Mid-Infrared chemical sensing using a chalcogenide integrated transducer

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Mid-Infrared (2-20 µm) spectroscopic techniques are widely used to identify chemicals substances, allowing quantitative real-time measurements in gases, liquids and solids. The current trend heads to the miniaturization of optical sensors, replacing bulky laboratory instruments (FTIR, monochromators, ATR etc..) by lab-on-chip devices providing portability, mechanical stability, immunity to electromagnetic noise and the potential for batch production [1]. In recent years, optical integrated devices have been fabricated using different technologies such as GaAs, Si, Si_3N_4 and Ge. Chalcogenide glasses have also emerged as good candidates to manufacture Mid-Infrared photonic integrated circuits thanks to their ability to be deposited as thin films, their broad transparency (up to 20 µm), their potential to be doped with rare earth ions and their refractive index tunability obtained by varying glass composition [2].

In this paper, we present the optical detection of isopropanol solutions by evanescent field in the Mid Infrared using a chalcogenide single-mode ridge waveguide as integrated transducer. The optical absorption of isopropanol at 7.7 µm (Fig. 1) is detected through the variation of the transmitted optical power as a function of analyte concentration.

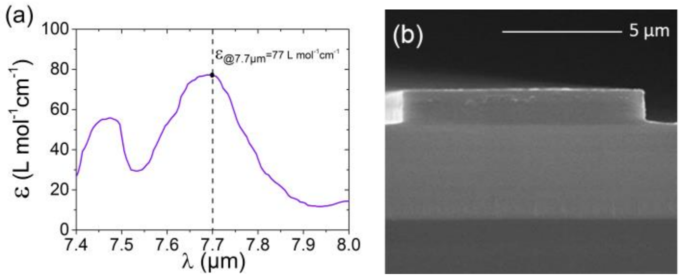

Fig. 1. (a) Molar absorption of isopropanol in the Mid-IR [3]. (b) Cross section of ridge waveguide (SEM image) made of two different compositions of chalcogenide glasses: $Ge_{12.5}Sb_{25}Se_{62.5}$ as guiding layer, $Ge_{28.1}Sb_{6.3}Se_{65.6}$ as confinement layer and the silicon substrate.

Chalcogenide multilayer structures were deposited on a silicon substrate by RF magnetron sputtering and processed as ridge waveguides using standard i-line photolithography and fluorine-based reactive ion etching (Fig. 1b) [2]. Refractive index values of 2.77 and 2.44 have been measured at λ=7.7 µm, respectively, for the guiding ($Ge_{12.5}Sb_{25}Se_{62.5}$) and confinement ($Ge_{28.1}Sb_{6.3}Se_{65.6}$) layers of the integrated transducer.

Optimal dimensions of the single-mode ridge waveguide (width=10 µm and height=1.7 µm) led to an evanescent power factor η=5%. Intrinsic propagation losses α= 2.5 dB/cm were measured by a cutback method from S-shape waveguides [2].
The sensitivity of the device is represented by the variation of output optical power P as a function of the solute concentration C [1] according to the expression 1.

$$S = \left|\frac{dP}{dC}\right| = \varepsilon\, \eta\, L\, P_0 \exp\left(-\varepsilon\, \eta\, C\, L - \alpha_{prop} L\right) \qquad (1)$$

The evolution of the sensitivity S as a function of the waveguide length L was calculated and plotted in Fig. 2a taking into account the following parameters: ε=77 L $mol^{-1}cm^{-1}$, η=5 %, α=2.5 dB/cm, P_0= 0.5 mW. From this figure, it can be seen that the maximum transducer sensitivity S is obtained for a waveguide length L_{opt} equal to 0.63 cm.
Furthermore, the absorption of isopropanol at 7.7 µm is detected by measuring the attenuation of the transmitted power as a function of the analyte concentration. The performance of the evanescent optical integrated sensor was tested by depositing a droplet of 2 µL of the solution (isopropanol dissolved in cyclohexane) on the ridge waveguide surface. The intensity of guided mode, observed at the output of the waveguide by near-field at λ=7.7 µm, was measured by the Mid-IR camera for several concentrations between 2 and 10 v/v%, the results are displayed in Fig. 2b, 2c.

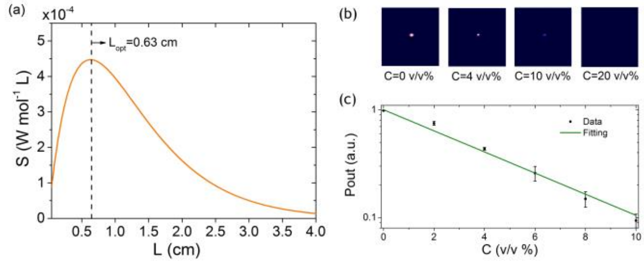

Fig. 2. (a) Evolution of the sensitivity *S* as a function of the waveguide length *L* for α=2.5 dB/cm. (b) Near field intensity of propagated light and (c) transmitted optical power at 7.7 µm for different concentrations of isopropanol.

The optical transmitted power decreases by increasing isopropanol concentration following Beer-Lambert law. These experimental results demonstrating on-chip real-time detection of isopropanol at 7.7 µm could be extended to other substances of interest and represent therefore an outstanding progress in lab-on-chip sensing schemes.

[1] A. Gutierrez-Arroyo, E. Baudet, L. Bodiou, V. Nazabal, E. Rinnert, K. Michel, B. Bureau, F. Colas, J. Charrier, *Theoretical study of an evanescent optical integrated sensor for multipurpose detection of gases and liquids in the Mid-Infrared*, Sens. Actuators B Chem, In press. DOI:10.1016/j.snb.2016.09.173 2017

[2] A. Gutierrez-Arroyo, E. Baudet, L. Bodiou, J. Lemaitre, I. Hardy, F. Faijan, B. Bureau, V. Nazabal, J. Charrier, *Optical characterization at 7.7 µm of an integrated platform based on chalcogenide waveguides for sensing applications in the mid-InfraRed*, Opt. Express, vol. 24, no. 20, pp. 23109-23117, 201

[3] See: *vpl.astro.washington.edu/spectra/allmoleculeslist.htm* for IR absorption cross-sections from PNNL (Last accessed December, 2016)