French contribution to ICAN-B

A French consortium from both academic and industrial origins is currently setting up a research program dedicated at the CAN physics and named XL-CAN. One of the major research axis aims at the development of a multichannel (≥60) prototype delivering a 300 fs, >10 mJ, 10 to 100 kHz pulse train. It will rely on Yb doped microstructured optical fiber amplifiers to be bundled together for collective phase measurement and combination. This prototype is named XCAN.

The partners are Ecole Polytechnique, Thales, ONERA and IOGS/Amplitude

This consortium contribution to ICAN-B will focus at 3 proposed research activities which could be structured in 3 Work Packages:

- Fiber development
- Phase Measure and control
- Pulse duration reduction

<u>WP1 : Fiber development</u>

XCAN's main objective is to demonstrate a proof of concept of efficient coherent amplification combination with several tens of spatially separated channels. At this prototype stage, the total energy level is set as the second priority, considering that adding low-cost moderate-energy channels will be the approach of choice for future scaling. The spatial separated amplification architecture considered here requires to be able to bundle together all channel outputs in a section as compact as possible. This will be achieved by using flexible PCF which outputs are free of any pumping hardware. Pumping will therefore be performed in a co-propagating scheme. Such approach is not favorable in terms of B-Integral management. Keeping the non-linear phase distortion as low as possible will ensure an efficient phase control feedback loop operation. One option is to moderate the gain of each amplifying channel to end-up with a few hundreds of µJ output energy.

Alternatively, in order to improve the energy per channel production, we seek PCF fibers with improved performances in terms of mode diameter when compared with state of the art products like NKT DC-200/40-PZ-Yb.

This work package would be dedicated to the test of Yb doped PCF amplifiers able to amplify modes of at least 40 µm (to be compare with ~30µm with above mention NKT fiber). The fiber will need to keep a reasonable flexibility to satisfy the ultimate bundling requirement.

This WP is therefore dependent of an ORC WP dedicated at such fiber development.

Advances beyond state of the art:

- 40µm mode PCF amplifiers

<u>WP2 : Phase Measure and control</u>

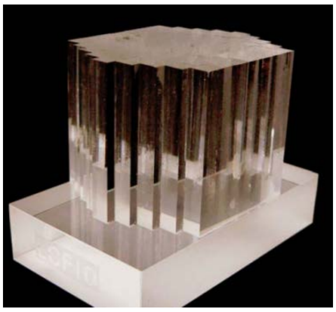
We propose here to work on 4 key aspects of spatial coherent combining:

- Linear phase noise evaluation in fs amplifiers
- Collective synchronization & phase measurements of fs pulses with large delays
- Absolute phase calibration
- Optimization of the near field spatial distribution

Linear phase noise evaluation in fs amplifiers will be performed on an amplifier provided by XCAN and based on ORC 40 µm mode amplifying PFC when available. This will allow identifying the main sources of noise and helping improving the design to minimize phase noise. This will also allow identifying the phase sensor, controller and actuator requirements in terms of bandwidth and range.

Promising **collective phase & synch** Pupil-plane-sensors include lateral shifting interferometer and reference arm interferometer associated with wavelength diversity strategies. Focal plane techniques such as phase-diversity can also be adapted. We propose to study theoretically those techniques and test the best candidate(s) on:

- A fully calibrated “Giant's Causeway” reference developed in initial CAN project by the IOGS for this purpose. Objective: demonstration of Phase and Sync measurement with a femtosecond source with max delay 100µm.

- A CW passive 64 fibers platform already developed by Thales. Objective: demonstrate collective Phase and Sync measurement of 64 fibers with max delay ~several meters and λ/100 accuracy.

Reference arm interferometry will also be evaluated on XCAN intermediate passive 19 channels femtosecond platform. The most effective technique will be ultimately implemented on the amplifying XCAN 60+ channels prototype.

Absolute phase calibration of Pupil-plane-sensors must be considered to guarantee a flat phase at the combination output. A Focal-plane sensor may also be helpful for the calibration of phase distortion and to maintain required focalized beam quality. For this purpose, we propose to study the calibration of pupil-plane sensors and the possibility to use focal-plane sensor for phase measurement. If possible, the focal-plane sensor will be tested on the “Giant's Causeway” reference.

Optimization of the near field. The period intensity distribution in the near field leads to side lobes in the far field and reduce the energy in the central lobe. In order to reduce this spurious effect, the near field intensity distribution must be tailored to increase the fill factor and increase the overall recombination efficiency. For this purpose, we propose to use set of phase plate arrays in the collimation apparatus. This solution will have to be theoretically studied in order to optimize the phase profiles. Such phase plates will then be fabricated and implemented in the fiber combining setup.

Advances beyond state of the art:

- collective and highly scalable synchronization & phase-lock of fs pulses phase measurement of an array of fiber in the focal plane

<u>WP3 : Pulse duration reduction</u>

The ICAN laser concept is based on massive coherent combining of ytterbium-doped fiber amplifiers that have numerous advantages, but do not allow the generation of high-energy pulses shorter than 300 fs. Depending on the targeted applications, shorter pulse widths are either mandatory, or considerably decrease the energy per pulse needed. It is therefore of primary importance for the project to have serious options to generate pulses down to 50 fs. In the context of the FET-OPEN call, we will focus on the investigation of such solutions to generate sub-100 fs pulses from a coherent combining system. This can be done in two ways.

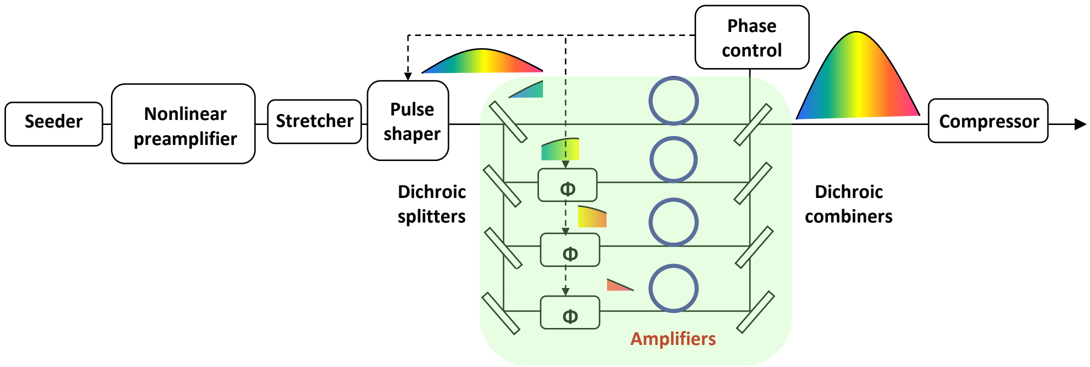
Nonlinear post-compression of the pulses after amplification. To maintain acceptable spatial quality, this is usually done either in hollow-core fiber or glass capillaries up to energies of a few mJ. We plan to investigate the energy limits of such setups using both hollow-core fiber (HCF) structures and capillaries, and the possibility to overcome these limits using passive coherent combining techniques such as the divided pulse technique. This energy limit will dictate the location of a possible post-compression stage in a full-scale system, i.e. possibly at an intermediate recombination stage.

The HCF would/could results from on ORC work package dedicated at optimizing the relevant HCF for such application. Experimental validation would be perform on XCAN prototype at several intermediate energy

Advances beyond state of the art:

- Post-compression in hollow-core fibers / capillaries at energy levels beyond the current state of the art using divided-pulse techniques
- Optimal post-compression system designs for coherent combining demonstrators in the ICAN FET-OPEN proposal

Pulse spectral synthesis: IOGS plan also to investigate the use of coherently combining different spectral contents to generate short pulse width in a 4-channel demonstrator depicted in fig. 1. The goal is to demonstrate sub-100 fs capability from Yb-doped fiber amplifiers seeded with different spectra at an energy level around 100 µJ. This will allow us to study various effects related to the spatially and spectrally separated architecture such as influence of B-integral, group-delay, group-delay dispersion. Ways to implement this architecture in a full-scale system will also be investigated.



Schematic layout of the 4-channel spectral synthesis demonstrator

Advances beyond state of the art:

- First pulse synthesis setup based on fibers to generate sub-100 fs pulses.
- Investigations of all related coherent combining effects with spatially and spectrally separated beams.

<u>Budget:</u>

FET-OPEN: 1 M€

Consortium internal budget: 1.2 M€