Chalcogenides photonic integrated circuits for near- and mid-infrared applications

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Chalcogenide glasses are an important class of amorphous semiconductors that contain at least one of the chalcogen elements from group 6a of the periodic table (S, Se and Te but excluding oxygen) as major constituent [1]. These elements are covalently bonded to network formers such as As, Ge, Sb, Ga, Si or P. The unique optical properties of these glasses are motivating intense research towards the development of a wide range of photonic applications [2]. In particular, all-optical signal processing in near-infrared (IR) telecommunications window is taking advantage of their high optical nonlinearities [3]. These glasses also exhibit low maximum phonon energies (values range from 350-425 cm^{-1} for sulphide, 250-300 cm^{-1} for selenide and 150-200 cm^{-1} for telluride) which yields a broad transparency in the mid-IR, independently of the exact glass composition. Mid-IR trace molecules sensing platforms could therefore also benefit from the development of these materials. For both applications (telecommunication and sensing), the current trend is directed toward minimizing device footprints and cost by implementing integrated optical components.

In this paper, we will present the technological processing of photonic circuits based on selenides ridge waveguides for the implementation of integrated mid-IR sensing platform and ultrahigh-bandwidth signal processing. The selenides layers are deposited on a silicon substrate by RF magnetron sputtering. Different waveguiding structures such as straight ridge waveguides, micro-ring resonators or spiral waveguides are subsequently patterned using standard i-line photolithography and fluorine-based RIE/ICP dry etching techniques (Fig.1). Optical demonstration of integrated four-wave mixing and sensing are respectively presented in the near- and mid-IR.

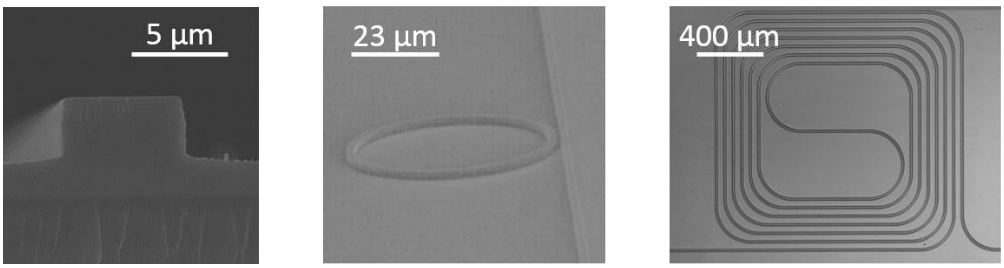

Fig. 1. Scanning electron microscope image of the processed waveguide after ICP-RIE a) ridge waveguide, b) micro-ring resonator and c) spiral waveguide.

Third order nonlinear effects such as four wave-mixing can be used for all-optical signal processing and frequency comb generation. The efficiency of such process depends on the waveguide nonlinear parameter $\gamma = \omega n_2 / cA_{eff}$ where A_{eff} is the area of the propagating mode, c is the speed of light and ω is its frequency. In chalcogenides ridge waveguides, this parameter can reach more than 100 $W^{-1}m^{-1}$ and enable the observation of four-wave mixing in cm-long waveguides (Fig2a). The use of chalcogenides-based high quality factor micro-ring resonators could further enhance the optical field in the cavity and therefore lead to an increase efficiency. The enhancement factor of the optical field using resonating structures will be presented in relation to the design of the micro-ring resonator (waveguide dimensions, coupling coefficient κ between bus waveguide and ring resonator, loss α per round trip).

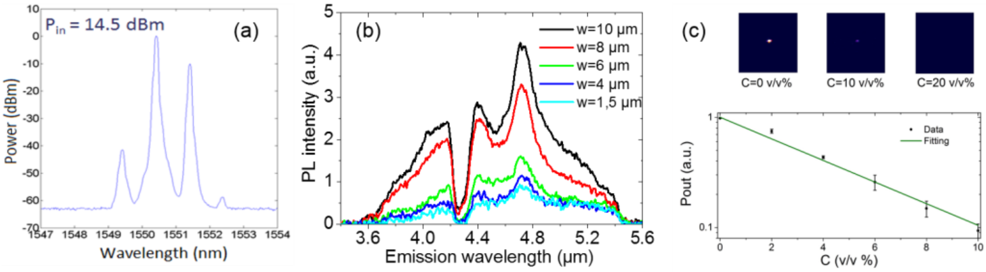

Fig. 2. a) Four-wave mixing spectrum obtained from 1-cm long selenides ridge waveguides, b) guided mid-IR photoluminescence spectrum from Pr^{3+}-doped selenides ridge waveguides c) Isopropanol detection @ 7.7µm using selenides waveguides.

The growing need for traces molecules detection is pushing towards the development of compact sensing platforms able to monolithically integrate a mid-IR light source, waveguides (also acting as transducers) and a detector [4]. Thanks to their broad mid-IR transparency, efficient waveguiding properties [5] and ability to be doped with rare earth (RE) ions, chalcogenides (ChGs) glasses are a compelling alternative to other mid-IR transparent materials (silicon, germanium or gallium arsenides…) to sustain this demand. Guided mid-IR praseodymium (Pr^{3+}) photoluminescence (PL) recorded between 3.5 and 5.5 µm using a continuous wave excitation at 1.55 µm in co-propagative configuration is presented in Fig. 2b. The incorporation of these efficient mid-IR emiters in micro-disk microcavities could enable the implementation of low-threshold on-chip mid-IR lasers with emission wavelength overlapping the strong characteristic vibrational transitions displayed by chemical molecules in the mid-IR. Mid-IR chemical detection has also been demonstrated by recording the transmitted power at 7.7 µm though chalcogenides spiral waveguides with different isopropanol concentrations deposited on the surface (Fig. 2c).

In conclusion, ridge waveguides were fabricated by RF magnetron sputtering and subsequent patterning using standard photolithographic steps. Different waveguiding structures (straight and spiral waveguides, micro-ring and micro-disk resonators) were processed and successfully tested for diverse applications in the near- and mid-IR.

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