Mid-IR linear optical properties of hybrid Sb_2S_3/SiGe waveguides

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Abstract. We study the antimony trisulfide's (Sb_2S_3) linear optical properties for potential applications in reconfigurable chip-based supercontinuum mid-IR sources. We experimentally demonstrate that Sb_2S_3 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 band-width, 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 (Sb_2S_3) - 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 Sb_2S_3-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]).

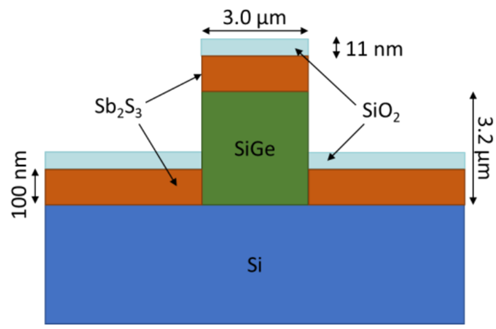

Fig. 1. Schematic view of the fabricated waveguide.

Afterwards, the chip was processed in the INL cleanroom facility. A 100 nm thick amorphous Sb_2S_3 (a-Sb_2S_3) 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 SiO_2 capping layer, see Fig. 1.

The crystallisation process (c-Sb_2S_3) 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 Sb_2S_3 refractive index

We performed ellipsometry measurements of Sb_2S_3 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.

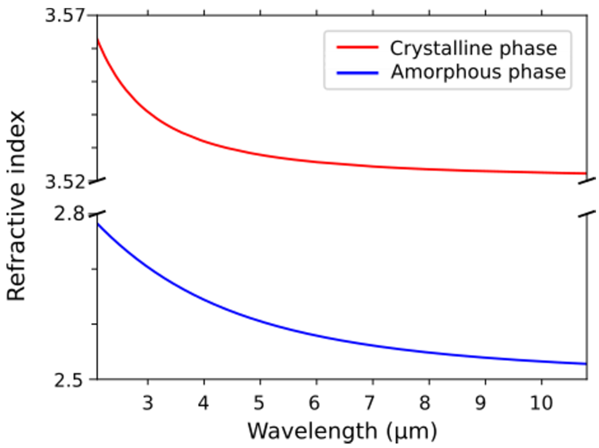

Fig. 2. Sb_2S_3 refractive index in the amorphous (blue) and crystalline phase (red) in the mid-IR range

2.2 Propagation loss in Sb_2S_3-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 PDA2OH-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 Sb_2S_3 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.

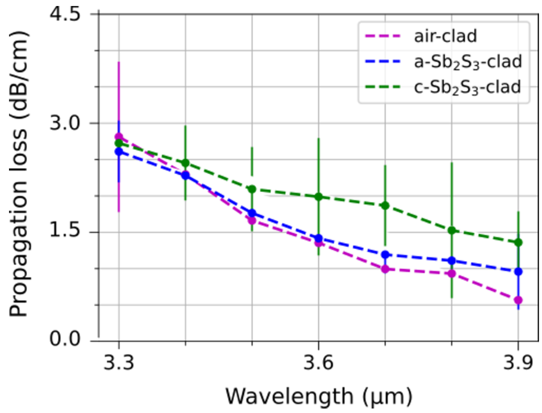

Fig. 3. Measured linear propagation losses in air- and Sb2S3-cladded waveguides.

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 Sb_2S_3 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 Sb_2S_3 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 Sb_2S_3 is a highly promising PCM for reconfigurable mid-IR supercontinuum sources.

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