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Integrated Platform in Chalcogenide Glasses for Optical Sensing in the Mid-InfraRed

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In the last few years, the mid-infrared (mid-IR) spectral region, extending from 2 µm to 20 µm, has become a strategic wavelength range for photonic sensing applications due to the presence of a wide variety of fingerprints of gases (including CO_2, CO, N_2O, NO, CH_4) and liquids (acetone and emerging pollutants: BTEX - Benzene, Toluene, Ethylbenzene, Xylene) [1,2]. The development of low-loss optical platforms and quantum cascade laser sources operating beyond 2 µm have been the key enabler of the development of mid-IR optical sensors [3]. Integrated optical sensors are now allowing quantitative, sensitive and selective detection of numerous molecules for health, defence and environmental applications. In addition, they provide several advantages over other kind of sensors, such as high integration of elements in a compact device, low fabrication cost and immunity to electromagnetic interference.

Mid-IR integrated sensors have been implemented using several materials transparent in this spectral window (silicon, germanium or gallium arsenide). Chalcogenides (ChGs) glasses present a compelling alternative to the aforementioned mid-IR optical platforms. Indeed, these materials, mainly composed by tellurium (Te), selenium (Se) and/or sulphur (S) in combination with As, Ge, Sb, Ga, exhibit high transparency through the whole mid-IR, refractive index tunability depending on the glass composition and rare-earth doping capability [4].

This paper presents the design, technological processing and optical characterization of a mid-IR evanescent optical sensor based on a chalcogenide platform. This device is expected to be suitable to detect traces of gas and substances dissolved in aqueous media. The integrated platform is composed by ridge waveguide in which the guiding ($Ge_{12.5}Sb_{25}Se_{62.5}$) and lower confinement ($Ge_{28.1}Sb_{6.3}Se_{65.6}$) layers have, respectively, a refractive index of n_1=2.81 and n_2=2.41 at λ=7.8 µm [5]. The superstrate is given by the substance to be detected, then the air will be assumed as the superstrate for the gas sensor and the water for case of liquids detection. These ChGs thin films layers were deposited on a silicon substrate by RF magnetron sputtering. The ridge waveguides were subsequently patterned using standard i-line photolithography and fluorine-based reactive ion etching.

Computer simulations based on the effective index method were first performed to obtain the geometrical dimensions (width and height) of a ridge waveguide exhibiting single-mode behavior at 7.8 µm while maximizing the evanescent power factor in the superstrate.

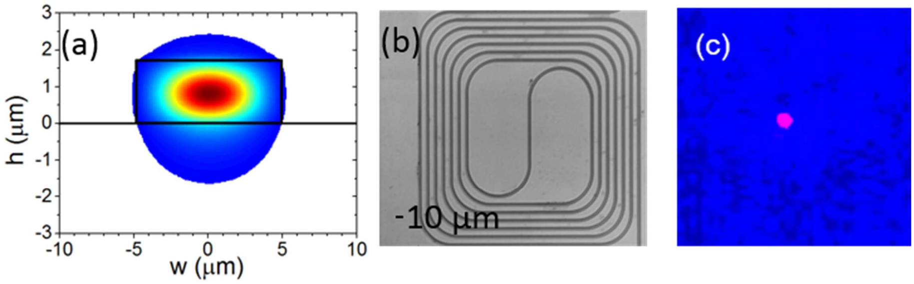

Fig. 27. (a) Fundamental TM mode intensity profile of waveguide in chalcogenide glasses (width: w=10 µm and height h=1.7 µm) at λ=7.8 µm. (b) Microscope image of a spiral waveguide made of chalcogenide glasses from Ge-Sb-Se ternary system. (c) Propagation-mode near-field in a spiral waveguide at λ=7.8 µm.

Optimal dimensions of the monomodal ridge waveguide (width w=10 µm and height h=1.7 µm) led to an evanescent power factor of 8% (Fig. 1a). Assuming propagation losses of 1 dB/cm, the waveguide length maximizing the integrated sensor sensitivity was derived from Beer-Lambert's law to be L_{opt}=43 mm.

A spiral ridge was then fabricated (Fig. 1b) and optically characterized. A microstructured ChGs fiber was used to launch a QCL laser source operating at 7.8 µm into the waveguides. Single mode propagation at 7.8 µm was confirmed by imaging the output facet of the waveguide on mid-IR camera through a high magnification and numerical aperture ZnSe microscope objective (Fig. 1c). Splitter waveguides and S-shape waveguides were also characterized to evaluate the optical losses at 7.8 µm.

These theoretical and experimental results represent the first step towards the development of a ChGs-based spectroscopic integrated sensor working in the mid-IR. Using this platform, it would be possible to detect chemical substances in gaseous and liquids media achieving limits of detection in the order of ppm.

References

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