# ORC project plan for ICAN

*DRAFT for discussions*

**DOCUMENT STARTED:** July 18 2014

**AUTHOR:** J. Nilsson and others

## Introduction

The fiber gain medium is at the heart of the ICAN laser, with specifications and requirements that exceed state of the art and requires improvements in design, fabrication, and understanding in fibers as well as fiber amplifiers. Similarly, passive fiber for delivery and / or compression greatly improves the flexibility in the overall architecture. Efficiency, energy, peak power, average power, phase distortions, uniformity, cost, and reliability are all of great importance for gain as well as delivery fiber.

ORC's proposes work on fibers as well as amplifiers in a way which is both synergetic between the partners and reduces the risk brought about by interdependence.

Three types of fibers are considered and can be targeted. This stretches the budget. While in all cases the fibers will advance the state of the art in terms of the ICAN requirements, we need to decide whether we should focus on two types of fibers to allow for more pronounced progress.

Fibers with increasing improvements can be made available to partners throughout the project. ORC's initial assessment of performance will help us to jointly decide if / when specific fibers / amplifiers should be further evaluated in the French and German test-beds. A fraction of the fibers is expected to be too poor to warrant further evaluation.

The wavelength is a key parameter which at least in some cases hasn't been finalized.

Fiber fab work will be directly funded by ICAN, by and large, whereas resources that are not directly funded may focus on amplifier work.

## Scope

ORC's contribution focuses on fiber and amplifiers, the details of which will be determined jointly. Tentative priority is as follows.

- R&D on fibers, fiber fab & amplifier configurations
    - Gain fiber for high average power
    - Gain fiber for high pulse energy with low B-integral
    - Hollow-core fiber for delivery and compression of higher-energy pulses
- Model development & simulations
- Assessment of fibers in different roles and configurations
- Construction of test bed which includes experimental tandem-pump source
- R&D on interface between gain and delivery fiber (may be best left to partners)

Pump coupling and costing exercises could also be included, but are not at present

Inclusion of micro-optic expertise (outside ORC) should be considered, to provide options for pump coupling and interfacing. These are intimately linked to the fiber amplifier.

## Objectives

ORC's overall objective is to design, fabricate, and prove improved fibers for ICAN using suitably adapted fabrication approaches.

- Develop fabrication approaches for required physical parameters (homogeneity, concentration, host composition, core size, etc.) & low cost[1]
    - Flexible / quasi-flexible / rod?
- Design and fabrication of large core fibers for high average power
    - 1 kW at core diameter > 40 – 50 µm
    - To be assessed in amplifier configurations
    - Thermal effects (e.g., thermal mode instabilities) are major point
    - ORC has at least four approaches of interest including thermal pre-compensation and tandem-pumping
- Design and fabrication of large core fibers for high energy with low B-integral
    - Core diameter > 40 – 50 µm
    - Can be used in XCAN
    - To be assessed in CPA configurations to multi-mJ energy in single pulse from single fiber
    - B-integral is major point
    - ORC has at least three approaches of interest
- Design and fabrication of hollow-core fibers for delivery and / or compression of high-energy pulses
    - Needs matching to gain fiber
- Assess approaches to polarization control
    - Required for all ICAN fibers
    - Hi-bi options
    - Can low-bi be an option also for bent fibers?
- Assess lifetime (photodarkening)
- Fiber supply to ICAN partners

### *Advance on state of the art*

- Improved designs & fabrication approaches for ICAN-type fibers
    - Low cost, longitudinal and transverse control, ...
    - High-energy CPA fibers
    - Fibers with improved power scalability / thermal effects & management
- Hollow-core fiber: loss & power handling to fit ICAN objectives
- Comparison & improvement of pumping schemes
- Lifetime of fibers
- Improved understanding of fiber & amplifier physics as relevant for phasing of fs pulses

## Program of work

### *A. Gain fiber*

ORC will use existing facilities for the fabrication of gain fibers. Within ICAN, we will largely use existing fabrication approaches that will be tweaked to our specific needs. There is also more fundamental fab research which is hoped to contribute to ICAN.

The methodology will be one of experimental iteration, which will involve fabrication and rapid evaluation of a significant number of fibers, and which has been proven in many previous successful projects.

[1] We don't want to prescribe details such as "PCF".

Each fiber iteration costs around 25 k€ in fabrication. We expect that on average one third of the fibers will be useful for experimentation beyond basic characterization.

The designs to be pursued can be determined jointly with partners. We are keen to pursue index-matched fibers, thermally engineered fibers, and multi-trench fibers, amongst others.

### *B. Assessment of fiber and amplification configurations*

This work package serves to assess and design fiber, and crucially to improve our understanding of fiber and CPA physics for high-power, high-energy coherent combination. It will largely rely on existing testbeds (e.g., for CPA), but will be extended to allow for tandem-pumping. Aging (photo-darkening) and phase characterization is also planned.

### *D. Hollow-core fibers for delivery and / or compression*

Development of large mode area hollow core fibers based on a novel anti-resonant design that offers effective single mode operation through large high order mode differential loss, wide operational bandwidth, low propagation and bend loss, and an MFD that can be matched to that of the preferred amplifying fiber.

On a 36 month project we would foresee the following (tentative) deliverables:

D1, Mo2: first generation hollow core anti-resonant fiber (HC-ARF) based on tubular lattice, node-less design and state-of-the-art fabrication process. The fiber will have reasonably low propagation loss but likely quite high bend losses for the large MFDs of interest.

D2, Mo12: second generation HC-ARF based on improved design to considerably reduce leakage and bend loss and introduce a high differential loss for high order modes.

D3, Mo24: third generation HC-ARF: MFD matched to active fiber and with improvements to address the feedback from pulse delivery trials.

(D4, Mo34: HC-ARF with a suitable interconnection to the active fiber to minimize loss and back-reflections)[2]

## Budget

A. Gain fiber ~ 25k per churn; expect three churns per useful fiber. Cost estimate for full program 620 k€ (£496k).

B. Assessment of fiber and amplification configurations. 561 k€ (£449k) for full program. Cuts would be in rough proportion to those in the gain fiber budget.

C. SPI work: No separate budget[3]

D. Hollow-core delivery fiber. 150 k€ (£120k) each for D1 – D4 so 600 k€ for full program.

Total 1,761 k€ (£1,409k) for full program

## Gain fiber schedule (draft)

| Date | Event / fiber no. | Objective / advance | Cost / funding | Core size | Pumping [4] | Performance | Pol. / rod [5] | Comments |
|---|---|---|---|---|---|---|---|---|
| July 1 2015 | ICAN-B starts | | | | | | | |
| July 1 2018 | ICAN-B ends | | | | | | | |

[2] While ORC has expertise and alternative high-risk ideas on this topic, budget constraints and overall project planning suggests that ORC will not pursue this.

[3] According to plans from April, SPI would focus on the development on high-brightness pump sources. A different role may now be considered for SPI, which would not require a separate budget.

[4] Diode-pumped fibers are double-clad, but can also be tandem-pumped in the core.

[5] For coherent combination (active phasing), fibers should be either polarization-maintaining, single-polarization, or rod-type (with negligible birefringence)