MINERVA project newsletter #7

Dec-2016

Welcome to the seventh MINERVA project newsletter!

The project has been granted an extension, in order to complete the integration and application of the MINERVA imaging systems, and will now run until 31-Jul-2017. In this newsletter we report:

- High-energy Er:ZBLAN fibre laser (lead partner: LISA Laser)
- Mid-IR fibre developments including Pr-doping and ultra-low loss (University of Nottingham)
- Effect of pixel size in high resolution FTIR imaging (GHNT/Exeter/UPV)
- Record supercontinuum in tapered photonic crystal fibres (lead partner: DTU)

There is much more information available from the project website (www.minerva-project.eu). For any other questions, further contact info is given below.

MINERVA workshop

Räter Park Hotel, Munich, Germany; 30-Jun-2017

The MINERVA project is pleased to announce its final workshop on mid-IR technology. The agenda will be released shortly, and will include presentations on:

-MINERVA hardware: mid-IR fibres; lasers, supercontinuum sources, components and detectors
-MINERVA applications: high resolution mid-IR imaging & spectroscopy, automated analysis of cell spectra for cancer diagnosis
-Expert guest speakers covering a range of topics on mid-IR technology and applications.

The event will be held the day after LASER World of Photonics (inc. ECBO & CLEO Europe).

Attendance is free, but places are limited. Please get in touch if you would like to attend!

Gooch & Housego · Westfälische Wilhelms-Universität Münster · Vivid Components · University of Exeter · LISA · NKT Photonics the power of light · DTU · The University of Nottingham United Kingdom · China · Malaysia · Gloucestershire Hospitals NHS Foundation Trust · Universidad Politecnica de Valencia · BBT · IRnova · Xenics Infrared Solutions

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High-energy Er:ZBLAN fibre laser

LISA Laser (Germany) demonstrated a high-energy Er:ZBLAN fibre laser with unprecedented performance using components from Gooch and Housego (UK). The partners followed the approach of acousto-optic Q-switching of an external cavity to exploit the full flexibility of the system. This effort led to world record values for both the pulse energy and peak power.

The main components are the 976 nm diode-pumped Er:ZBLAN multimode fibre and a novel TeO_2-based acousto-optic modulator (AOM) fabricated by G&H. The 330 µm cladding pumped active fibre had an Er-dopant concentration of 6 mol.% (33 µm core; NA_{CORE} 0.12, NA_{CLAD} 0.5, FiberLabs Inc.) and an absorption of ~5 dB/m at 980 nm. The laser resonator was set up by an external highly reflective mirror at 3 µm and the Fresnel reflection at the opposite fibre end. The AOM was used for Q-switching the cavity at 1 kHz pulse repetition rate. Both facets of the AOM were anti-reflection coated from 2.7 µm to 3 µm and the active aperture was 1.5 mm.

For more info
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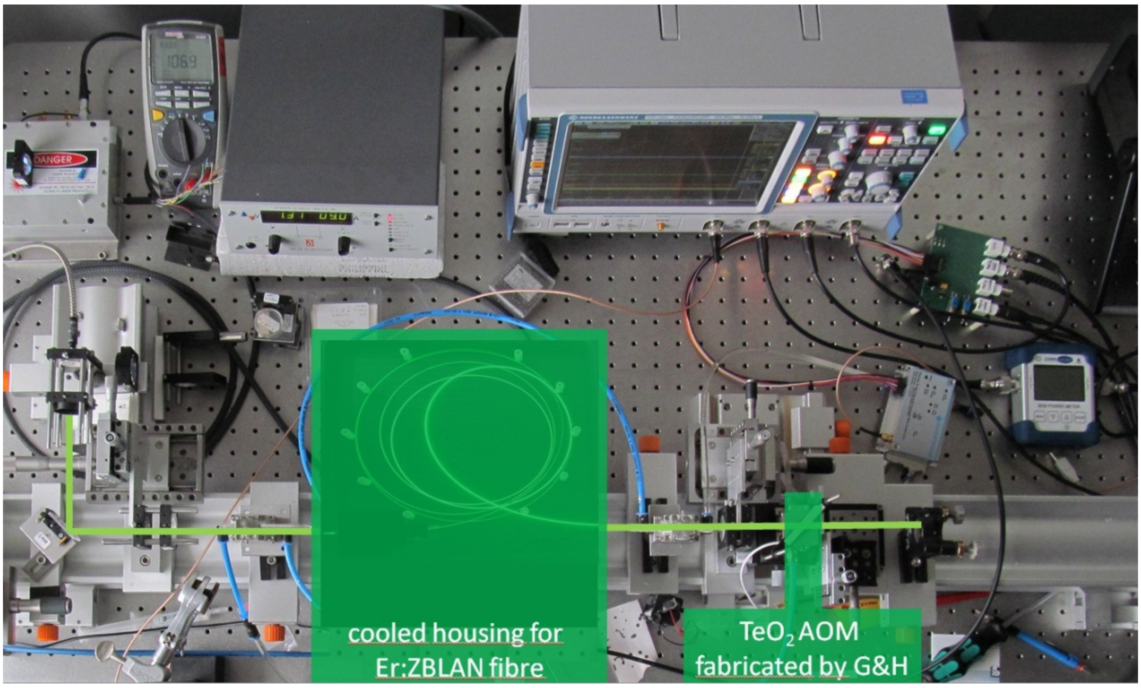
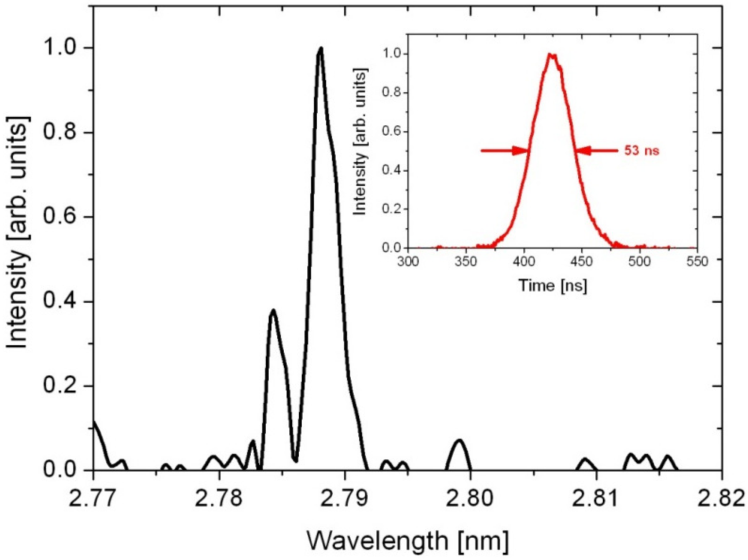


Photograph of the experimental high-energy Er:ZBLAN fibre laser arrangement. The active fibre was conductively cooled to 20°C by placing it on an aluminium plate. The ends of the fibre were sandwiched in cooled fibre chuck holders.

The maximum pulse energy extracted from the laser oscillator was 560 µJ at a pulse repetition rate of 1 kHz. The corresponding minimum pulse duration was 53 ns corresponding to a maximum pulse peak power of 10.6 kW. The energy fluence at the output fibre end was calculated to be ~70 J/cm² at the maximum pulse energy level.

These values exceed already published work by an order of magnitude and clearly demonstrate the potential for the practical use. Work continues at LISA and products are expected in the near future.



Laser spectrum at 2.79 µm and pulse duration (inset graph) of the Q-switched Er:ZBLAN fibre laser at room-temperature. [From S. Lamrini et al., CLEO-E, paper CJ_7_2 (2015).]

MINERVA improved medical diagnostics

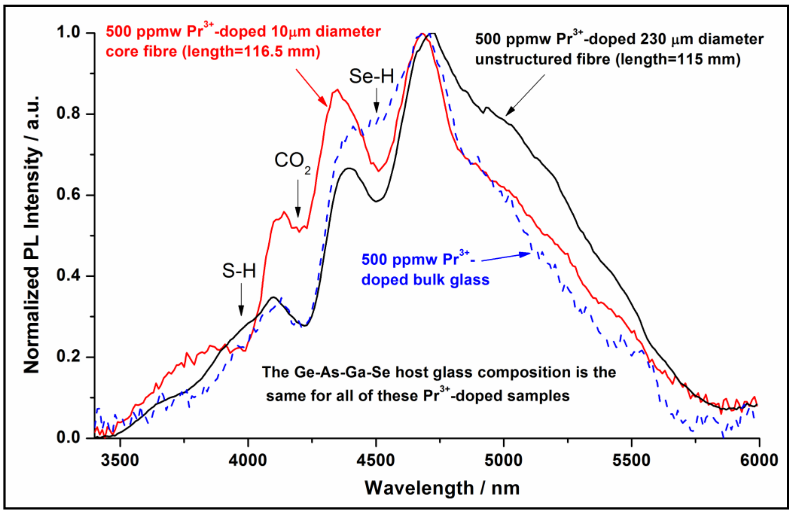
The University of Nottingham UNITED KINGDOM · CHINA · MALAYSIA

Mid-IR fibre developments

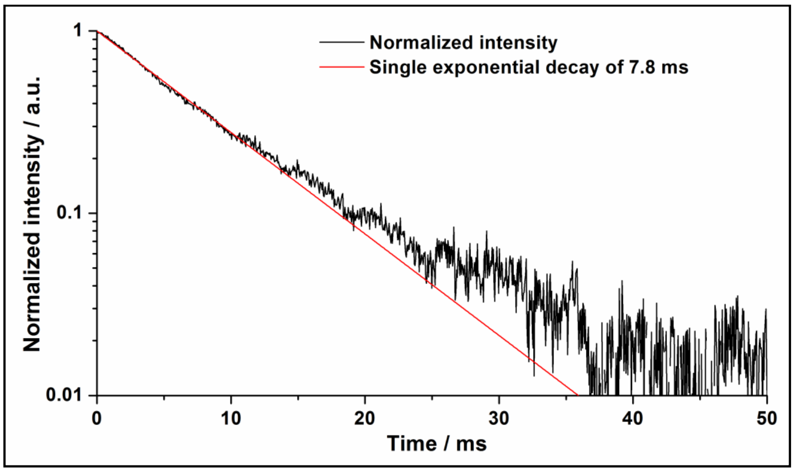
Rare earth ion doped small core fibres

Prof. Seddon's group at University of Nottingham (UK) has made excellent progress on several areas of mid-IR fibre development. In the quest for a mid-IR tunable laser, fibres fluorescing in the 3-6 µm region are of great interest, including praseodymium (Pr) doped fibres.

Fluorescence measurements (pump laser: 65 mW; 1550 nm) show the same photoluminescence (PL) lifetime as the bulk glass for both unstructured (230 µm diameter) and small core (10 µm) fibres.



Mid-IR fluorescence at ~3.5 to 5.7 µm wavelength for rare earth ion doped bulk glass compared with large and small core fibres.



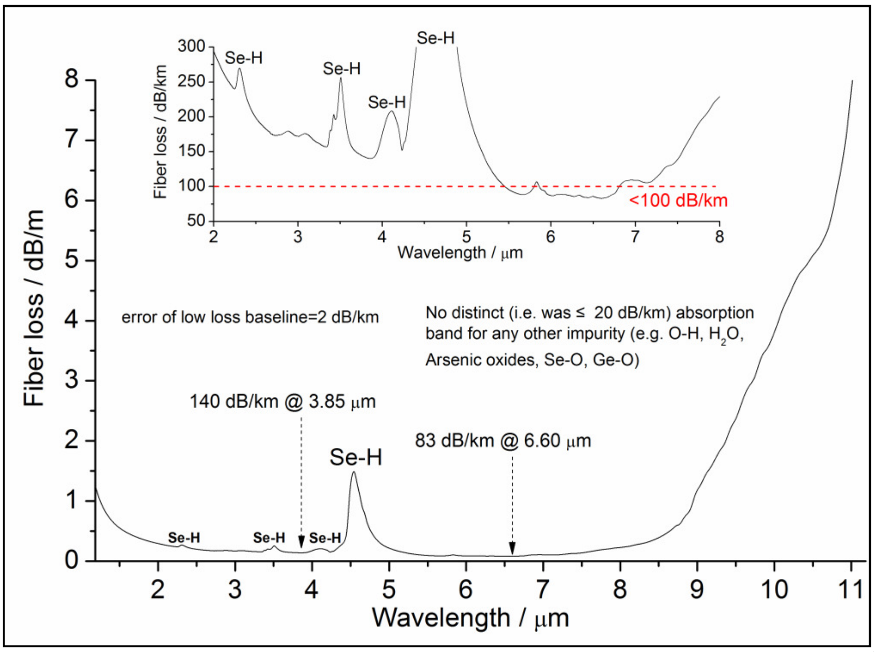
PL lifetime=7.8 ms for 500 ppmw Pr^{3+} doped Ge-As-Ga-Se, SI 10 µm core fibre at 4700 nm. Pump: 64.8 mW @1550 nm.

This shows that the local environment of the doped rare earth ions has survived the demanding processing required to form the small core fibre.

Further details may be found in: Z. Tang, *et al.*, "*Mid-infrared photo-luminescence in small-core fiber of praseodymium-ion doped selenide-based chalcogenide glass*," Opt. Mater. Expr. **5**, p. 870-886 (2015).

Towards ultra-low loss mid-IR fibre

World-beating loss! The inset in the figure opposite shows the sub-100 dB/km loss characteristic. Mid-IR radiation is propagated through a (remarkable!) 52 m of fibre, which has the lowest loss yet reported for Ge-As-Se fibre (83±2 dB/km at 6.60 µm). For more details see Z. Tang *et al.*, "*Low loss Ge-As-Se chalcogenide glass fiber…*", Opt. Mater. Expr. **5**, p. 1722-1737 (2015).



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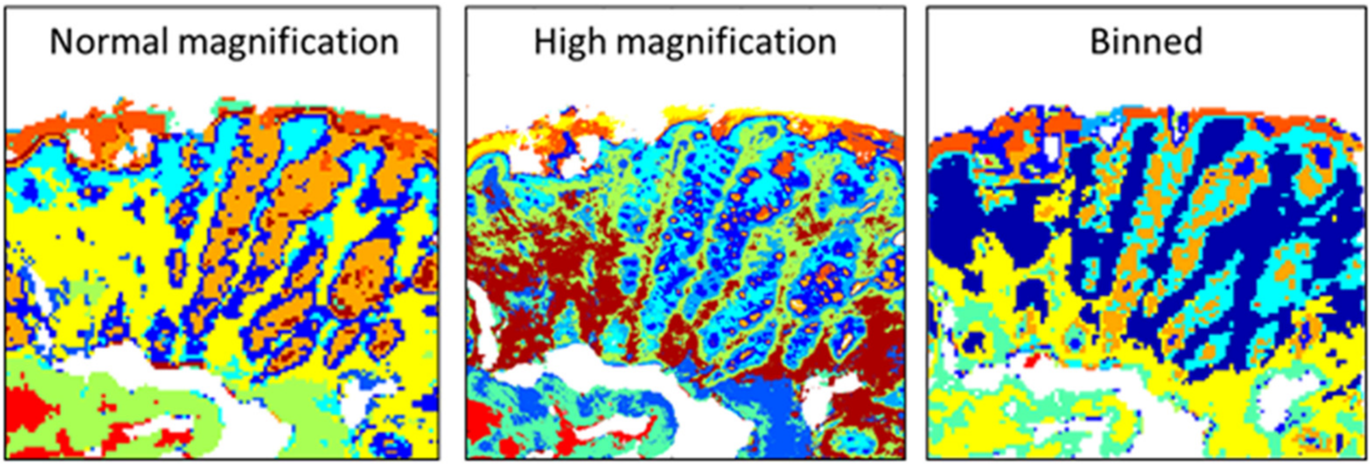
SEVENTH FRAMEWORK PROGRAMME

Effect of pixel size in high resolution FTIR imaging

Pixel binning

Until recently FTIR pixel size has been limited to 5.5 µm which results in a comparatively low magnification image for histology applications and potentially the loss of important diagnostic information. The recent introduction of higher magnification optics gives image pixels that cover approx. 1.1 µm. This reduction in pixel size gives images of higher magnification and improved spatial detail can be observed. However, the effect of increasing the magnification on spectral quality and the ability to discriminate between disease states is not well studied. The team tested the discriminatory performance of FTIR imaging using both standard (5.5 µm) and high (1.1 µm) pixel size for the detection of colorectal cancer and explored the effect of binning to degrade high resolution images in order to determine whether similar diagnostic information and performance can be obtained using both magnifications.



Pixel maps for normal (left) and high (centre) magnification, and the map resulting from "binning" the high magnification image (right).

Results indicate that diagnostic performance using high magnification may be reduced compared with standard magnification when using existing multivariate approaches (see table). Reduction of the high magnification data to standard magnification via binning can potentially recover some of the lost performance.

PLS-DA	Sensitivity	Specificity
Normal magnification	87%	79%
High magnification	88%	63%
Binned	85%	96%

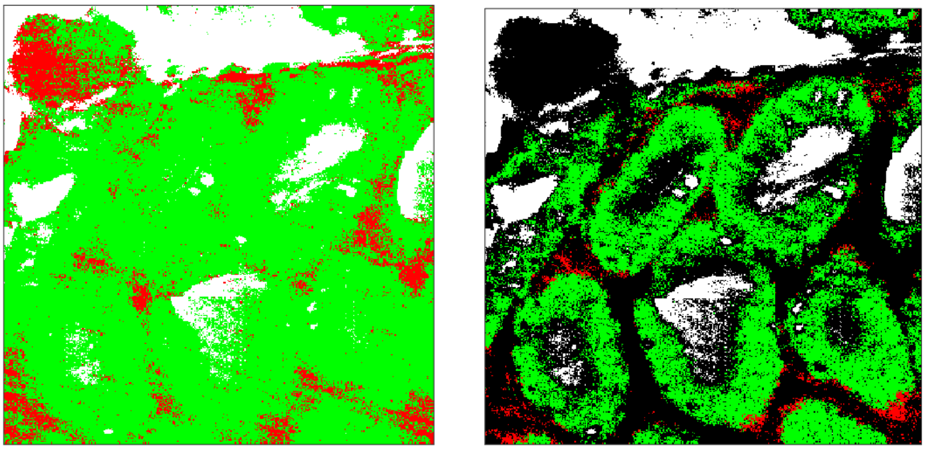
For more information see: G.R. Lloyd, J. Nallala and N. Stone, "*Investigating the effect of pixel size of high spatial resolution FTIR imaging…*" Proc. SPIE **9703**, 970306 (2016).

Automated strategies

Providing a prediction from poor quality spectra or assigning the wrong pathology is potentially very serious in a clinical setting. Gloucestershire Hospitals NHS Trust, University of Exeter and UP Valencia are developing novel automated strategies for test set outlier detection which will prevent predictions being generated for low quality pixels or pixels from pathologies that should not be considered (*e.g.* blood vessels, connective tissue). These modifications make the methods considerably more applicable to clinical problems such as those being investigated in MINERVA. An example of the results is given on the following page.

Left:
Standard approach gives prediction for all pixels

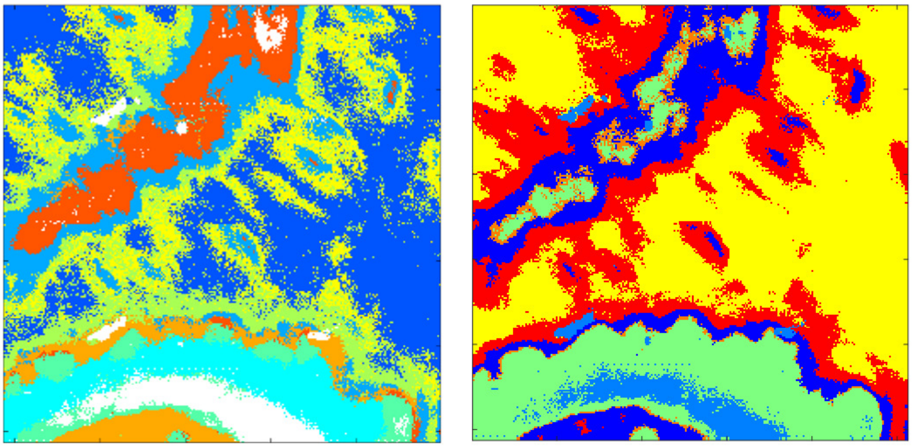
Right:
Modified approach rejects non-epithelial regions



Red = cancer
Green = normal
Black = rejected

Spatially guided clustering techniques

As the magnification of the FTIR images has increased so has the detail available. However, this detail comes at the cost of signal quality due to decreased light intensity per pixel on the detector. This can result in poor quality 'noisy' clusters that are not representative of the underlying biochemical signals. To overcome this the team has been investigating spatially guided clustering techniques. By making the assumption that neighbouring pixels are likely to be members of the same cluster, the quality of the clustering can be improved. Preliminary results indicate that this may improve cluster performance, which is essential for MINERVA as clustering forms one of the first fundamental steps in the diagnostic algorithms.



Left:
Standard clustering

Right:
Spatially guided clustering

For more info contact
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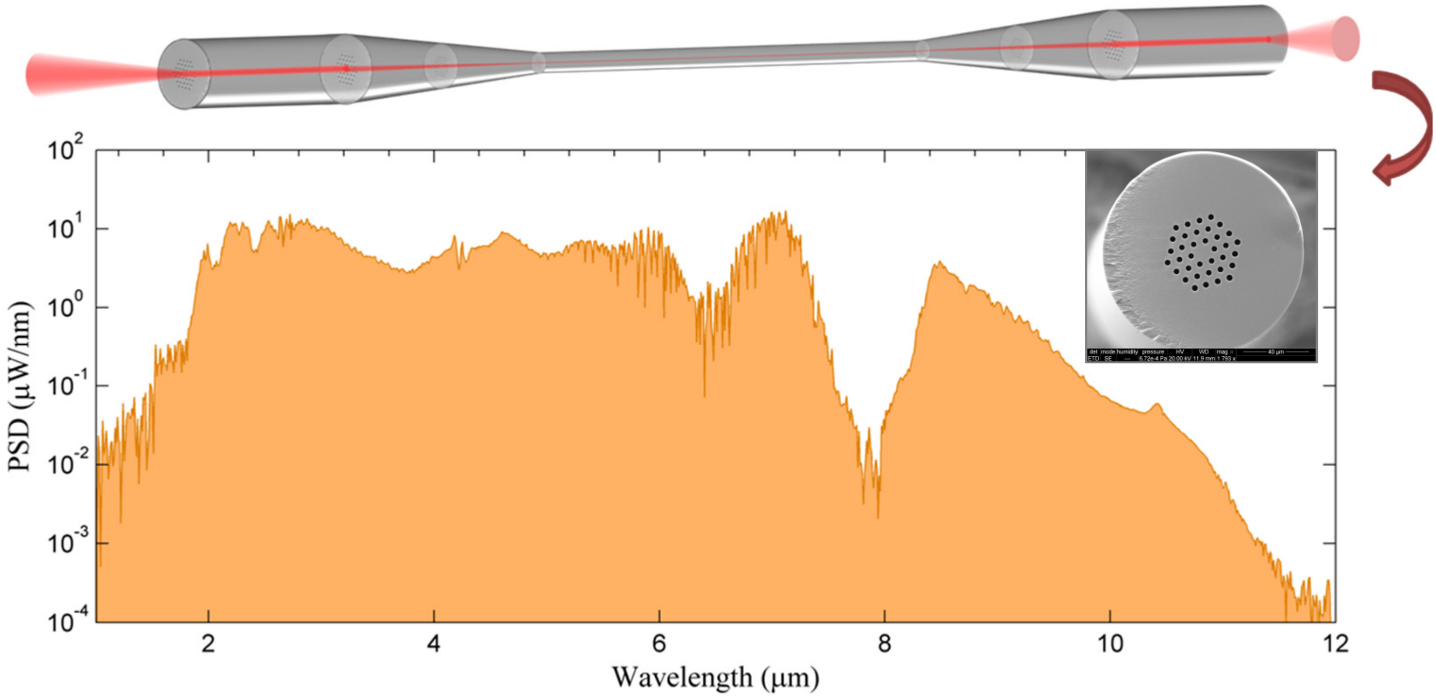
Record supercontinuum in tapered photonic crystal fibres

The team at DTU Fotonik has recently demonstrated the broadest mid-IR supercontinuum generation (SCG) ever obtained in a chalcogenide photonic crystal fibre, spanning a region in wavelength from 1-11 µm (or 10000-900 cm^{-1} in wavenumbers). Building on this success, the team also managed in separate experiments to produce a maximum supercontinuum output power of 57 mW with 24.5 mW above 4.5 µm (*i.e.* below 2220 cm^{-1}), and 9.3 mW above 6.5 µm (below 1540 cm^{-1}), which are the highest ever demonstrated in the long wavelength region.

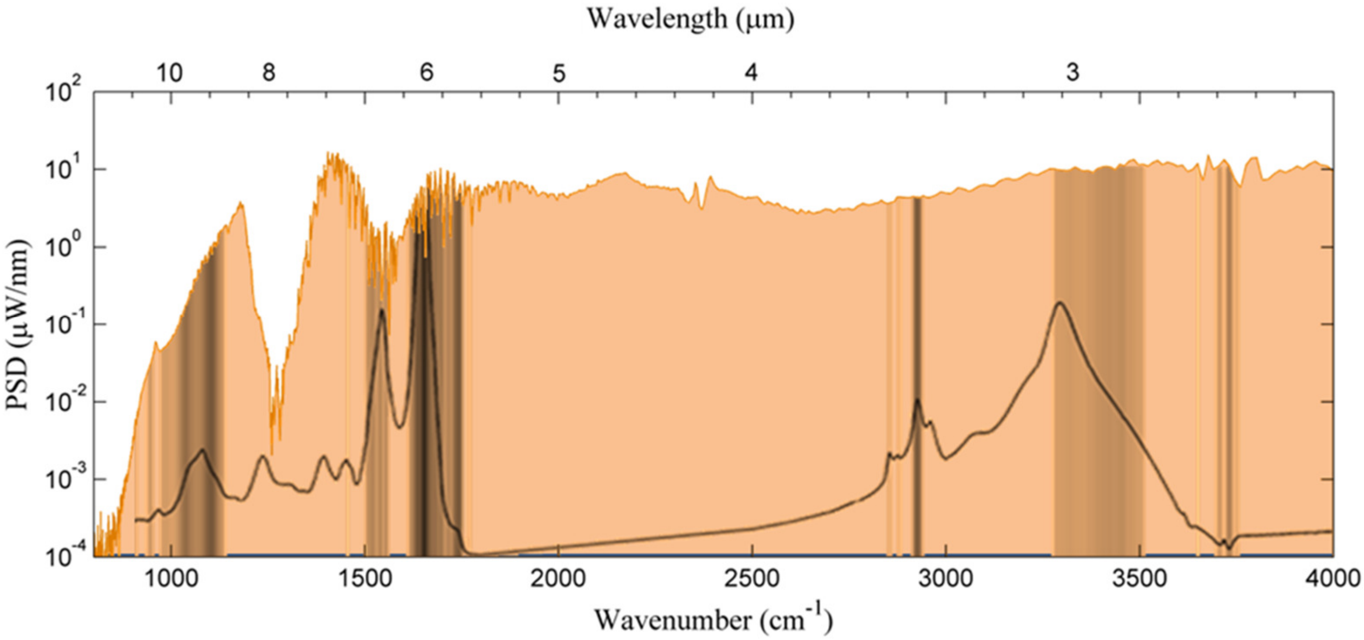
The results came out of a collaboration with the company SelenOptics, which produced the specialty tapered chalcogenide fibres, and is now working on supplying a fully packaged and connectorised solution with polished end caps for improved stability and robustness.

Following these demonstrations, the project partner Gooch & Housego will visit the newly built lab facilities at DTU early in 2017 to implement the source into a scanning mid-IR micro-spectroscopy system, and an imaging spectroscopy system based on the Xenics/IRNova long-wave camera technology.



Schematic showing SCG from a tapered PCF spanning 1-11 μm.

The new source covers the MINERVA target wavenumbers between 4000-1000 cm^{-1}, as can be seen in the figure below. Nevertheless the DTU researchers will continue to develop the source to increase the power and improve the flatness of the spectrum above 6 μm (below 1660 cm^{-1}).



Schematic showing SCG from a tapered PCF with key absorption peaks of interest for MINERVA.

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