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► **To cite this version:**

Adam Bieganski, Marko Perestjuk, Remi Armand, Alberto Della Torre, Vincent Reboud, et al.. Mid-IR linear optical properties of hybrid Sb₂S₃ /SiGe waveguides. 11th EOS (European Optical Society) Annual Meeting (EOSAM 2023), Sep 2023, Dijon, France. pp.01013, 10.1051/epjconf/202328701013 . hal-04253912

HAL Id: hal-04253912

<https://hal.science/hal-04253912v1>

Submitted on 23 Oct 2023

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Mid-IR linear optical properties of hybrid Sb₂S₃/SiGe waveguides

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Abstract. We study the antimony trisulfide's (Sb₂S₃) linear optical properties for potential applications in reconfigurable chip-based supercontinuum mid-IR sources. We experimentally demonstrate that Sb₂S₃ cladding on SiGe-on-Si waveguides induces relatively low extra propagation loss below 1 dB/cm between 3.3 and 3.9 μm wavelength.

1 Introduction

Developing a chip-based and CMOS-compatible mid-IR broadband light source is of great interest for applications such as spectroscopy or optical communication [1-5]. In our group, an air-cladded Si_{0.6}Ge_{0.4}-on-Si waveguide was used to demonstrate supercontinuum generation across more than one octave (from 3 up to 8.5 μm) [2]. Nonetheless, the spectral characteristics of the generated supercontinuum can strongly vary (in terms of bandwidth, flatness, and coherence) depending on the waveguide dispersion profile since supercontinuum generation is driven primarily by soliton fission in the anomalous dispersion regime or by self-phase modulation and optical wave breaking in the normal dispersion regime [3]. Depending on the potential application, one or the other may be more desirable. However, in most of the existing devices, the waveguide dispersion profile is set at the moment of fabrication and cannot be modified *a posteriori*.

An attractive solution for controlling the dispersion characteristics on-demand, and thus for reconfigurable supercontinuum generation, is the use of phase-change materials (PCMs), that can be switched thermally, optically, or electronically between amorphous and crystalline phases. The different phases are characterized by different optical properties (such as refractive index) and thus allow to control the waveguide dispersion.

In this paper, we study the suitability for mid-IR applications of antimony trisulfide (Sb₂S₃) - a promising but very little studied PCM. For both phases, we measure its complex refractive index (between 2 and 10 μm) and linear propagation losses in Sb₂S₃-coated SiGe-on-Si waveguides (between 3.3 and 3.9 μm).

2 Experimental results

We designed a 3.00 μm × 3.20 μm cross-section SiGe-on-Si waveguide. For the given geometry, the waveguide is single-mode beyond 3.6 μm with a fundamental TE mode. The photonic chip was fabricated at CEA-Leti, Grenoble, France using standard epitaxy and lithography processes (detailed in Ref. [2]).

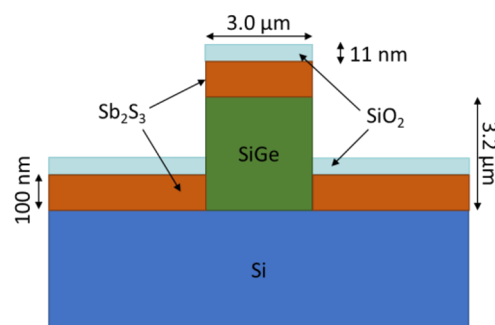


Fig. 1. Schematic view of the fabricated waveguide.

Afterwards, the chip was processed in the INL cleanroom facility. A 100 nm thick amorphous Sb₂S₃ (a-Sb₂S₃) layer was deposited by e-beam physical vapor deposition preceded by image reversal UV lithography. Eventually, to avoid its degradation, the PCM was covered with a 11 nm SiO₂ capping layer, see Fig. 1.

The crystallisation process (c-Sb₂S₃) was carried out using a hot plate. Temperature was varying from 27°C up to 280°C with a rate of 10°/min and the sample was heated for a total time of 60 min.

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2.1 Sb₂S₃ refractive index

We performed ellipsometry measurements of Sb₂S₃ complex refractive index ($\tilde{n} = n + ik$, where n describes the refraction of light and k its extinction coefficient) between 2 and 10 μm . The extinction coefficient k is found to be below the detection threshold ($k < 10^{-2}$) in the entire measurement range both in the amorphous and crystalline phase.

The refractive index contrast Δn varies between 0.78 (2.1 μm) and 0.99 (10 μm), see Fig. 1. Between 3.5 and 4 μm (pump wavelength targeted in the future to generate reconfigurable supercontinuum) the index contrast is typically between 0.86 and 0.89.

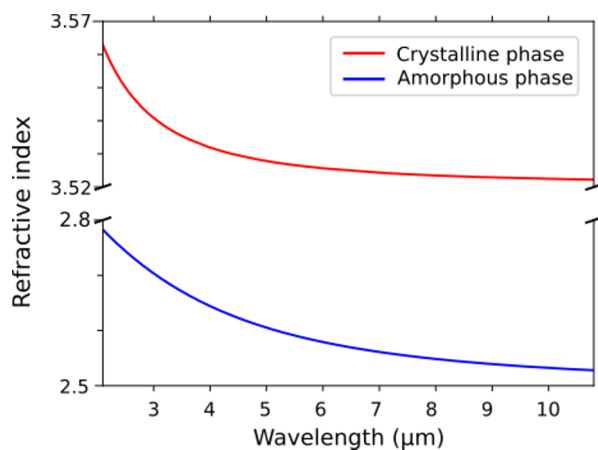


Fig. 2. Sb₂S₃ refractive index in the amorphous (blue) and crystalline phase (red) in the mid-IR range

2.2 Propagation loss in Sb₂S₃-cladded waveguides

For measuring the linear propagation losses, we used a tunable pulsed OPA laser source (MIROPA-fs, Hotlight Systems) with a repetition rate of 63 MHz. The laser wavelength varied from 3.3 to 3.9 μm with ~ 200 fs pulse duration and TE polarization. To evaluate the propagation losses, we measured the transmission on three waveguides with different length (4.2, 6.2, and 8.2 cm) and geometry described in Section 2, under relatively low average power (~ 1 mW). At each wavelength, the losses were calculated as the slope of the linear fit to the decimal logarithm of the output voltage signal, measured with a Thorlabs PDA20H-EC photodetector. Measurements were performed for air-, a-Sb₂S₃- and c-Sb₂S₃-cladded waveguides.

The results (presented in Fig. 3) show that the deposition of a 100 nm amorphous Sb₂S₃ layer brings negligible additional propagation losses compared to the air-clad SiGe waveguide. Its crystallisation introduces less than a dB/cm extra loss, which is still compatible with efficient supercontinuum generation.

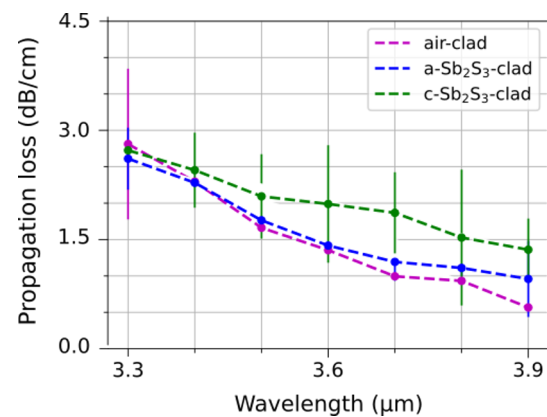


Fig. 3. Measured linear propagation losses in air- and Sb₂S₃-cladded waveguides.

3 Conclusion and perspectives

We measured by ellipsometry in the mid-IR range (between 2 and 10 μm) the linear properties (refractive index and extinction coefficient) of Sb₂S₃ in amorphous and crystalline phase. The index contrast between the two phases can reach up to 0.99 with the extinction coefficient lower than 10^{-2} in the entire measurement range. What is more, we showed that Sb₂S₃ cladding induces negligible (in the amorphous phase) or relatively low < 1 dB/cm (in the crystalline phase) extra propagation loss to the SiGe-on-Si waveguides between 3.3 and 3.9 μm . Our preliminary results show that Sb₂S₃ is a highly promising PCM for reconfigurable mid-IR supercontinuum sources.

Acknowledgements

We acknowledge the support of the International Associated Laboratory in Photonics between France and Australia (LIA ALPhFA), the Agence Nationale de la Recherche (MIRSICOMB, ANR-17-CE24-0028; MetaOnDemand, ANR-20-CE24-0013 and MIRthFUL, ANR-21-CE24-0005), the Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Actions (MSCA) (REDI, grant agreement No 101034328 and ECLAUSion, grant agreement No 801512).

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