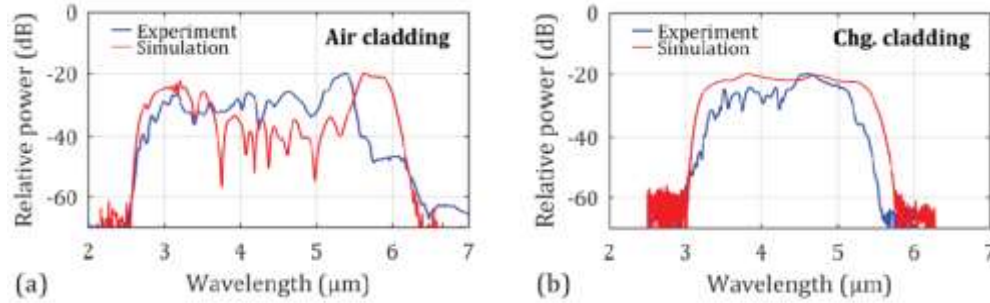


Fig. 2. Experimental (blue) and simulated (red) spectra measured out of the air clad (a) and chalcogenide clad (b) SiGe/Si waveguide with the same $3.75 \times 2.7 \mu\text{m}^2$ core cross-section. The waveguides were pumped with pulses at 4 μm and 4.15 μm respectively, with 2.3 kW of coupled peak power.

3. Conclusion

In summary, we report the addition of a top chalcogenide layer as a simple post-processing technique to fine tune the dispersion profile of a nonlinear SiGe on Si waveguide for integrated SC generation. We experimentally show that, by adding a chalcogenide top layer to a ridge waveguide, anomalous-to-normal dispersion shift takes place and we numerically study the impact of the chalcogenide layer thickness on the group velocity dispersion.

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