Low-noise visible-near-infrared supercontinuum sources for optical coherent tomography applications

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SUPUVIR

SUPercontinuum broadband light sources covering **UV** to **IR** applications

NKT Photonics

Objectives

- The ESR is involved in the WP 3 and 5. The main objective of the ESR is to realize an all-fibre all-normal dispersion supercontinuum generation with femtosecond pumping for OCT application. For this ESR 9 will develop an all-fibre 200 fs laser (using chirped-pulse amplification followed by compression in a hollow core fibre) and use this to generate very low noise SC by pumping a dispersion-flattened PCF. When the setup will be operationnal the ESR will test it in collaboration with ESR 3 & 8.

Expected results

- The expected result is to reduce the noise in SC system for near-IR SD OCT reduced by an order of magnitude. For this, ESR 9 has several options: use tapered anomalous dispersion fibers, increase the repetition rate of a picosecond source and pump an ANDi PCF in femtosecond regime. Furthermore, the developed system must have a repetition rate higher than 1 MHz (the faster the better), a spectral bandwidth going from 750 nm to 1000 nm (to cover at least the first OCT band) to be efficient for OCT applications.

Secondments

- A secondment in CNRS, Besancon was done from June 26th to July 13th, 2018. During this period the ESR work with ESR 4 and 5 on two different topics. With ESR 4, the collaboration was focus on pump the PM-ANDi PCF of ESR 9 with an OPO to generate an ANDi femtosecond SC generation. Also ESR 9 developped a Matlab code to generate an LP11 mode on an SLM and ESR 5 use this mode to generate a multimode cascading SC. A joint publication with both ESR 4 and 5 on these topic is planned in the future.

- Another secondment at RECENDT, Linz is foreseen for 2 months around December 2019 of the project, to test the ESR 9 optical setup and check if the noise in near-IR SD OCT is reduced by an order of magnitude. A joint publication with ESR 8 on this topic should be planned.

Description of the Optical setup

- After the purchase of OneFive by NKT photonics, a 50 mW, 80 Mhz and 70 fs seed laser (Origami 10) can be used by ESR 9. The problem with this seed is the output peak power, indeed this one is too low to obtain a bandwidth going from 800 nm to 1400 nm. Hence the need to build an Ytterbium amplifier (to reach a peak power higher than 80 kW) but, due to the induced dispersion, a compression stage, using a hollow core fiber, must be add after the amplifier and before the ANDi PCF to reach again a pulse duration lower than 70 fs. The dispersion and loos profile of the ANDi PCF is shown above including the different parameters of the fiber.

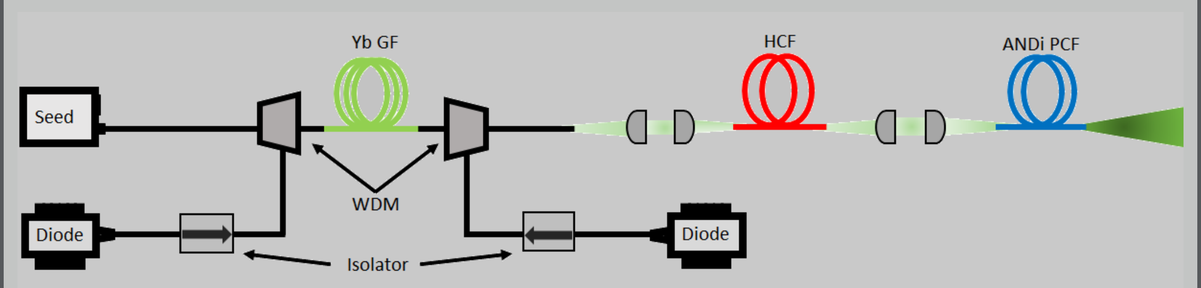

Figure: Schematic of the optical setup composed by a femtosecond seed, an amplifier, a compressor and a nonlinear stage

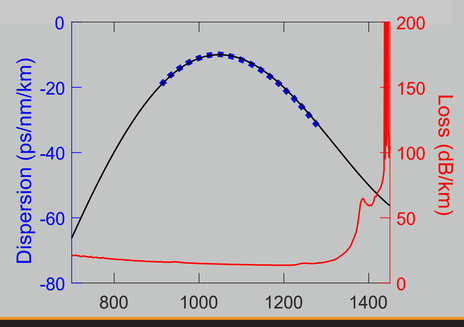

Figure: Dispersion and loose profil of the PM-ANDi PCF, γ=0.0265 $W^{-1}m^{-1}$, birefringence = 2.10^{-4}, relative hole size of d/L = 0.45, hole-to-hole pitch of 1.44 µm, minimum of dispersion = $-13ps.nm^{-1}.km^{-1}$ at 1040 nm.

Numerical results

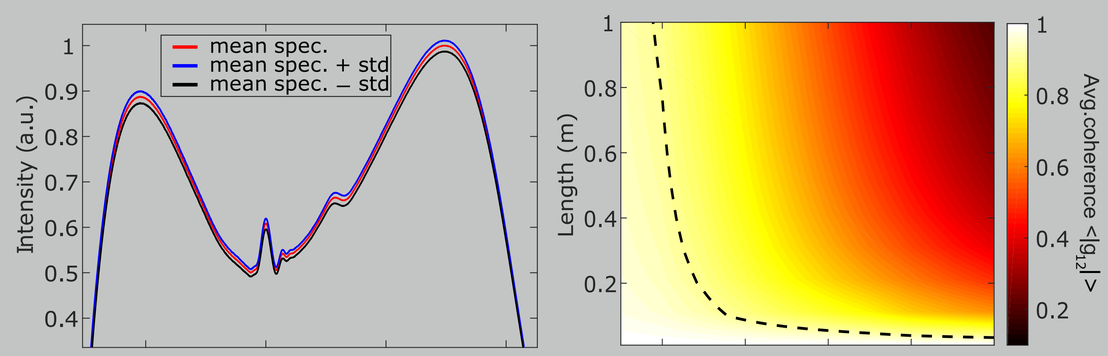

Figure: Numerical supercontinuum spectra after 1 m of ANDi fiber showing fluctuation in spectral power and shape for 0.5 % amplitude noise and a pulse duration standard deviation of 0.4 fs. The simulation uses an average pulse duration of 50 fs and a peak power of 100 kW at 1054 nm. Average spectral coherence of SC pulse generated with 100 kW peak power pump pulses as a function of pump pulse duration and propagation distance including an amplitude noise value of 0.3 %.

- In theory, this system should have a Relative Intensity Noise (RIN) of 0 % and a flat coherence spectrum equal to 1 through the entire spectrum. But to be more accurate, we have to simulate different kind of noises present in every real laser system (phase noise, amplitude noise, pulse duration noise and shot noise).

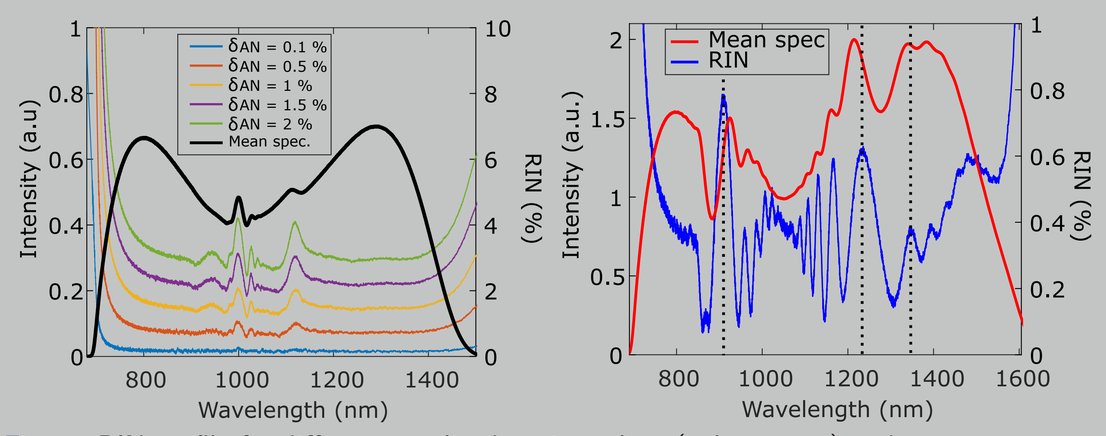

Figure: RIN profile for different amplitude noise values (color curves) and mean spectrum of an ensemble of 20 pulses (bold black curve) after 1 m of fiber with 100 kW peak power, 50 fs pulse duration at 1054 nm for an amplitude noise value of 0.5 %. RIN profile (blue line) and mean spectrum (red line) of an ensemble of 20 pulses after 10 cm of fiber with 100 kW peak power, 50 fs pulse duration at 1054 nm for an amplitude noise value of 0.5 %.

- Current typical picosecond SC sources used for OCT have an average RIN of 70 % so in theory this should fulfill the goal of the project, but this will now be have to be verified experimentally.

Dissemination

- As of now, the following publications and communications have been produced during ESR 9 work:
  - E. Genier, P. Bowen, T. Sylvestre, J. Dudley, P. Moselund and O. Bang, *Amplitude noise and coherence degradation of femtosecond supercontinuum generation in all-normal-dispersion fibers*, to be submitted soon (**peer-reviewed paper**)
  - E. Genier, P. Bowen, T. Sylvestre, J. Dudley, P. Moselund and O. Bang, *Coherence degradation and noise properties of allnormal dispersion femtosecond supercontinuum generation*, International OSA Networks for Students Scandinavia 2018, Copenhagen, Denmark, and Lund, Sweden, 7 June 2018. (**oral presentation**)
  - E. Genier, P. Bowen, T. Sylvestre, O. Bang and P. M. Moselund, Lownoise supercontinuum sources for UHRPSOCT applications, ShapeOCT meeting, Lyngby, Denmark, 26 February 2018. (**oral presentation**)
  - E. Genier, P. Bowen, T. Sylvestre, J. Dudley, O. Bang and P. M. Moselund, Low noise visiblenearinfrared supercontinuum sources for optical coherent tomography applications, Future Prospects for Photonics on MidInfrared Light Sources and Applications Symposium, Tampere, Finland, 14 December 2017. (**poster presentation**)

Acknowledgments

- This project has received funding from the European Research Council (ERC) under the European Unions Horizon 2020 research and innovation programme under grant agreement No 722380.