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Mid-Infrared supercontinuum absorption spectroscopy beyond 7 μm based on free Arsenic chalcogenide fiber

Rémi Bizot¹, Frédéric Désévedavy^{1,*}, Arnaud Lemièr¹, Esteban Serrano¹, Damien Bailleul¹, Clément Strutynski¹, Grégory Gadret¹, Pierre Mathey¹, Bertrand Kibler¹, Idris Tiliouine², Sébastien Février², and Frédéric Smektala¹

¹ Laboratoire Interdisciplinaire Carnot de Bourgogne (ICB), UMR 6303 CNRS-Université de Bourgogne, Dijon, France

² XLIM, UMR 7252 CNRS-Université de Limoges, Limoges, France

Abstract. Mid-Infrared methane (CH_4) spectroscopy results were obtained in band III beyond 7 μm . To achieve this, the generation of supercontinuum covering the spectral range between 5 and 12 μm was realized by using purified chalcogenide optical fibers free of highly toxic elements such as arsenic and antimony. Besides a pumping with an optical parametric amplifier, an all fibered pumping scheme has also been investigated. In both configuration, supercontinuum absorption spectroscopy experiments have allowed for CH_4 sensing, concentration as low as 14 ppm has been detected.

During the last decade there has been a surge of interest in developing mid-infrared (mid-IR) fiber-based supercontinuum (SC) sources [1-5]. Such broadband light sources take advantage of extreme spectral broadening of high-intensity laser pulses in infrared optical fibers usually made of soft glasses, such as chalcogenides that offer the widest transmission window and the highest nonlinearity [6]. Beyond their spatial coherence and high brightness, mid-IR fiber SC sources are nowadays operating over some wavelength ranges of thermal sources with superior performances for spectroscopic applications [7]. In this spectral region, between 2 and 16 μm , organic compounds such as biomolecules present fundamental vibrational resonances and an absorption pattern corresponding to their spectroscopic fingerprints [3, 8]. Furthermore, this spectral range covers the strategic atmospheric windows 3–5 μm and 8–12 μm . This is particularly interesting for practical applications such as greenhouse gas sensing [9], chemical sensing, medical therapeutics, and food safety monitoring [8]. Besides, it is worth mentioning that many applications of optical technologies related to healthcare, pharmaceuticals, and environmental monitoring are calling for biocompatible materials excluding compounds containing arsenic as well as antimony. The European [10] Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulation aims to limit or suppress as far as possible the usage of highly toxic substances. Presently, arsenic is already classified as acutely toxic in the REACH database. It is also considered as one of the ten substances of major concern for human health by the World Health Organization. In

the present work, we demonstrate the fabrication of single-material optical fibers as well as step-index ones based on chalcogenide fibers free of highly toxic elements such as arsenic and antimony. The studied compositions belong to the Ge-Se-Te ternary system for both core and cladding glasses.

More precisely they belong to the pseudo-binary GeSe_4 - GeTe_4 , on the Se-rich side [11]. The thermal and optical properties of bulks and fibers have been investigated, as well as the purification process, in order to obtain low-loss optical fibers (fig1). The figure 1 also evidences dispersion engineering in step-index fibers drawn from these glasses, according to their opto-geometric characteristics, in particular for optimizing SC generation. Such fiber pumped by a non colinear optical parametric amplifier (NOPA) followed by a difference frequency generation (DFG) module has led to large bandwidth supercontinuum extending from 1.8 up to 18 μm within 20dB of dynamic range [12].

Finally, the SCs have been employed for gas sensing in the mid infrared range, above 7 μm . Supercontinuum absorption spectroscopy experiments on CH_4 gas have been performed using a dedicated gas cell based on hollow fibers. Concentration as low as 14 ppm has been detected. An all fibered configuration has also been investigated. In that case the pump source is a fluoride-based fiber laser which emit a femtosecond pulse centered at 4.1 μm . The SC generated has allowed for CH_4 absorption gas sensing above 7 μm with a sensitivity down to 20 ppm. Limitations and perspectives of such sensor will also be presented.

* Corresponding author: frederic.desevedavy@u-bourgogne.fr

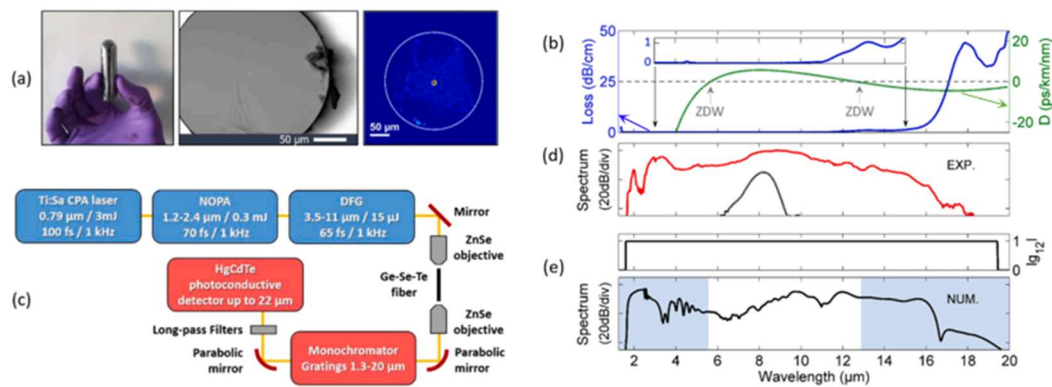


Fig. 1. (a) From left to right: Synthesized Ge-Se-Te glass rod; Scanning electron microscope image of the cross-section of our 12- μm -core step-index fiber; Output near-field profile of the fundamental guided mode measured for an input broadband mid-IR source (the outer fiber diameter is indicated by the white circle). (b) Left axis, blue curve: Large-core fiber losses (inset: zoom on background losses). Right axis, green curve: Calculated dispersion profile D of fundamental guide mode for the 12- μm core Ge-Se-Te fiber. (c) Experimental setup for SC generation. (d) Measured output SC spectrum (red solid curve) from a 40-mm-long segment of 12- μm core fiber. Input pulse spectrum centered at 8.15 μm (black dotted curve). (e) Corresponding numerical simulation (bottom panel: SC spectrum, top panel: first-order degree of coherence). Blue areas indicate regions with normal dispersion ($D < 0$). [12]

References

- [1] C. R. Petersen, U. Møller, I. Kubat, B. Zhou, S. Dupont, J. Ramsay, T. Benson, S. Sujecki, N. Abdel-Moneim, Z. Tang, *et al.*, *Nature Photonics*, **8**, no. 11, p. 830, 2014.
- [2] Y. Yu, B. Zhang, X. Gai, C. Zhai, S. Qi, W. Guo, Z. Yang, R. Wang, D.-Y. Choi, S. Madden, *et al.*, *Optics Letters*, **40**, no. 6, pp. 1081–1084, 2015.
- [3] Z. Zhao, B. Wu, X. Wang, Z. Pan, Z. Liu, P. Zhang, X. Shen, Q. Nie, S. Dai, and R. Wang, *Laser & Photonics Reviews*, **11**, no. 2, 2017.
- [4] S. Venck, F. St-Hilaire, L. Brilland, A. N. Ghosh, R. Chahal, C. Caillaud, M. Meneghetti, J. Troles, F. Joulain, S. Cozic, *et al.*, *Laser & Photonics Reviews*, **14**, no. 6, p. 2000011, 2020.
- [5] R. A. Martinez, G. Plant, K. Guo, B. Janiszewski, M. J. Freeman, R. L. Maynard, M. N. Islam, F. L. Terry, O. Alvarez, F. Chenard, R. Bedford, R. Gibson, and A. I. Ifarraguerri, *Opt. Lett.*, **43**, pp. 296–299, Jan 2018.
- [6] G. Tao, H. Ebendorff-Heidepriem, A. M. Stolyarov, S. Danto, J. V. Badding, Y. Fink, J. Ballato, and A. F. Abouraddy, *Adv. Opt. Photon.*, **7**, pp. 379–458, Jun 2015.
- [7] I. Zorin, J. Kilgus, K. Duswald, B. Lendl, B. Heise, and M. Brandstetter, *Applied spectroscopy*, **74**, no. 4, pp. 485–493, 2020.
- [8] M. F. Ferreira, E. Castro-Camus, D. J. Ottaway, J. M. López-Higuera, X. Feng, W. Jin, Y. Jeong, N. Picqué, L. Tong, B. M. Reinhard, *et al.*, *Journal of Optics*, **19**, no. 8, p. 083001, 2017.
- [9] C. Strutynski, J. Picot-Clémente, F. Désévéday, J.-C. Jules, G. Gadret, B. Kibler, and F. Smektala, *Laser Physics Letters*, **13**, no. 7, p. 075402, 2016.
- [10] <https://echa.europa.eu/fr/regulations/reach>
- [11] A. Lemièrre, F. Désévéday, P. Mathey, P. Froidevaux, G. Gadret, J.-C. Jules, C. Aquilina, B. Kibler, P. Béjot, F. Billard, *et al.*, *JOSA B*, **36**, no. 2, pp. A183–A192, 2019.

- [12] A. Lemièrre, R. Bizot, F. Désévéday, G. Gadret, J.-C. Jules, P. Mathey, C. Aquilina, P. Béjot, F. Billard, O. Faucher, B. Kibler, and F. Smektala, *Results in Physics*, **26**, p. 104397, 2021.

* Corresponding author: frederic.desevedavy@u-bourgogne.fr