# Mid-infrared supercontinuum source and evanescent wave spectroscopy based on multiple tapered sections of a singleoptical chalcogenide glass rod

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**Abstract.** Mid-infrared supercontinuum sources are particularly important for identifying and characterizing molecules and materials through spectroscopy, thus enabling key applications. We here demonstrate the possibility of combining both mid-IR supercontinuum generation and evanescent wave spectroscopy in a single chalcogenide fiber device by means of heat-and-draw processes to manage linear and nonlinear wave-guiding properties.

Fiber evanescent wave spectroscopy, also known as FEWS, is a powerful technique used for analysing chemical compositions in medical or environmental fields. It consists of a single-index or uncladded step-index optical fiber immersed in a sample media which acts as an absorbing cladding. The evanescent fraction of the guided light at the interface between the waveguide and sample to test is partially absorbed by the molecule's fingerprints (i.e., attenuated internal reflection), resulting in the detection of suitable absorption spectra at the fiber output. The development of this technology in the IR and especially in mid-IR, where a lot of molecules have their strongest absorptions, is a very active research field. The goal is to enhance sensitivity and expand operational range via studying different geometries, shapes, sources or materials [1-6]. One of the main limitations of this technique can be the light source itself. In general, a thermal emitter is used as the broadband light source coupled into the fibre, resulting in high insertion losses and low output power. In this work, we investigate the possibility to overcome this issue by combining simultaneously two optical functions in a single chalcogenide glass rod, namely mid-IR supercontinuum (SC) generation in a first tapered section of the glass rod and FEWS sensor in a second coiled tapered section.

Our experimental work is based on a TeAsSe glass rod (i.e., a single-index chalcogenide fiber) with a 180-µm diameter. For both SC generation and FEWS functionalization of the glass rod, we advantageously combine well-known post-processing techniques (i.e., heat-and-draw processes) of shaping optical fibers into different geometries to manage their wave-guiding features. For the first section in charge of the SC generation, a taper with a small waist diameter of 25µm is fabricated using a Vytran Glass Processor (GPX 3400). On the one hand it shifts the zero dispersion wavelength down to 6µm, and on the other hand, it significantly increases the light confinement and thus, enhances the nonlinear effects for efficient supercontinuum generation.

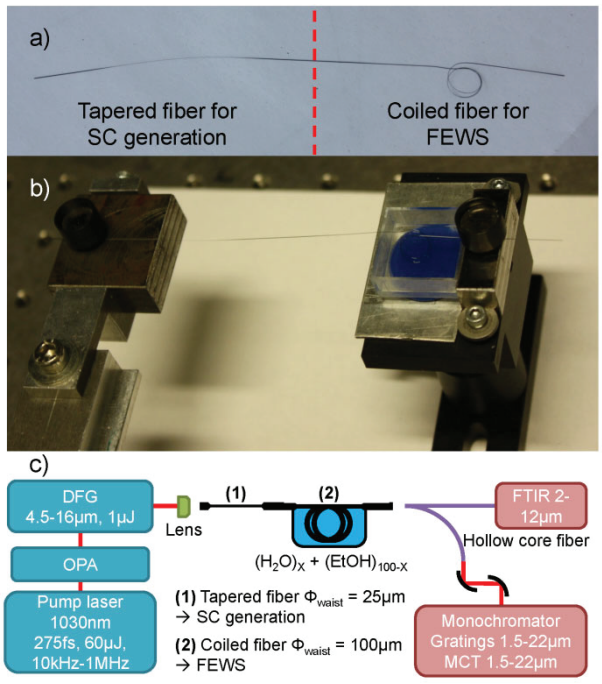


**Fig. 1.**(a-b) Picture showing the shaped chalcogenide rod in and out of the experimental device (red dashed line indicates the two different sections). (c) Full experimental setup.

The second part of the device is the sensing section, which is also tapered down but to a larger waist diameter of 100µm. This taper is used to increase the proportion of evanescent field, and thus, the sensitivity of the device [7], but does not participate in the generation of new frequencies. Additionally, this sensing part is coiled with a home-made system, in order to have a longer interaction length with the sample, as well as to simplify the handling of the whole device, as shown in Fig.1a. We then implemented the complete experimental setup shown in Fig. 1c.

We first characterized the SC generated in the first tapered section of our glass rod, pumped by a femtosecond laser source. We made use of 275-fs mid-IR pulses at 200-kHz repetition rate around 7-µm wavelength. Laser pulses are coupled into rods by means of a 40-mm-focal ZnSe lens and the output SC is collected through a mid-IR hollow-core fiber with high transmission over 2-16µm. Spectral characterizations were performed using a compact FTIR spectrometer or a monochromator combined with a MCT detector. A supercontinuum spanning from 5 to 12µm was achieved with an output power of more than 20mW (see Fig. 2a). Such a spectral coverage is comparable to previous measurements without sensing part in the fiber. We then assumed negligible losses due to the coiling in the SC spectral range. Then, we immersed the sensing part of the chalcogenide fiber in different blends of water and ethanol (see Fig. 1b) to assess the operation of our sensor. The transmission spectrum recorded for a 25:75 vol% blend is depicted in Fig. 2b and compared to the reference spectrum from database [8]. Two main absorption peaks of ethanol between 9 and 10µm are clearly observed, while the ones between 10 and 12µm are less visible due to the lower signal-to-noise ratio provided by our SC source.

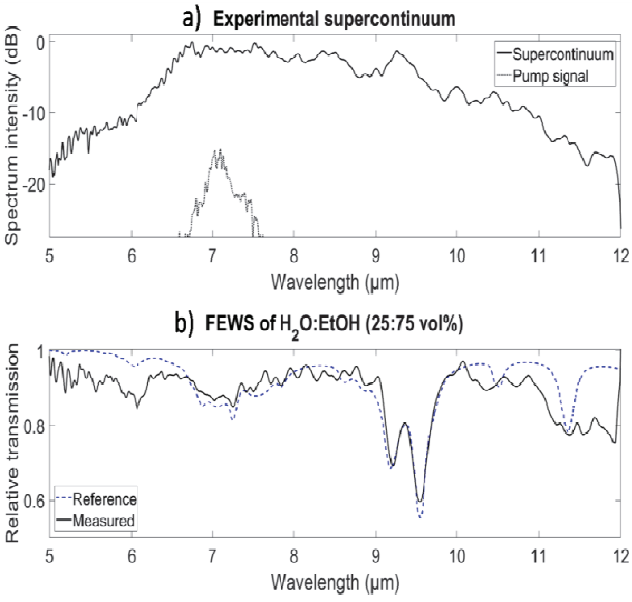


**Fig. 2.**(a) Supercontinuum spectrum measured at the output of the whole device. The input pump spectrum is also depicted. (b) Measured transmission spectrum of our device for a 25:75 vol% blend of water-ethanol applied to the FEWS section (black solid line) compared to the corresponding reference from database [8] (blue dashed line).

In conclusion, our preliminary results demonstrate the possibility to simultaneously combine two optical functions (a nonlinear broadband frequency conversion and a linear FEWS) in the mid-IR on a single chalcogenide fiber device by using suitable heat-and-draw processes. Nevertheless, several optimization procedures and challenges remain and are under investigations.

## References

1. V. Ruddy, B. D.MacCraith, J. A. Murphy, *Evanescent wave absorption spectroscopy using multimode fibers*, J. Appl. Phys. **64**(1990)
2. D. Littlejohn, D. Lucas, L. Han, *Bent Silica Fiber Evanescent Absorption Sensors for Near-Infrared Spectroscopy*, Appl. Spectro. **53** (1999)
3. S. Maurugeon, B. Bureau, C. Boussard-Plédel, A. J. Faber, P. Lucas, X. H. Zhang, J. Lucas, *Selenium modified $GeTe_4$ based glasses optical fibers for far-infrared sensing*, Opt. Mat. **33** (2010)
4. S. Korsakova, E. Romanova, A. Velmuzhov, T. Kotereva, M. Sukhanov, V. Shiryaev, *Peculiarities of the mid-infrared evanescent wave spectroscopy based on multimode chalcogenide fibers*, J. Non-Cry. Sol. **475** (2017)
5. I. Zorin, P. Gattinger, A. Ebner, M. Brandstetter, *Advances in mid-infrared spectroscopy enabled by supercontinuum laser sources*, Opt. Exp **30** (2022)
6. P. Chevalier, M. Piccardo, G-M. De Naurois, I. Gabay, A. Katzir, F. Capasso, *In-water fiber-optic evanescent wave sensing with quantum cascade lasers*, Sen. Act. B **262** (2018)
7. C. Yang, X. Wang, J. Su, S. Dai, *Spectroscopy analysis of mixed organic liquid detection with $Ge_{20}Se_{60}Te_{20}$ glass-tapered fiber*, J. Non-Cry. Sol. **500** (2018)
8. https://spectrabase.com/