Supercontinuum broadband light sources covering UV to IR applications (SUPUVIR EU Project)

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https://www.supuvir-itn.eu/

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Abstract. We review our recent advances in supercontinuum (SC) generation in specialty optical fibres in the context of the European H2020-MSCA-ITN-2016 project called SUPUVIR. Significant scientific progress was made in emerging UV and mid-IR wavelength ranges for biomedical applications and molecular spectroscopy, evidenced by many scientific publications and the development of new compact and reliable mid-IR SC fibre sources. As a result, supercontinuum technology and its industrial applications have been matured considerably.

1 Introduction

A standing challenge since the invention of the laser has been to use nonlinear processes to convert laser light to new wavelengths as lasers only operate efficiently at distinct wavelengths. Supercontinuum (SC) generation offers an elegant solution to this, as it massively broadens the laser spectrum. In its simplest case a powerful narrowband laser is sent into a short piece of fibre to generate a rainbow of colours at the output, pertaining the brightness and spatial coherence of the laser. This allows access to both new wavelengths and new applications exploiting coherent broadband laser radiation that are not available with conventional laser technology.

The scientific challenges addressed in the European project SUPUVIR was to overcome current shortcomings of SC sources in terms of wavelength coverage, noise, power density and robustness to offer a truly unique and disruptive technology for societal and industrial challenges, such as pollution and food quality monitoring, bio-imaging, molecular spectroscopy, detection and monitoring of key diseases, such as cancer and glaucoma.

15 Ph. D students (early stage researchers, ESR) were trained and involved in different work packages ranging from glass chemistry, fibre design and drawing, to the development of next generation SC sources and their applications.

Significant scientific progress was made in emerging UV and mid-IR wavelength ranges, evidenced by many publications, and some SC light-based demonstrators were developed in the project. As a result, supercontinuum technology and its industrial applications have been matured considerably.

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2 Major Results

The major advances in SUPUVIR beyond state-of-the-art are:

1. The development of a deep understanding of low-noise coherent so-called all-normal-dispersion (ANDi) supercontinuum (SC) generation and how is depends on pump laser noise and the birefringence of the optical fibre. This has enabled SUPUVIR researchers to develop these low-noise ANDi SC sources and demonstrate unrivalled performance in optical coherence tomography (OCT) imaging and scanning near-field optical microscopy in terms of sensitivity and penetration depth. This will allow faster and more accurate diagnosis of important diseases, such as skin cancer and glaucoma.

2. The development of SC cascading towards the mid-IR, which is a very complicated process in which a broadband SC is used to pump another optical fibre to generate an SC extending to even longer wavelengths. This knowledge has profound importance for the development of the future long-wavelength mid-infrared SC sources extending past 10 μm to cover the so-called molecular fingerprint region. Such sources are of key importance for pollution and food quality monitoring, as well as for performing ultra-fast optical biopsies of cancer tissue.

3. Through the scientific advanced industrial partner NKT Photonics is developing a new low noise SC laser product series with more than an order of magnitude lower noise than current state-of-of-the-art. Likewise industrial partners LEUKOS and NORBLIS have developed compact and reliable mid-infrared cascaded fibre SC laser product series that for the first time extends to wavelengths longer than 10 μm.

4. A fully automated multimodal fluorescence microscopy platform has been developed at UCAM incorporating an SC laser, which is capable of intensity, lifetime, and spectral imaging at unprecedented speeds (orders of magnitude faster than conventional approaches) without sacrificing accuracy or. The system fills a major gap in biomedical diagnostics and provides new opportunities for drug research in cells or organism models. The novel platform has already enabled SUPUVIR researchers to make significant contributions in the fields of neuroscience, stem cells, gene delivery, and material science.

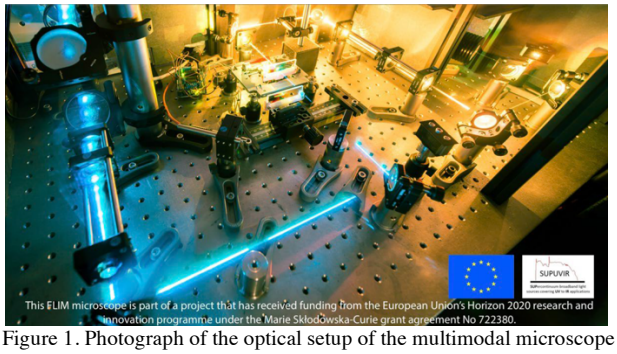

Figure 1. Photograph of the optical setup of the multimodal microscope including a SC light source.

5. A near-infrared SC laser with extremely high pulse energy has been developed and used as the light source in a new optical-resolution photoacoustic microscope (OR-PAM). The new system has allowed the researchers to demonstrate real-time in vivo hyper-spectral PAM of lipids and endogenous agents inside live tadpoles. The results have underlined the suitability of high-pulse energy SC lasers in endoscopic multi-spectral OR-PAM systems for the detection of atherosclerosis, a key disease in an increasingly obese society.

6. Industrial partner VALMET has been able to develop a short-range SC laser-based LIDAR system for remote profiling of the temperature and gas composition inside thermal devices, such as industrial furnaces and boilers. This represents the first non-contact system to be able to provide a profile (not just an average) of the temperature and gas composition.

7. A multimodal MIR OCT-Spectroscopy system based on SC light source has been developed and demonstrated by RECENDT for structural non-destructive testing.

8. New low-loss heavy-metal-oxide and chalcogenide glass photonic crystal fibres have been designed and successfully fabricated by UR1 and IMIT (formely ITME) for SC generation towards the mid-IR. New UV-grade silica PCFs have been also designed by CNRS.

9. Improved numerical modeling of SC generation and nonlinear dynamics in optical fibers, including input noise and all laser parameters, has been performed by CNRS and DTU, validated by real-time SC experimental measurements.