



exail

Exail Photonics : the « Wow » effect

CONFIDENTIAL – PROPRIETARY INFORMATION

Exail : the Wow effect Company

1 **Amazing**
An amazing story for this stunned company

2 **Wonderful**
The Specialty Fiber Division

3 **Over exciting**
Nothing but Over Exciting Application !

4 **Awesome**
Most recent awesome Success

Wonderful

AWESOME!

AMAZING

OVER EXCITING

WOW!

Exail : the Wow effect Company

1. An amazing story for this stunned company



Eca + iXblue = exail

Stronger together

1600*

EMPLOYEES

280+

MILLIONS EUROS
OF TURNOVER

20+

% OF TURNOVER
INVESTED IN R&D

80%

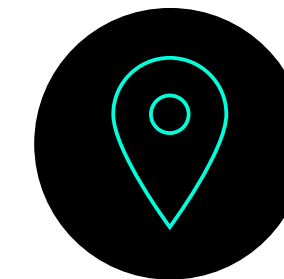
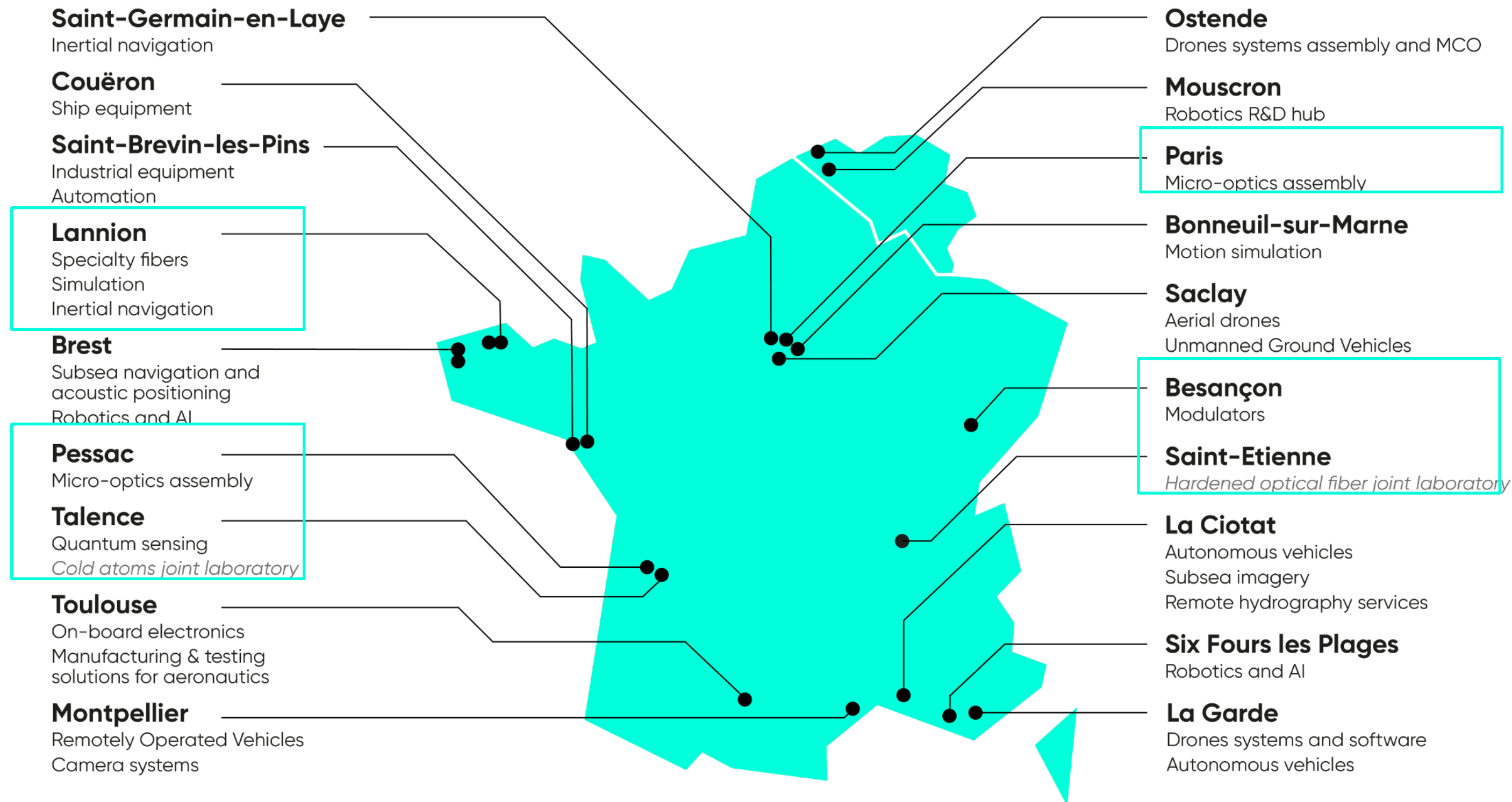
OF TURNOVER
IN EXPORT

Why exail ?

exail evokes both the excellence of our products and the idea of exploring new territories (sail)

* 1600 = 800+800 , 800 from iXblue, previously iXSea, iXFiber, Photline . A lot of those spin-off started in 2000-2006 with a handful of employees !!!

A unique technological know-how

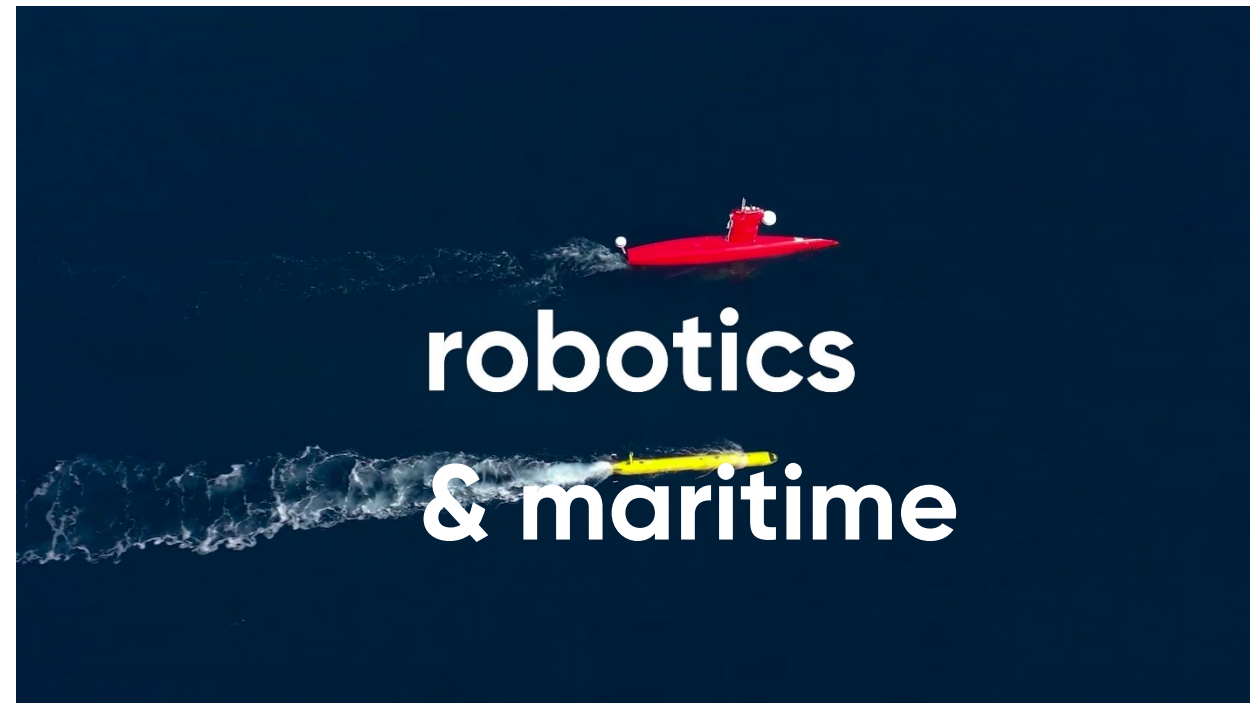


21 INDUSTRIAL SITES



2 JOINT RESEARCH LABORATORIES

Cutting-edge technologies



Photonics Division : from components to instruments

➤ Scalable technologies to address a full range of applications

Components

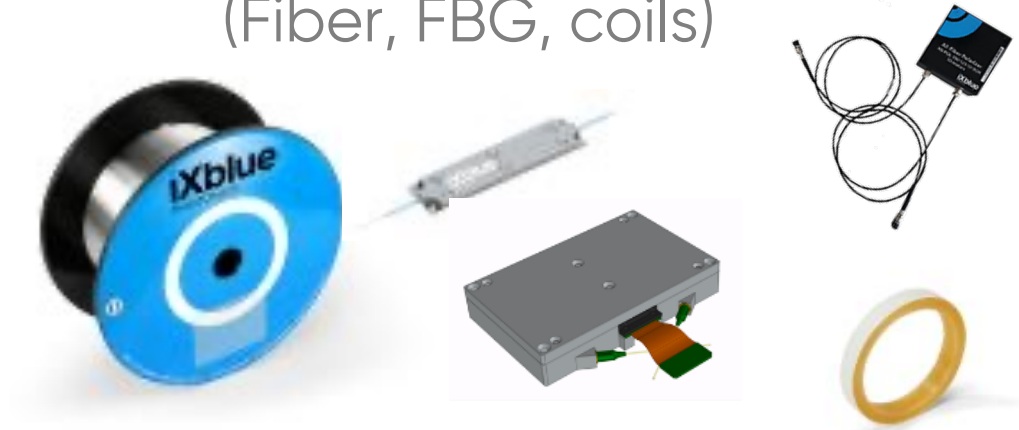
LiNbO₃ Phase, Amplitude, IQ Modulators (COTS, Space model)



Modulators Matching components (RF Amplifier, Low Noise Electronic)

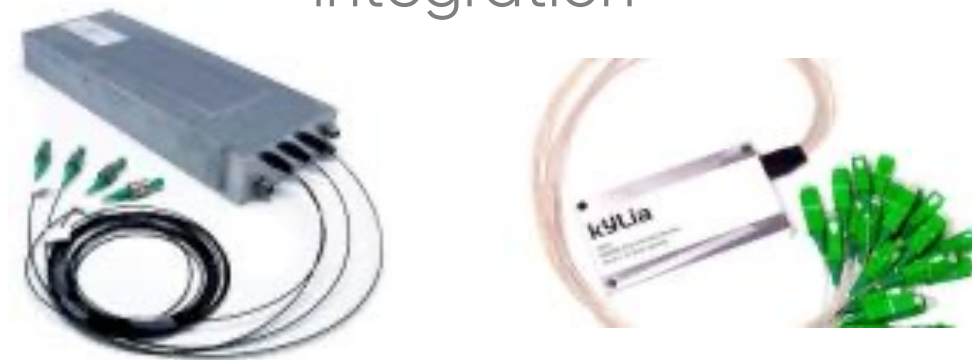


Fibers and fiber solutions (Fiber, FBG, coils)



Turn key devices

μoptics and passive optics integration



Transmitters, transceivers, laser pilot, coherent regeneration station



Lasers (Narrow-linewidth, high-power) Optical Low Noise & Power amplifiers



Absolute Quantum Gravimeter



Cold atom frequency metrology

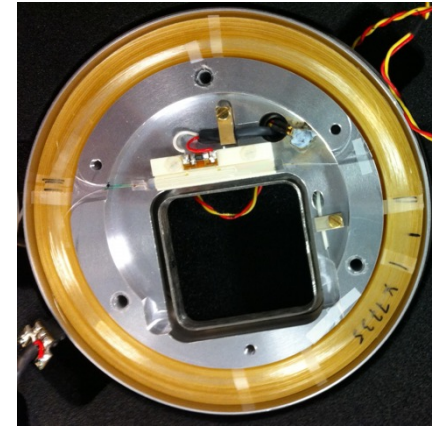


Photonics is at the heart of the Vertical Integration

All necessary know-how for any critical component is developed in-house

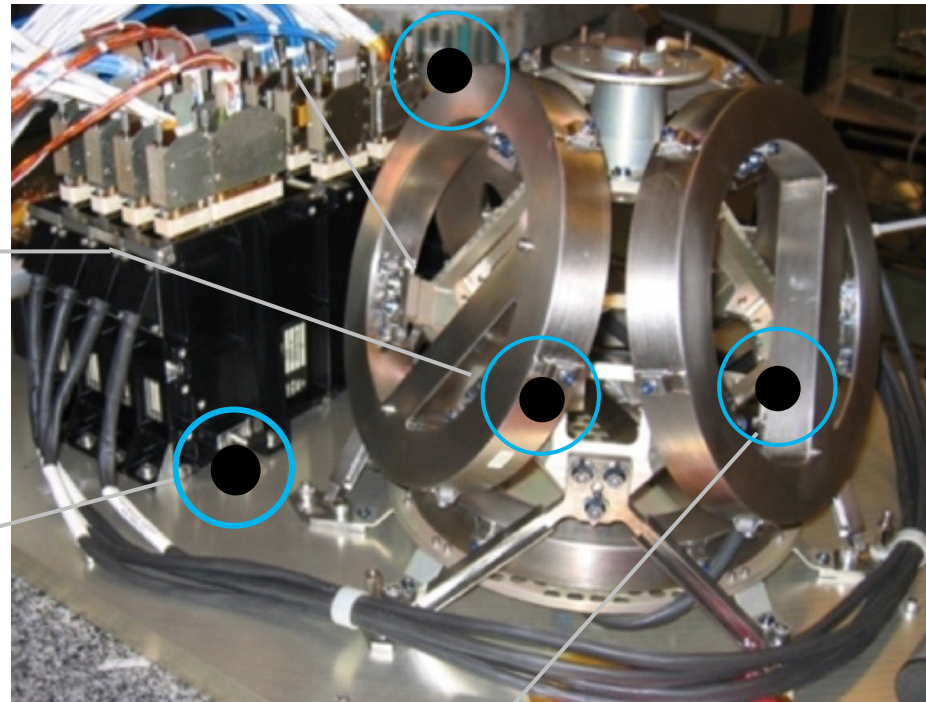
In a Fiber Optic Gyroscope (FOG)

Integrated optical circuit



PM Optical fiber for sensing

FBG Broadband Filter
Er doped ASE source



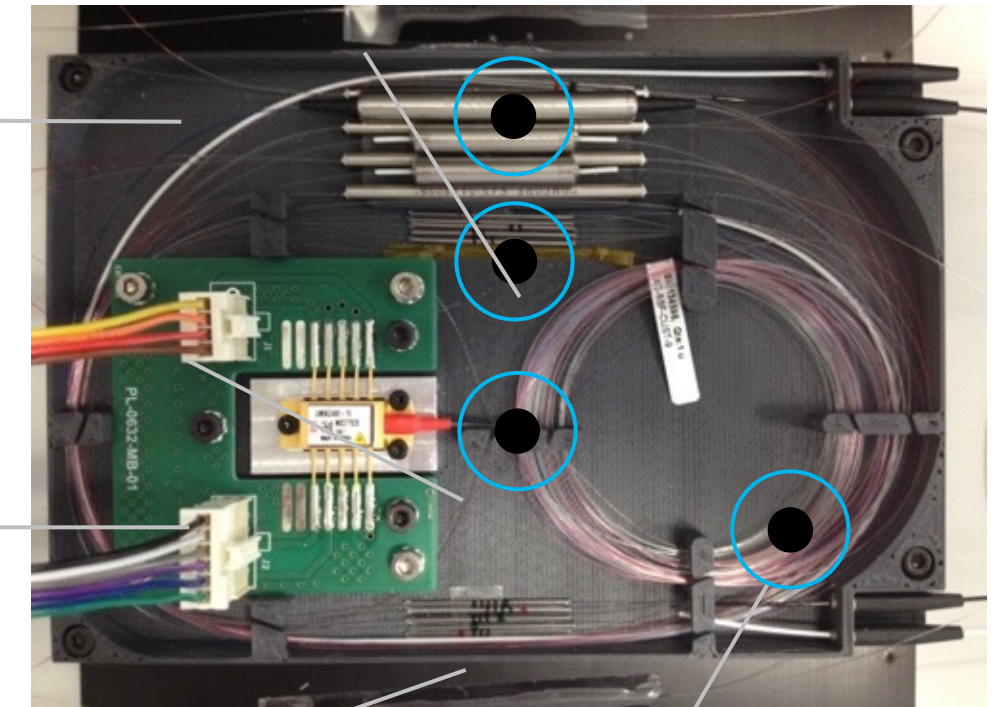
Quartz Accelerometers

In a Erbium Doped Fiber Amplifier (EDFA)

Space compatible selection of optical fiber components

FBG broadband filter

FBG Laser Diode Stabilizer



Radiation hardened Erbium doped fiber



IT IS



Exail : the Wow effect Company

1

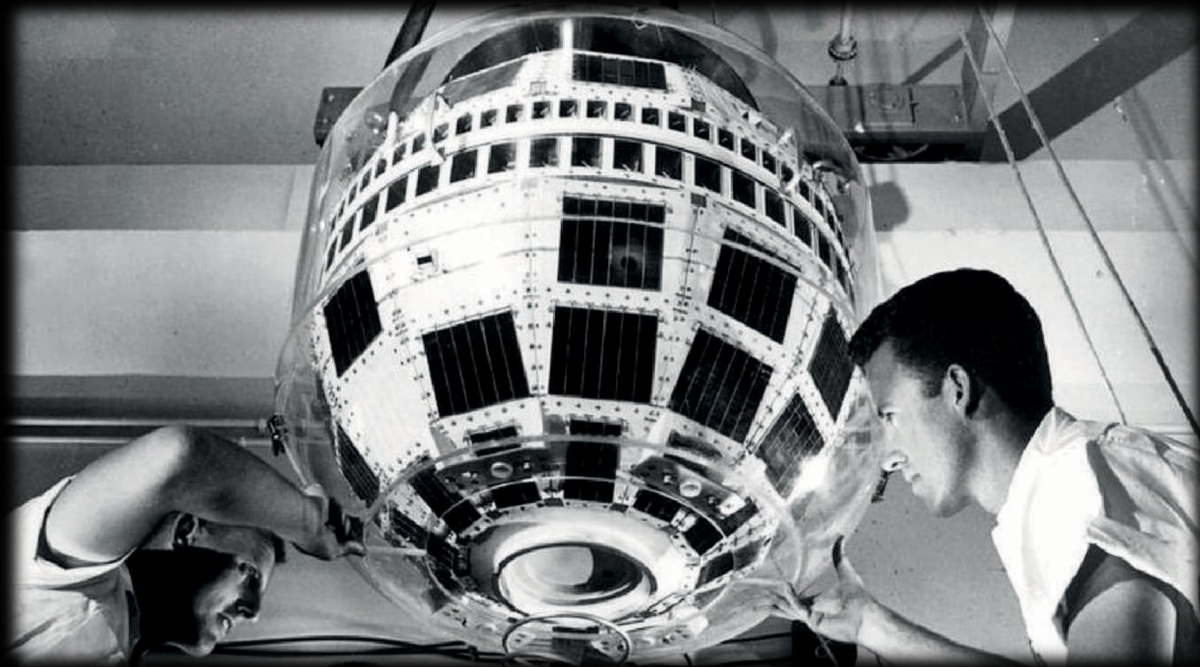
2

Wonderful

The Specialty Fiber Division

Wonderful

exail The wow effect



1962

TELSTAR1 and first live broadcast of television images between the U.S and Europe (right here!)



2024

FROM PHOTONICS FIBER OPTIC COILS TO
TRANSOCEANIC Uncrewed Surface Vessel DriX O-16

A Wonderful story : From Telecom to Photonics

➤ 20+ years experience in Specialty Optical fibers

- Heritage from CNET/France Telecom pioneer work on Optical fibers
- Mastering of entire process from glass/fiber draw to final testing
- Centuries of cumulated experiences / skilled team

➤ Continuous R&D efforts and breakthroughs

- First to highlight photodarkening in EY fibers in 2017, and to reach 20W on 12 μm core fiber
- EY based LIDAR for wind measurement: 16 km WWR with Onera on EY 30/300 PM fiber
- Large know-How in radiation resistant fibers With Long term collaborative research (LABCOM)

➤ Our Commitment

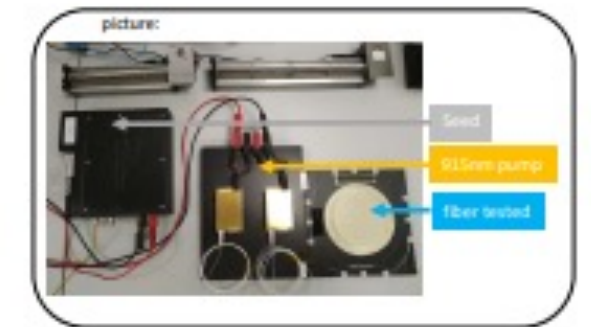
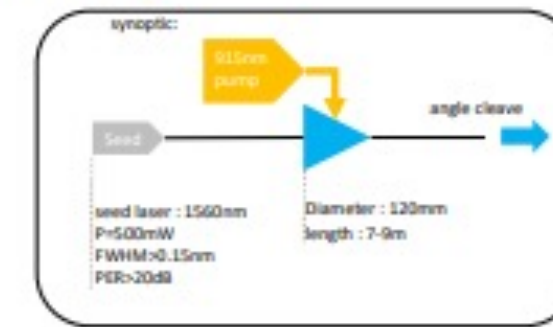
- Reliability : from the bottom of oceans to the depth of space
- Performances : RADIATION resistance guarantee
- Customer oriented & Long term supplier *Your need, our advice*

PERFORMANCE DATAS (amplifier mode)

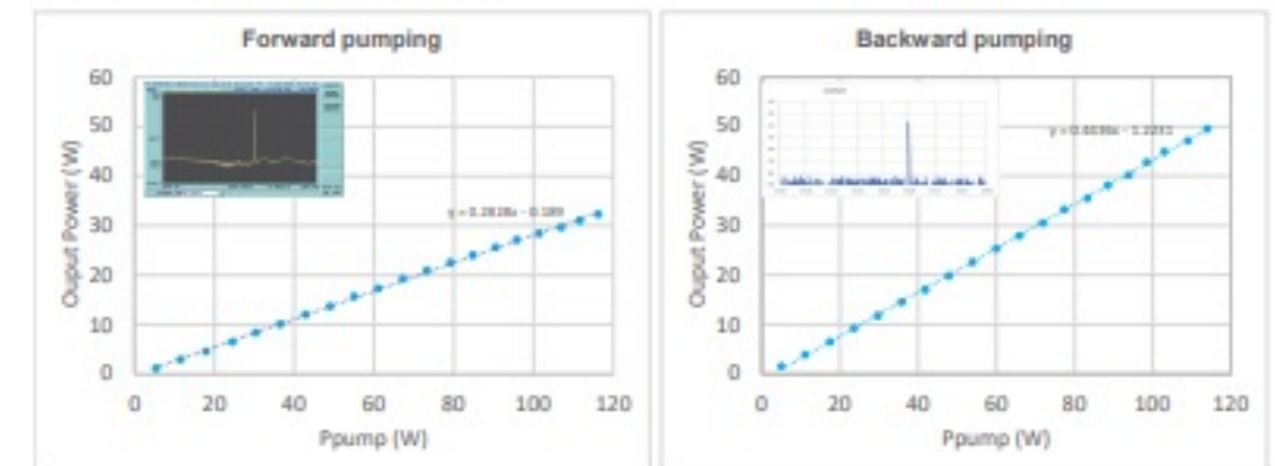
product code: 2CF-EY-PM-15-160-HPA

Parameters	Specifications	Units
reference	D0348M2F1C020	
Clad absorption @155nm	52.2	dB/m
Core absorption @155nm	2.51	dB/m
2CF-PAS reference (combineur)	2CF-PAS-PM-15-160-0.17 B1092M0F1C016	
PAS reference (output fiber)	PAS-PM-15-160-0.17 B1092M1F2C016	

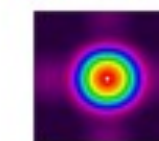
Test setup:



Output Power vs Pump Power:



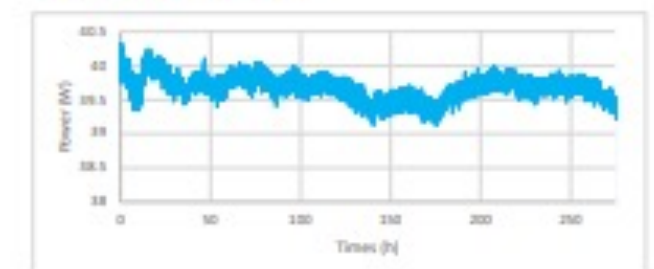
M2: 1.23



PER: xxdB

[NoData]

Endurance test:



Wonderful Facilities already !

- Founded in 2006 – iXFiber, based in Lannion, France
- Fibers & FBG are the Key Components to achieve complex systems

- **Core competencies**

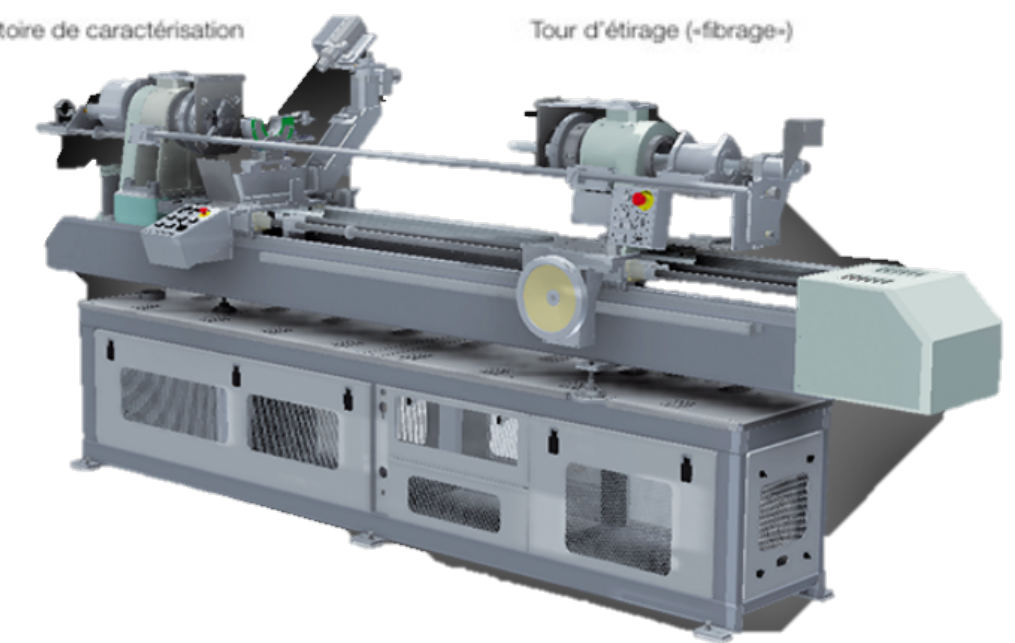
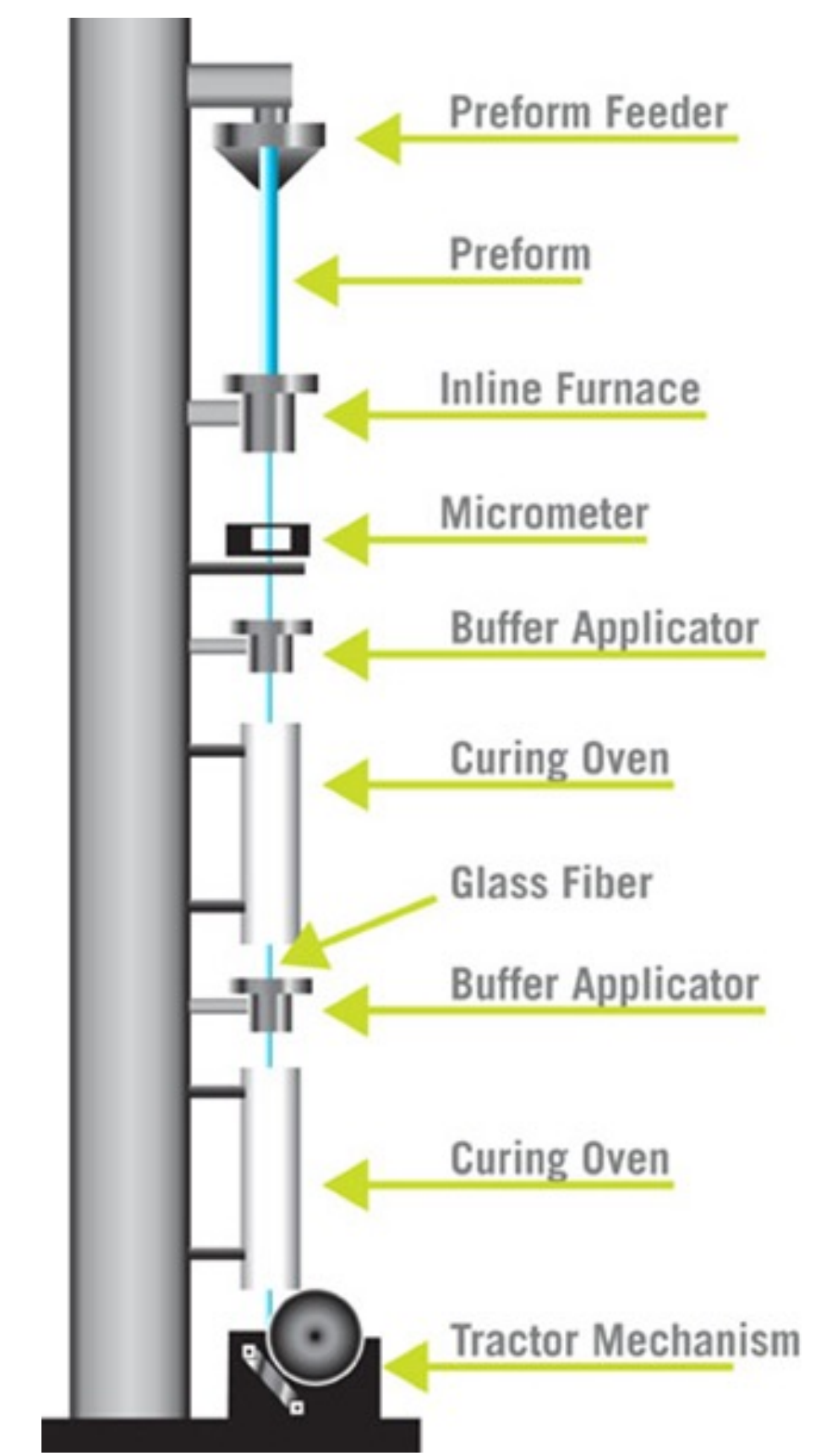
- Specialty Fiber based on silica
- Fiber Bragg Technologies
- 350 to 2200 nm

- **MCVD, SPCVD, drawing towers**

- **FBG lasers prod. line**

- **High Scientific skills:**

- 2 on-going PhD thesis per year
- 10-20 scientific papers published every year



Wonderful facilities : Extension Plan

Further activity growth

- Factory plant extension
- New MCVD and Fiber towers
- Fiber manufacturing capacity will be doubled in 2-3 years



FACADE NORD / EST





IT IS

Wonderful

Exail : the Wow effect company

1

2

3

Over exciting

Nothing but Over Exciting Application !



Nothing but Over-exciting Applications

TELECOMMUNICATION

Amplifier
High Power or
Low Noise LNOA



SPACE COM

Rad hard Amplifier
High Power OGS amplifier



MEDICAL

Ophtalmology
tatoo removal



LIDAR

Wind speed measurment



LIDAR

Autonomous vehicles
Telemeter



2 μ m Thulium FIBER LASER
156x Pump Laser

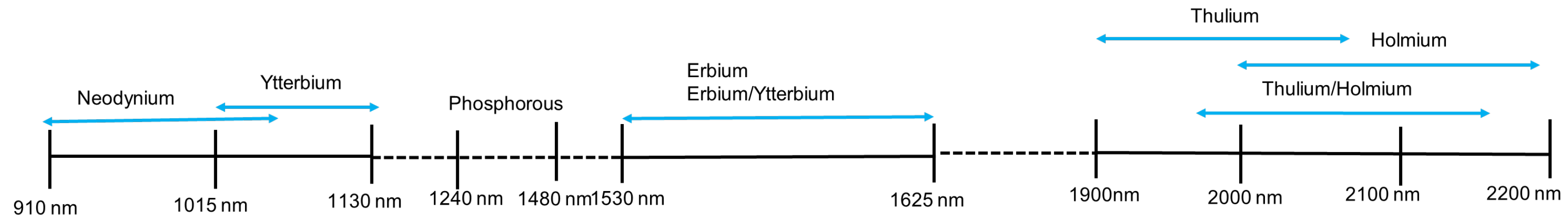


Many applications need different FIBER families

Actives, PM, Passives

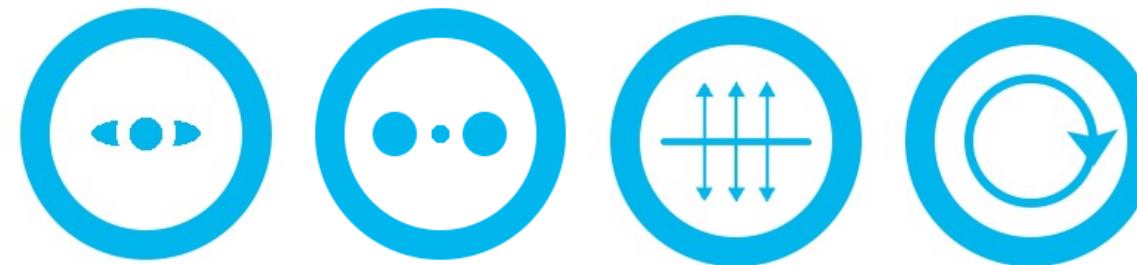
▶ Actives

- Doped
- PM / non-PM
- Single, double, triple-clad



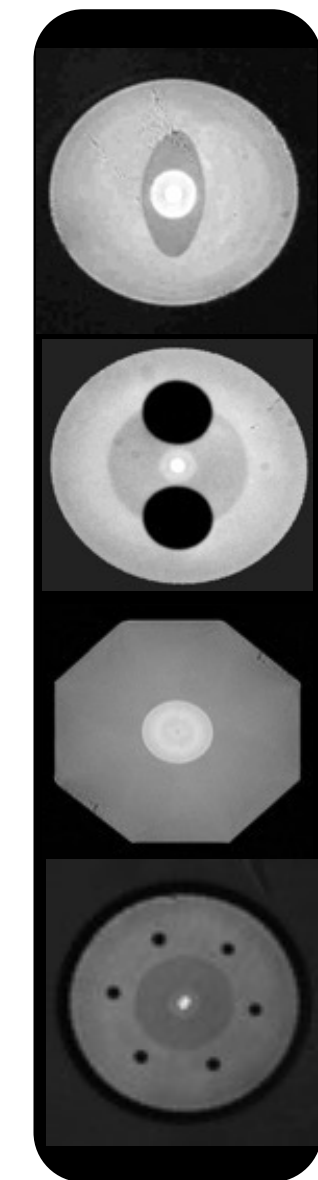
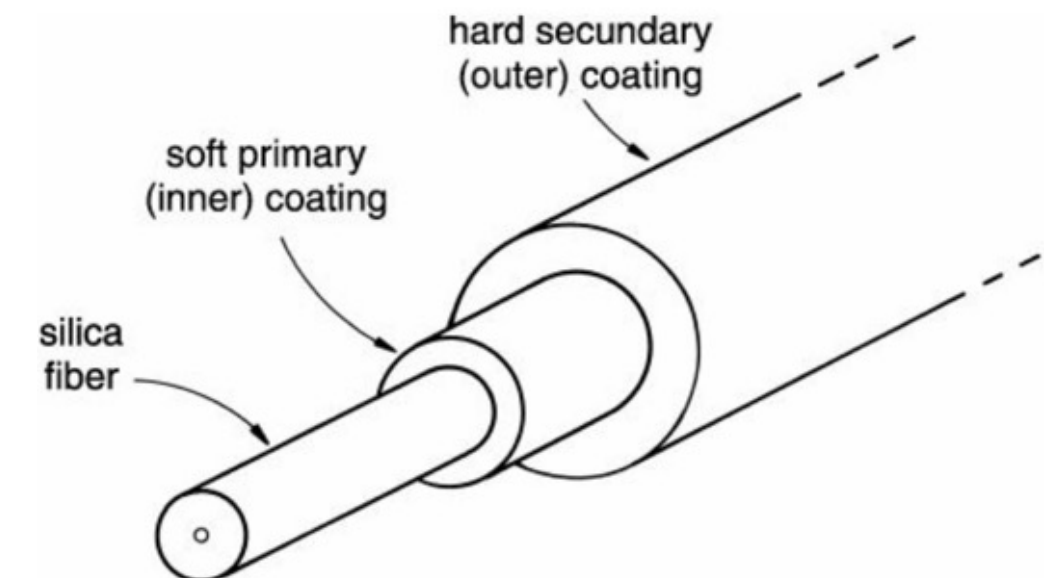
▶ PM

- Panda, Tiger, EC
- Øclad (125, 80 µm)
- Polarizing & spun fibers

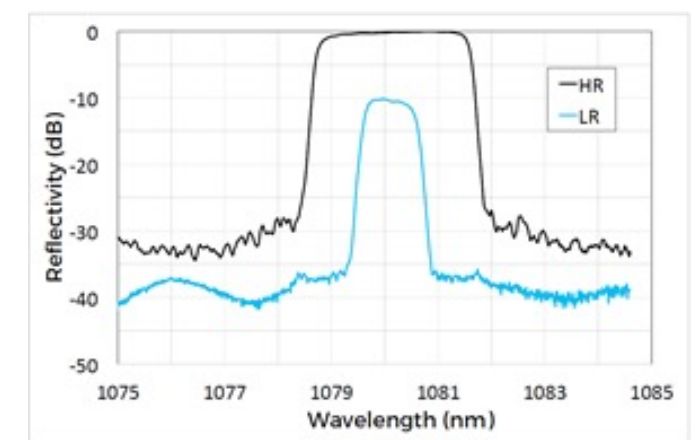
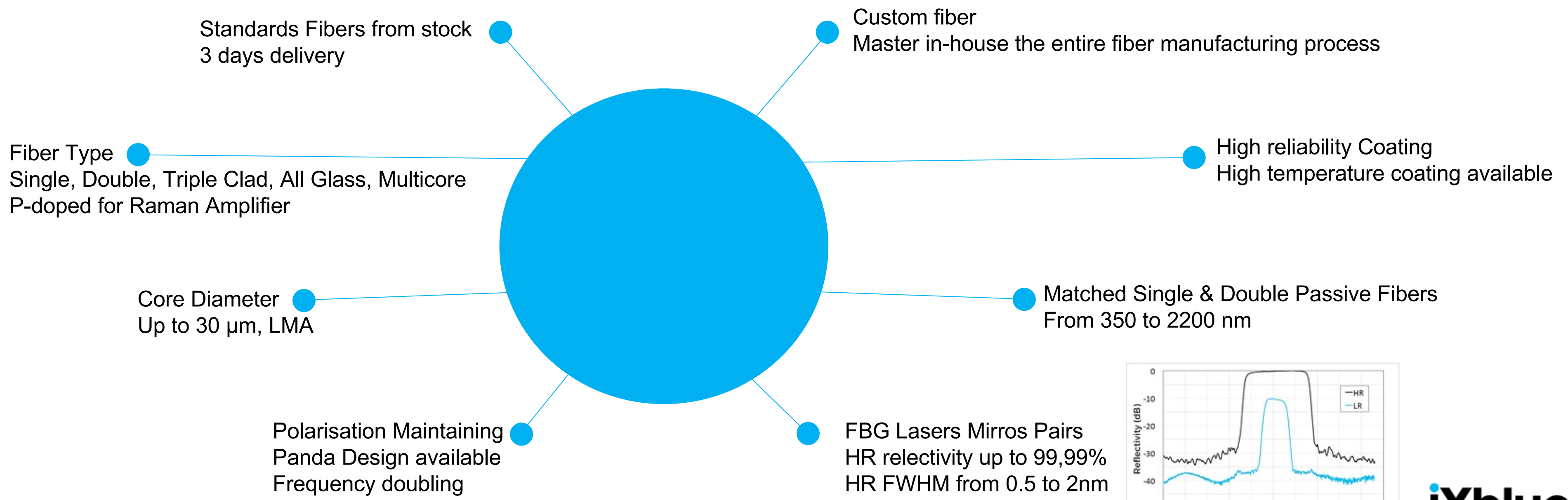
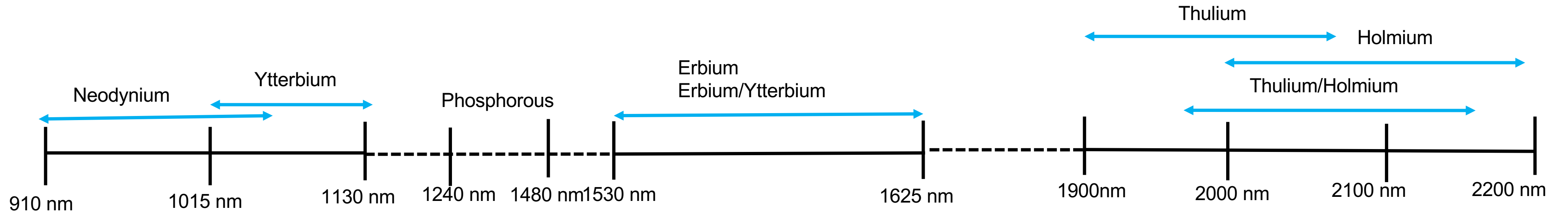


▶ Passives

- Singlemode, multimode
- Øclad, up to 600 µm
- Ge-doped, Rad-Hard (silica core)
- Harsh environment



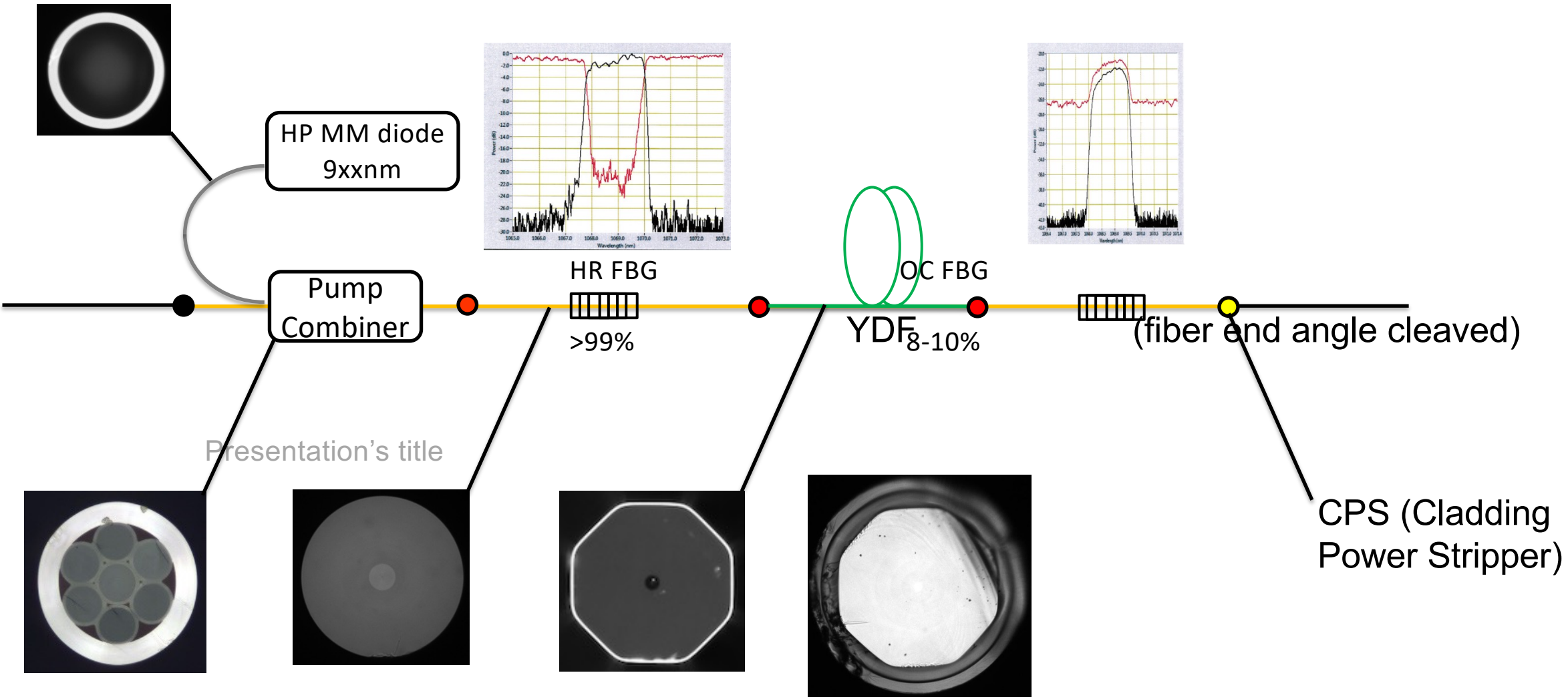
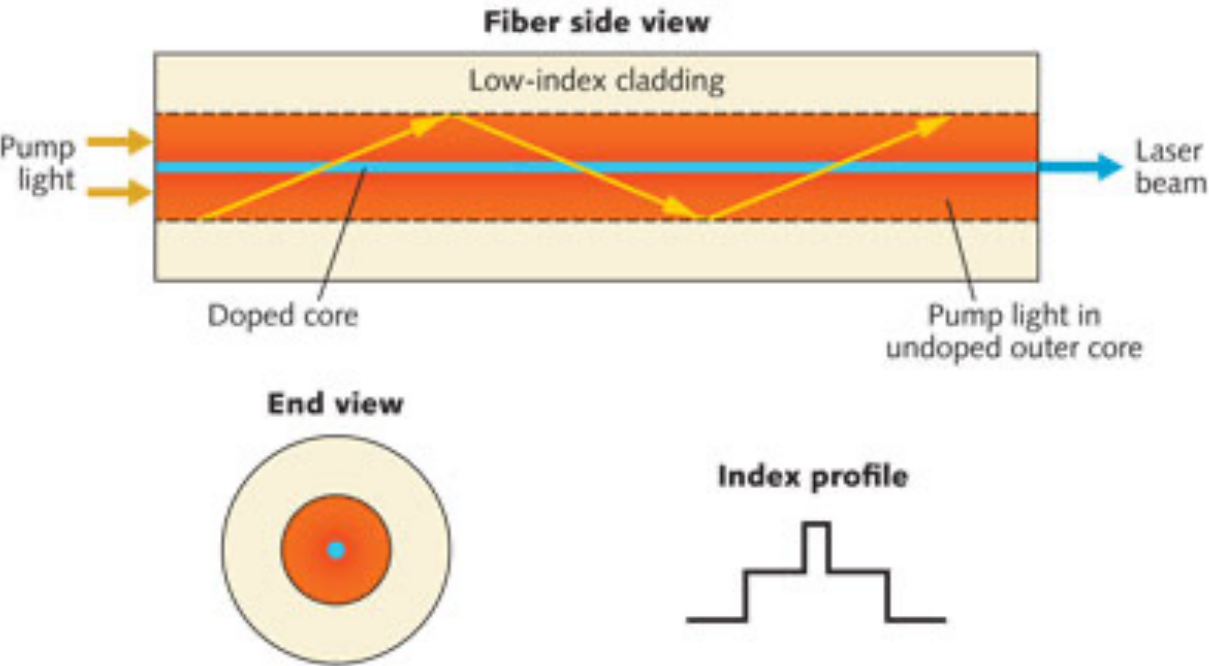
Lasers & Amplifiers fibers



As an example : WHERE DOES EXAIL FIT IN A LASER CAVITY ?

We master all key components !

Typical CW laser cavity architecture :



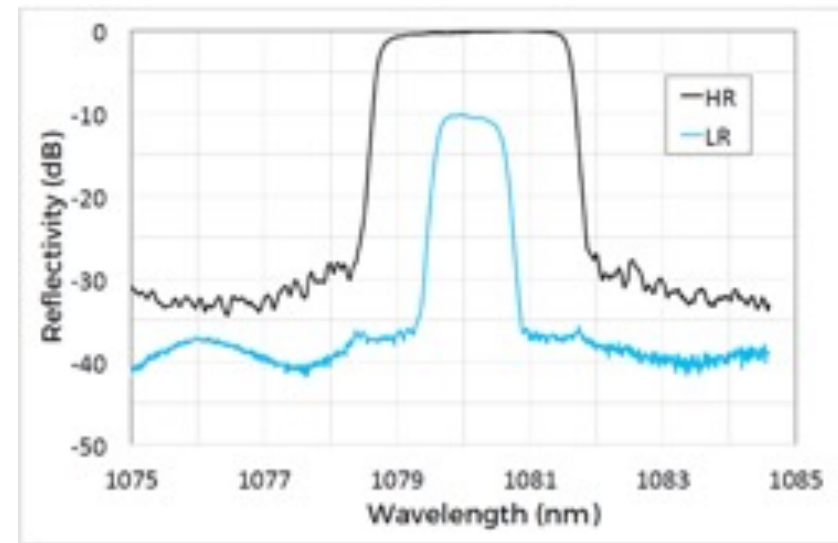
- Single clad Passive fiber
- Active Double Clad doped fiber
- Double Clad Passive fiber
- Multimode fiber 0.22 NA
- Power Delivery
- FBG



Fiber Bragg Gratings (FBG)

FBG laser mirrors pairs

- All fiber types: single, double or triple clads; PM
- From 600 to 2100 nm
- HR reflectivity up to 99.9%
- HR FWHM from 0.5 to 1.5 nm
- High Power Process: Thermal slope reduced by a factor 10

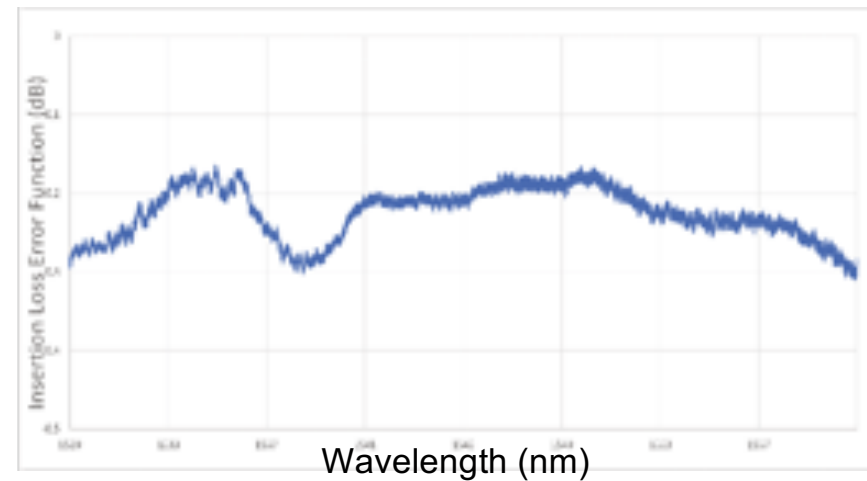


Thermal responses with IR thermograph

Fiber LASER

Gain flattening filters

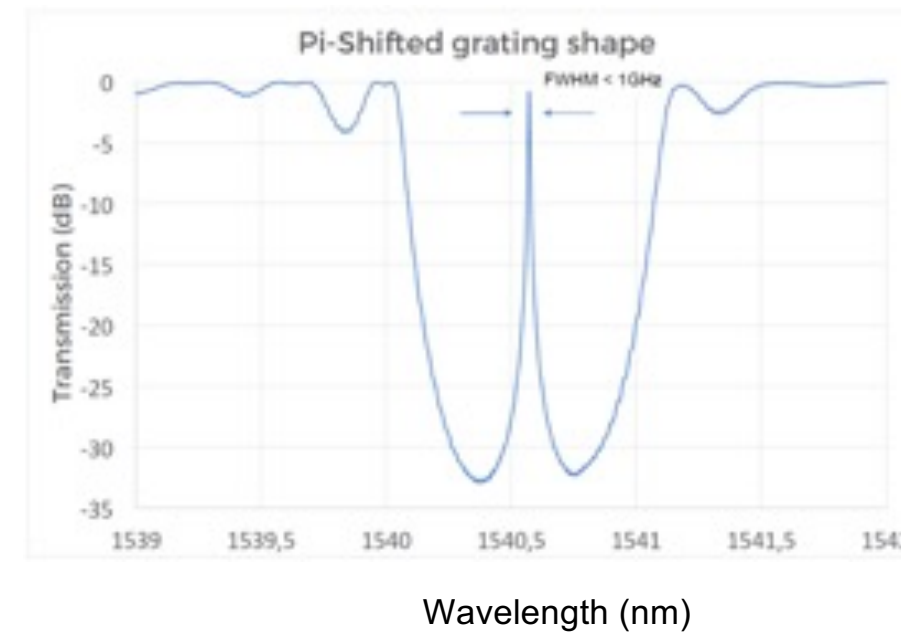
- Low reflection slanted GFF for Terrestrial and Submarine grades
- Available in recoat, athermal or non-athermal package
- C&L bands
- PM version available



Telecom Amplifier

Ultra-narrow bandwidth filters

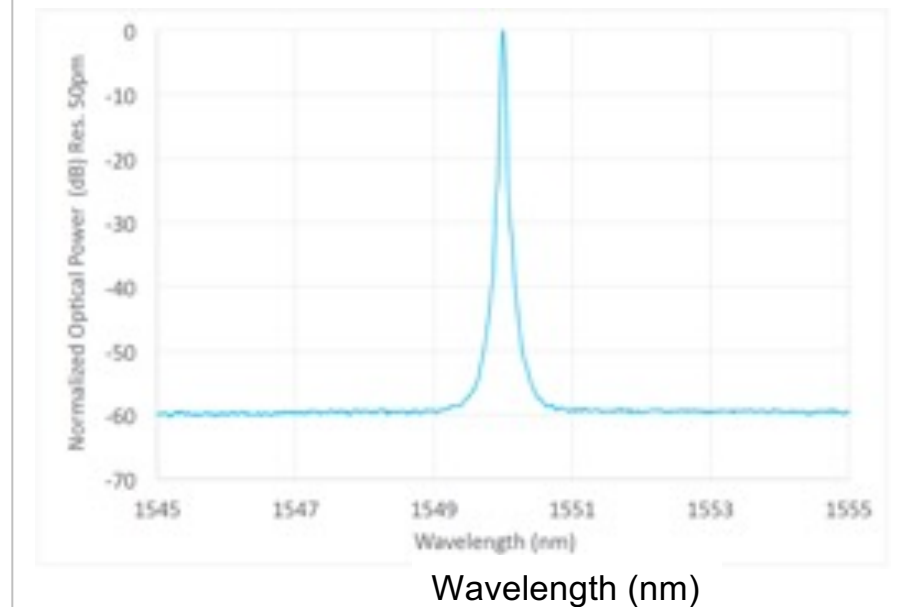
- Narrow band: < 1 GHz bandwidth filter
- Low Insertion Loss
- Fine adjustment of central wavelength
- Athermal packaging available



Optical Source

Low linewidth single frequency lasers (DFB)

- Combination of iXblue doped fibers and FBG technologies
- 1.5 and 2 μm available
- 1 kHz linewidth
- Up to 10 mW output power



Quantum / optical Source



IT IS



Exail : the Wow effect company

1

2

3

4

Awesome

Most recent awesome Success



5

Examples of most recent awesome Success

1 news for 2 μm

2 Fibers for High energy Lasers

3 Sensing in HARSH environment



News for 2 microns

➤ Motivations / State-of-the-art

Thulium-doped fiber laser

Better atmospheric transmission than 1 μm or 1.5 μm

High optical-to-optical efficiency

Max CW power > kW

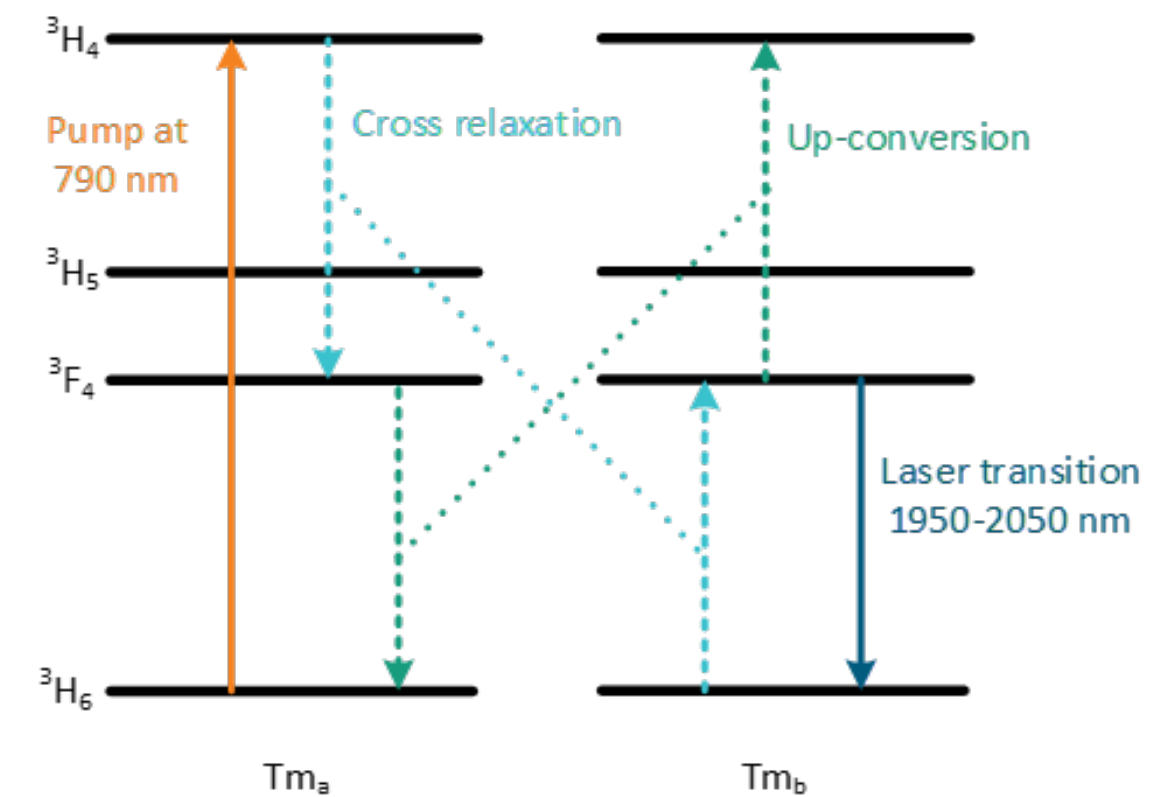
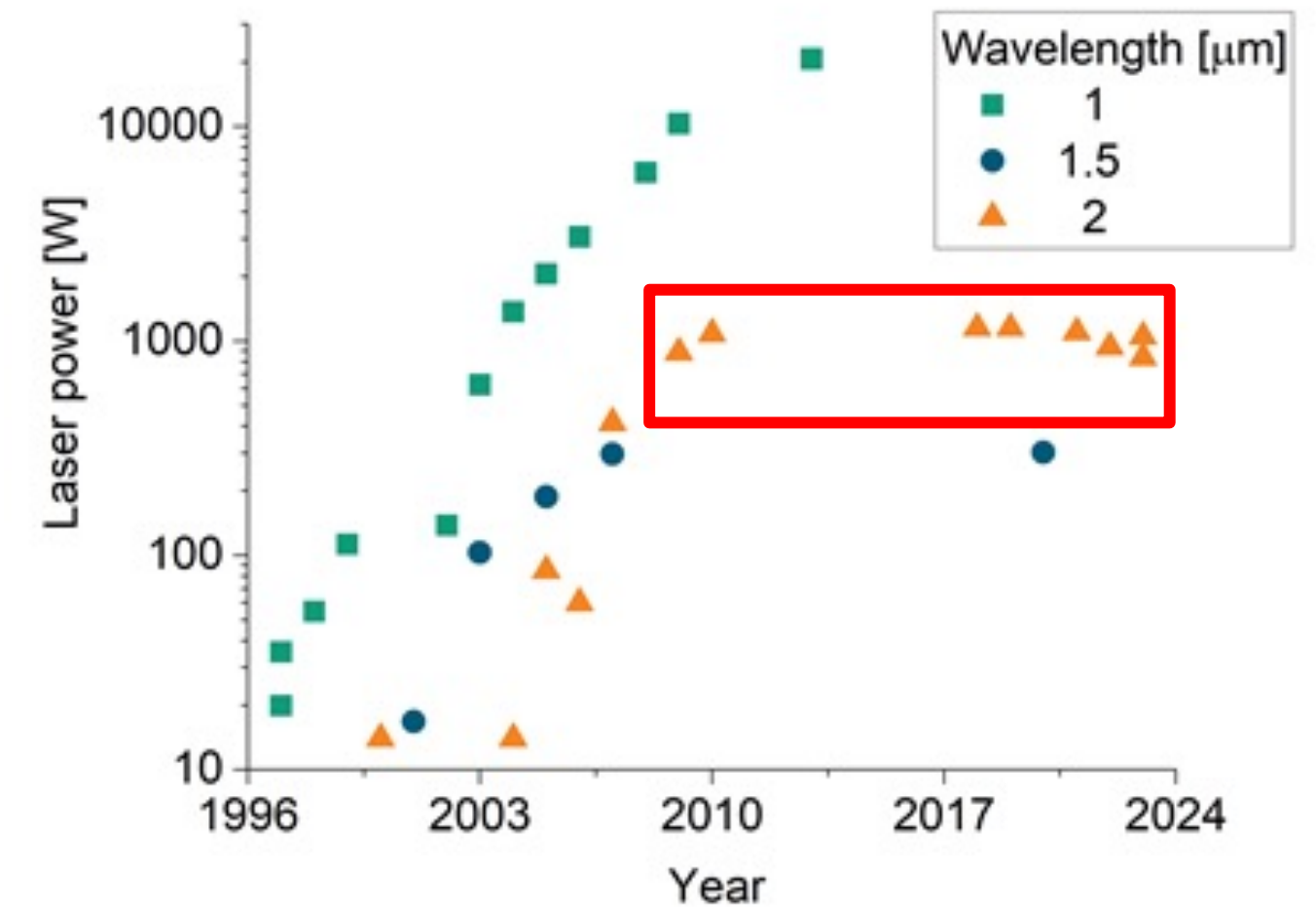
High threshold for nonlinear effects

Current power scaling limits

Heat load

Availability and performance of components

Thulium-doped fiber efficiencies



News for 2 μm : The largest offering for 2μm



Doped fibers for amplifier and laser cavity

Thulium	~1,7-2,1 μm	Single Clad 4 and 5 μm core, PM and non-PM Double Clad from 6 to 25 μm core, PM and non-PM
Thulium-Holmium	~1,9-2,1 μm	Double Clad from 6 to 25 μm core, PM and non-PM Triple Clad 18 μm core
Holmium	~2,02-2,2 μm	Single clad 8 and 20 μm core, PM and non-PM Triple Clad 20 μm core

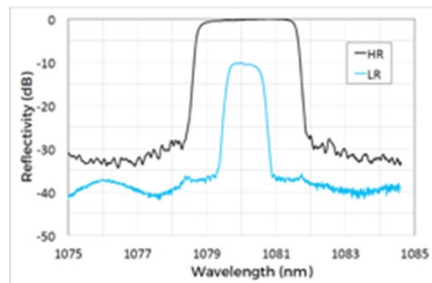


Passive fibers

Matched fibers	Single clad and double clad fibers matched with the doped fibers, from 6 to 25m core, PM and non-PM
Commodities	PM fiber : IXF-PMF-1950-125-P-021

High Power FBG Laser Mirrors- reduced heat

Standard Versions	1908, 1940, 1949, 2031, 2049 & 2120 nm
Custom versions	All wavelengths availbale on request



➤ Related Publications

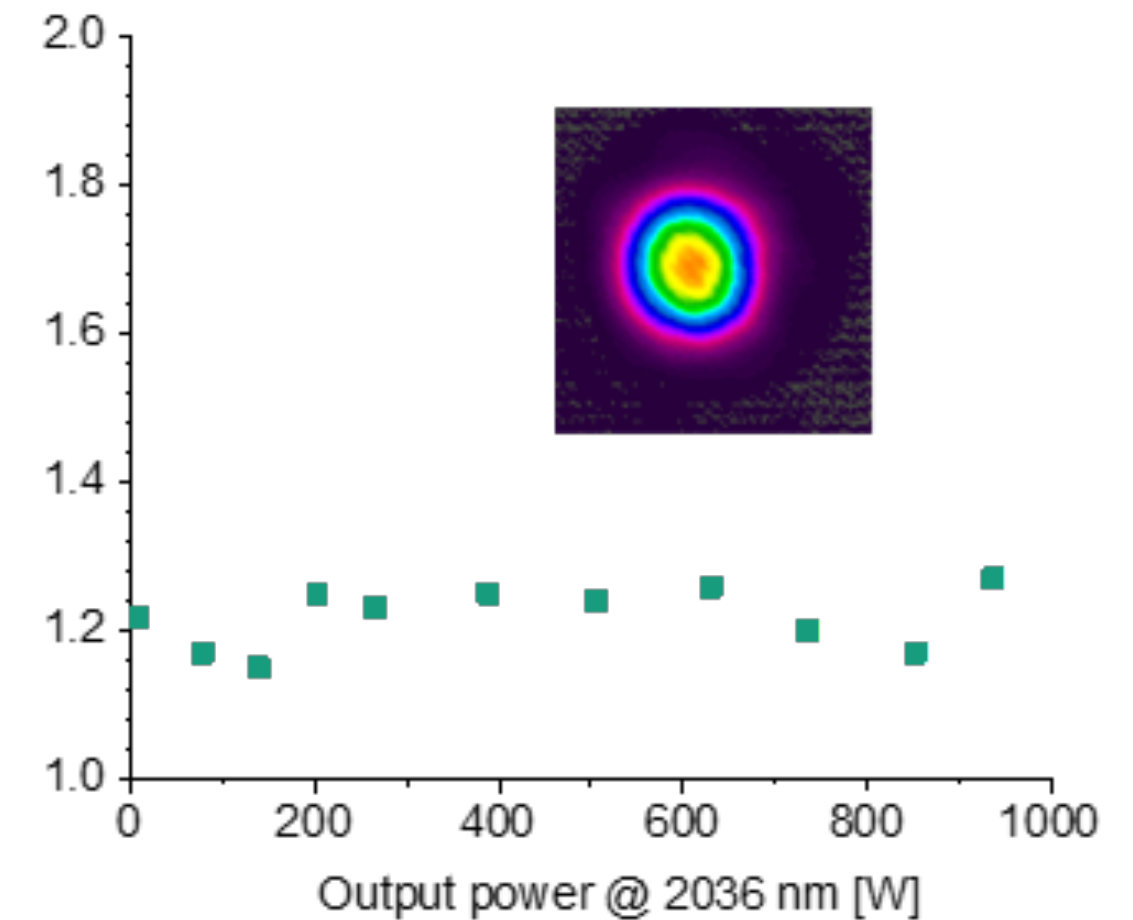
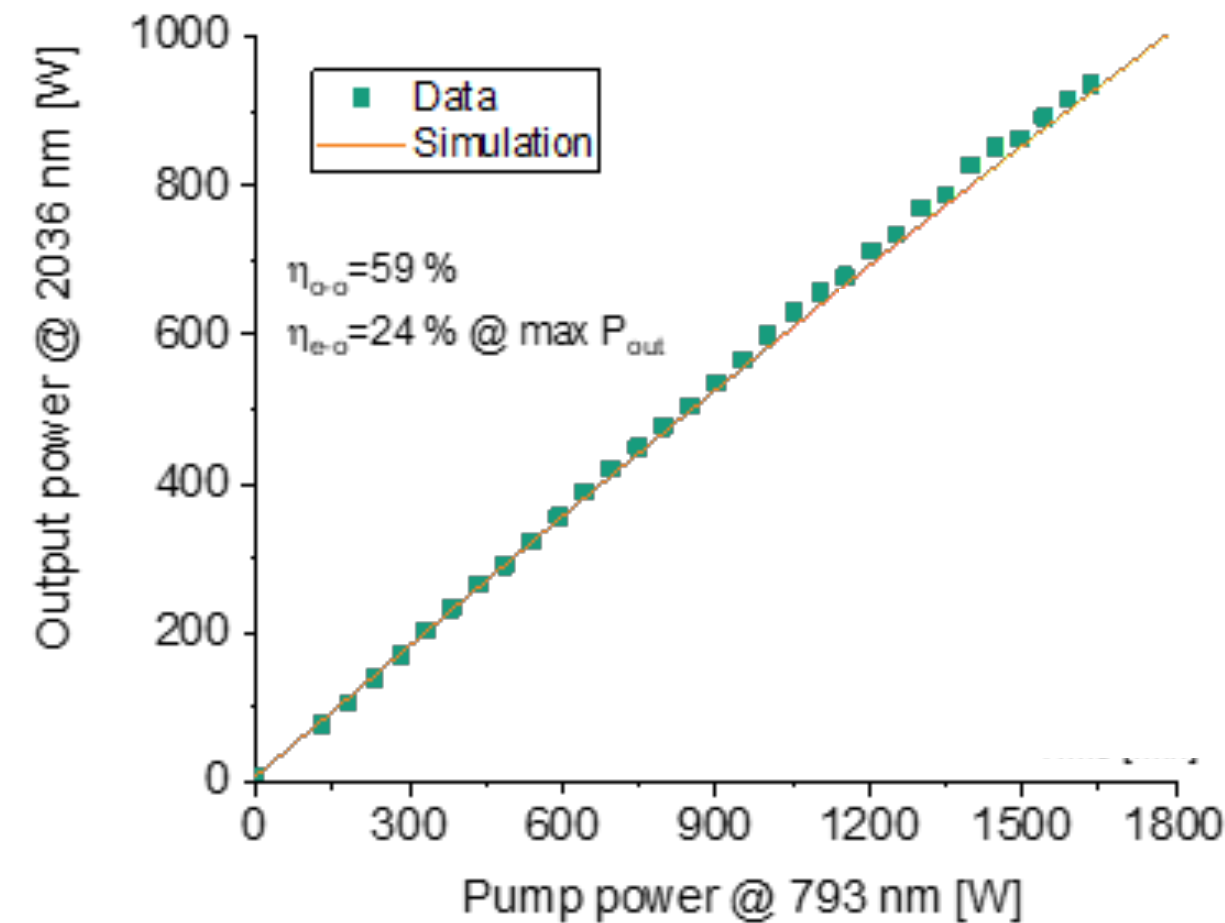
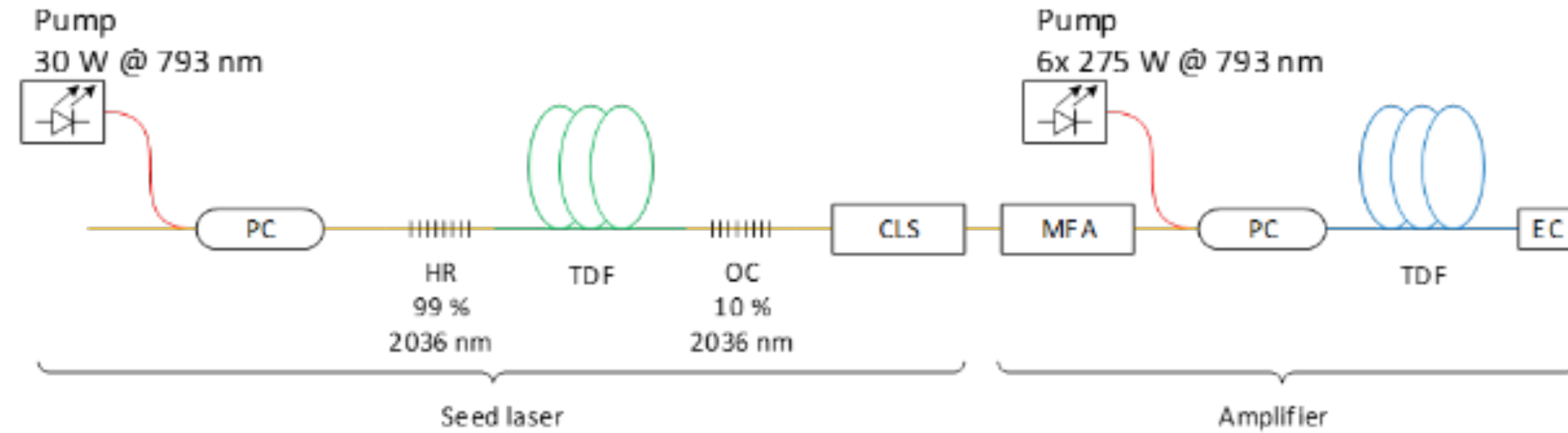
- Overview of various results @2μm using exail fibers: [LaserMunich 2022](#)
- [Few W @ 1760-1960 nm using PM Tm 5 μm Single clad fiber \(Cybel\)](#)
- [250 W peak, ns pulse @ 2,07μm nm using Holmium single clad fiber \(Cybel\)](#)
- [213 W @ 1,94μm using Thulium double clad fiber with passive fiber with pedestal](#)
- [195 W @2,09μm using PM double clad co-doped Thulium Holmium fiber \(ISL\)](#)
- [100W @ 2,12 μm using triple clad Holmium doped fiber \(Onera\)](#)

➤ Custom on demand

- Different doping version
- Single Clad / Double Clad /double Clad ALL-Glass / Triple Clad
- Coating selection (including metallic coating)

High-power TDFL @ IOSB

- MOPA architecture, all-fiber
- LMA 25 μ m tm 2CF
- **Output power nearly 1KW @ 2036 nm**
- Slope efficiency 59 %
- M2 < 1.3
- Linewidth FWHM 0.2 nm
- No nonlinear effects observed
- Pump power limited



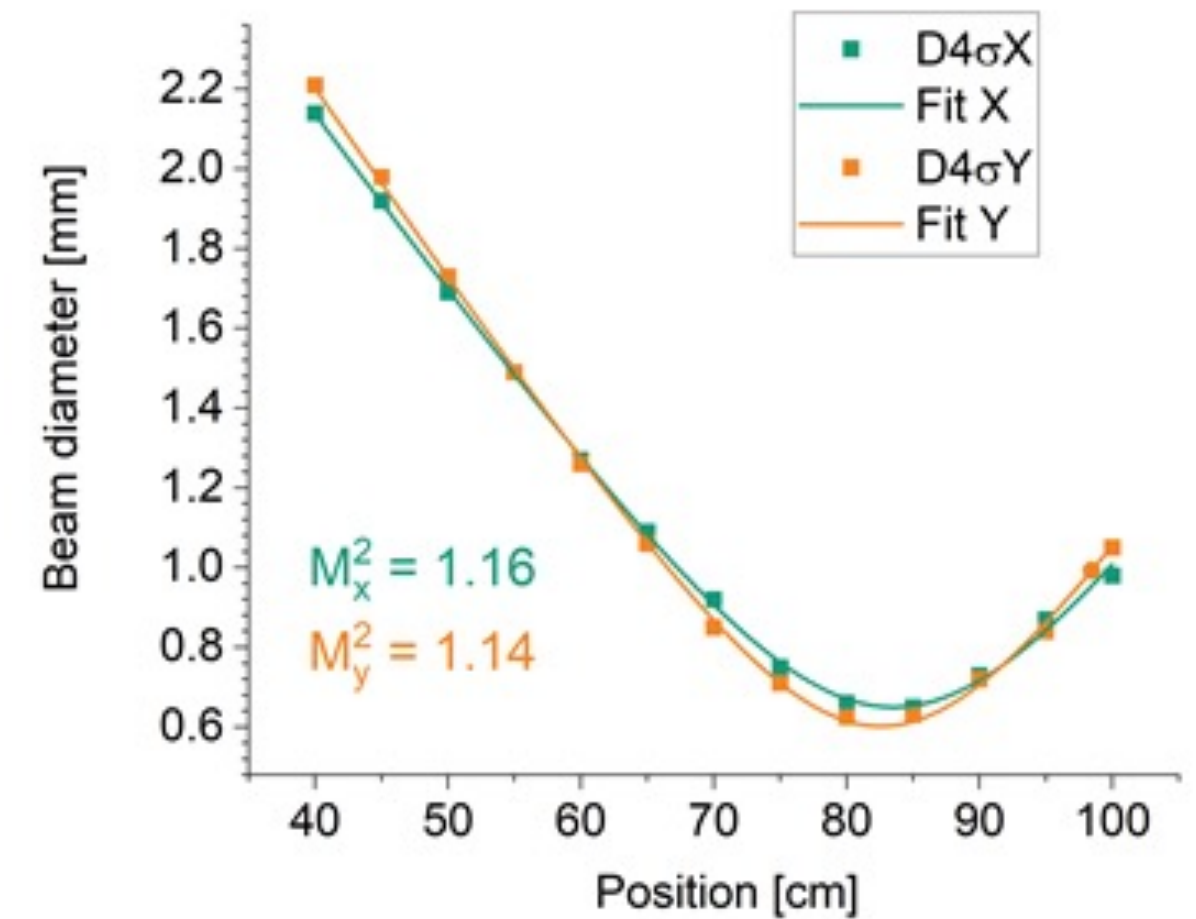
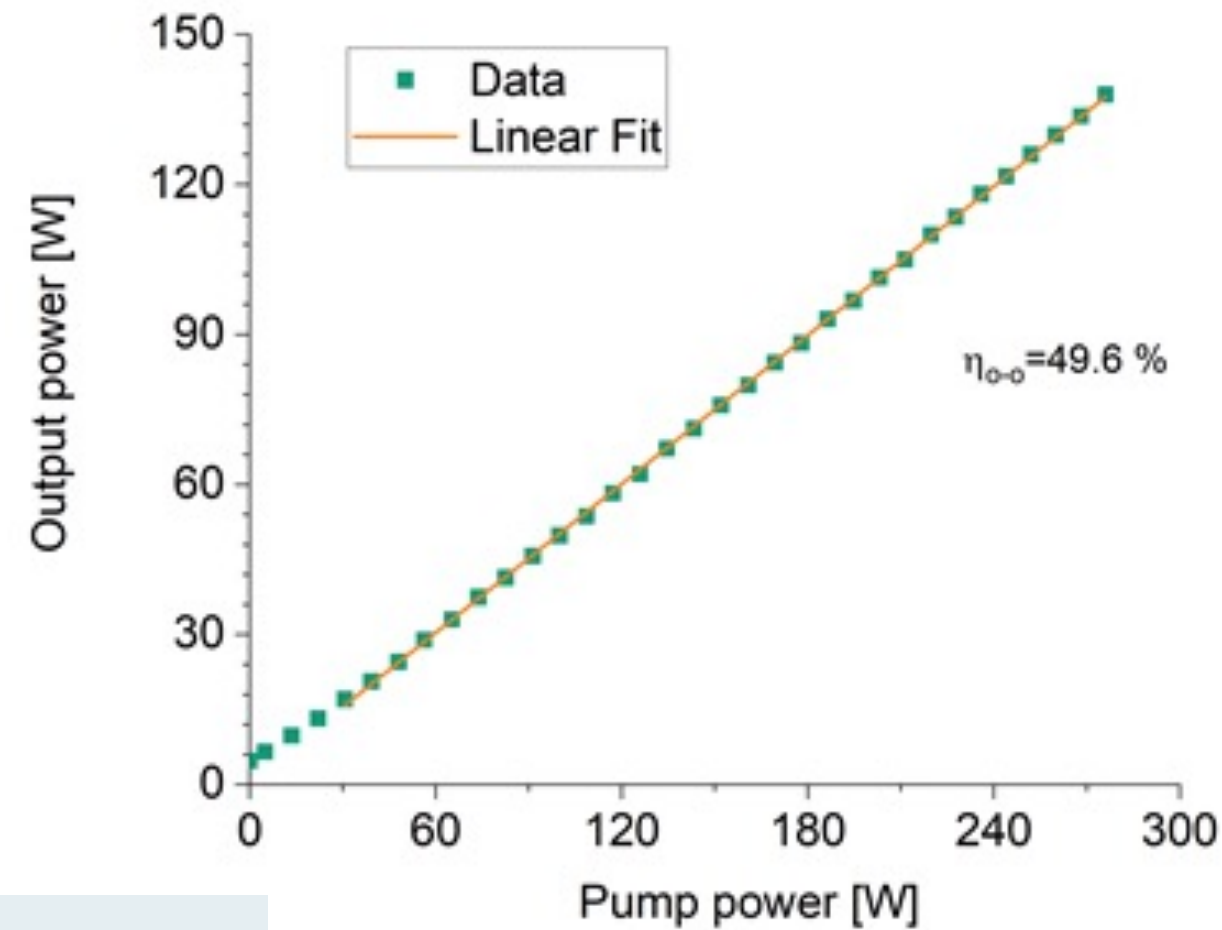
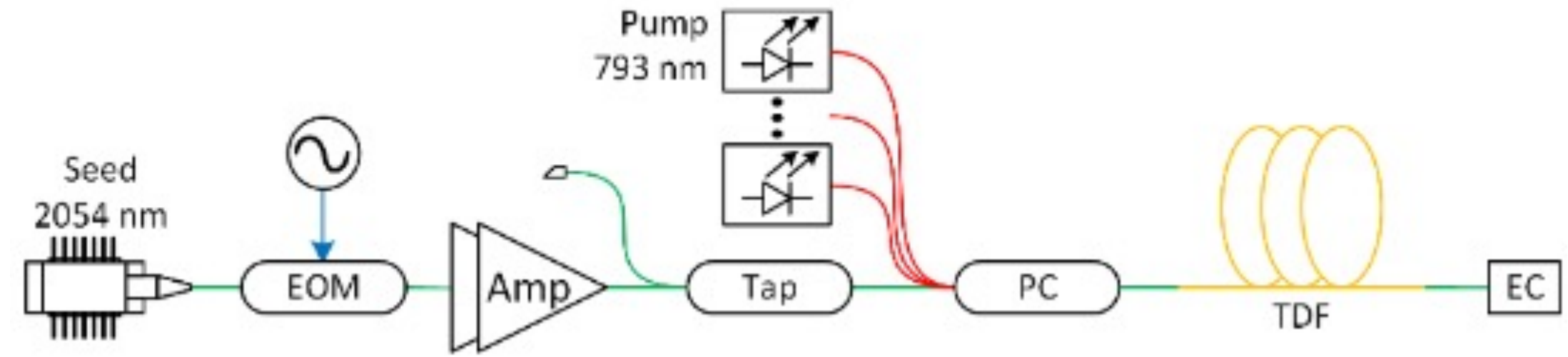
Fraunhofer IOSB

- Max output power 0.94 kW
- Pump power limited
- Narrow-linewidth
- MOPA all-fiber non-PM architecture

Exail's annual Photonics Users Conference 20may 2024 . Results Courtesy authorized by IOSB

High-power PM TDFL @IOSB

- LMA 25 μ mPM tm 2CF
- Seed linewidth < 1 MHz
- MOPA architecture, all-fiber PM
- **Output power 138 W @ 2054 nm**
- M2 < 1.2
- 50% eff
- Not limited by pump power or SBS



Fraunhofer IOSB

- Max output power 138 W
- Pump power limited
- Narrow-linewidth
- MOPA all-fiber PM architecture

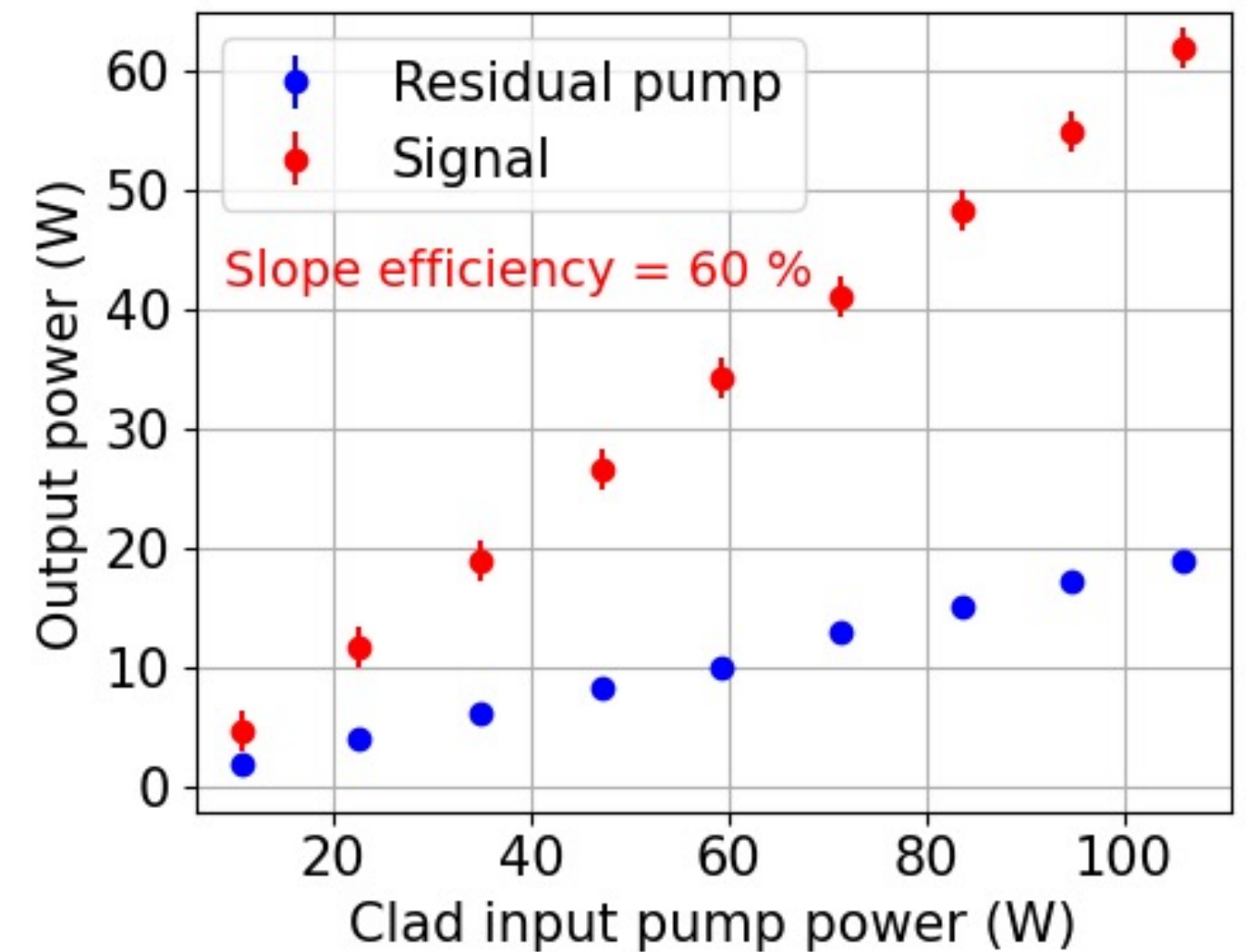
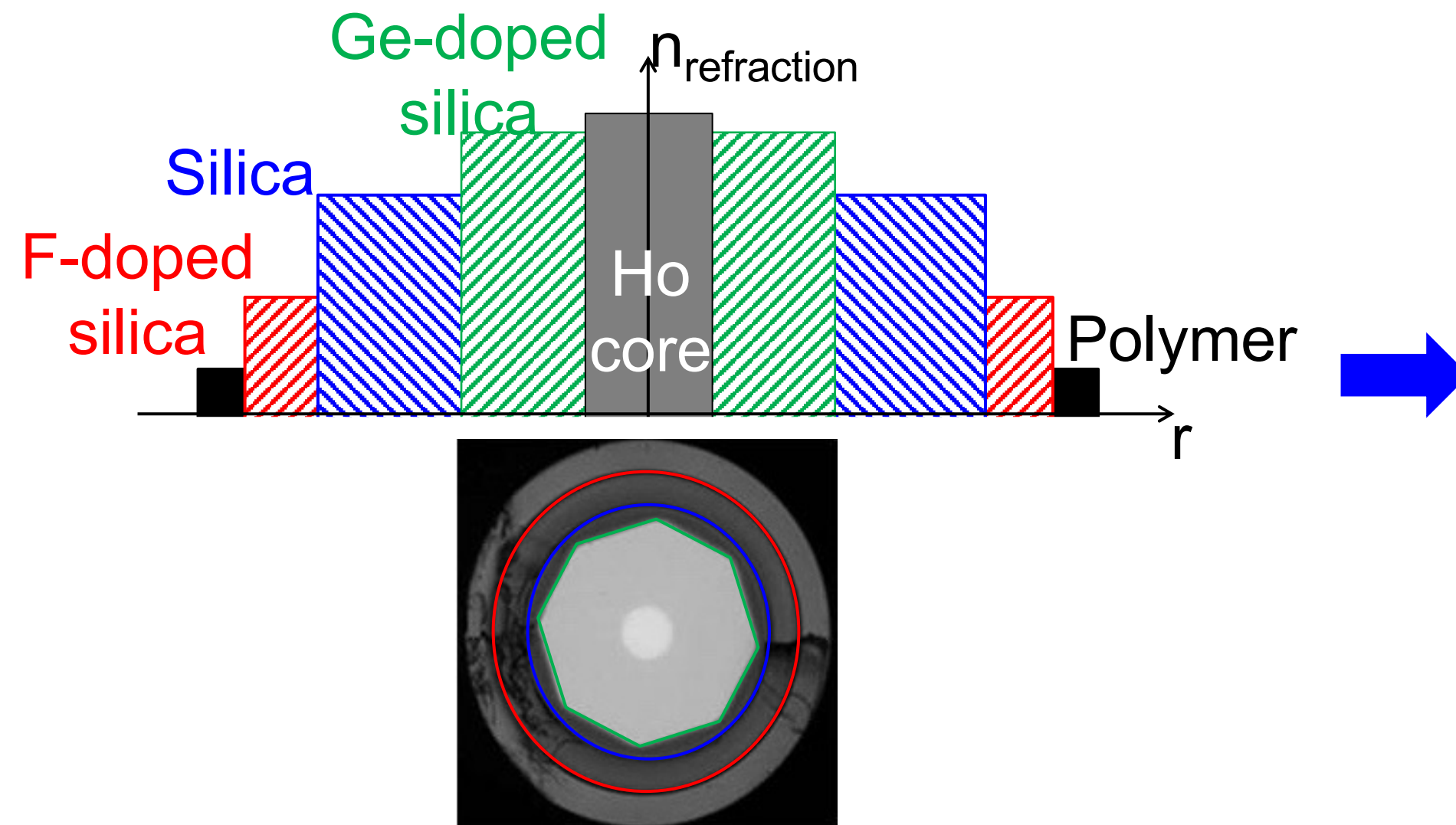
Exail's annual Photonics Users Conference 20may 2024 . Results Courtesy authorized by IOSB

High power 2 μm fiber amplifiers / resonant Pumping @ONERA

- **Resonantly pumped Ho-doped fiber amplifiers offer**
 - interesting power scaling potential
 - 'eye-safe' wavelength emission
- **Ho:Fiber pumped by Tm:Fiber laser emitting at 1940 nm**
 - → high P at 2.1 μm
- **Protective polymer coating strongly absorbs Tm:Fiber pump**
 - → Triple Clad Fiber (3CF) design required

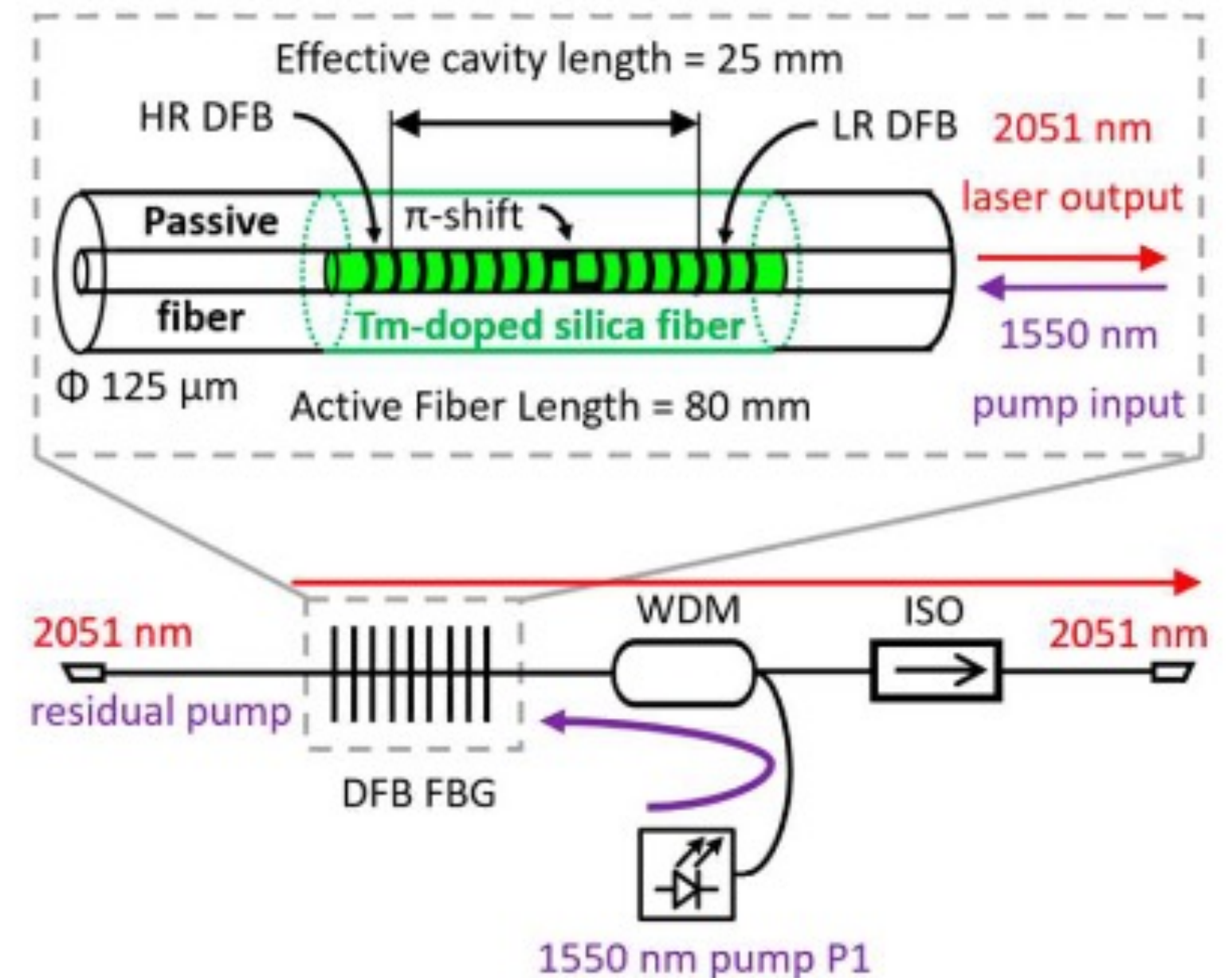
High power 2 μm fiber amplifiers / Fiber Design

- ▶ Ho:Fiber pumped by Tm:Fiber laser emitting at 1940 nm
 - \rightarrow high P at 2.1 μm
- ▶ Protective polymer coating strongly absorbs Tm:Fiber pump
 - Triple Clad Fiber (3CF) design required



2 μm Narrow Linewidth all Fiber DFB Fiber Bragg Grating

- **Pi-shift FBG inscription on exail Thulium doped fiber**
- **Ideal CW seeder:**
 - Ultra-narrow linewidth by design < 10 kHz
 - Flexibility in wavelengths vs semiconductor
- **Past realisations:**
 - Thulium fiber based: 1908 , 2032, 2039, 2049, 2050 nm
 - Holmium fiber based: 2090 nm
- **Related publications:**
 - [300mW 2039 nm PM DFB FBG \(Cybel\)](#)
 - [1W 852 nm laser based on the sum-frequency generation of 1540 and 1908 nm DFB FBG \(LP2N\)](#)



Examples of Most recent awesome Success

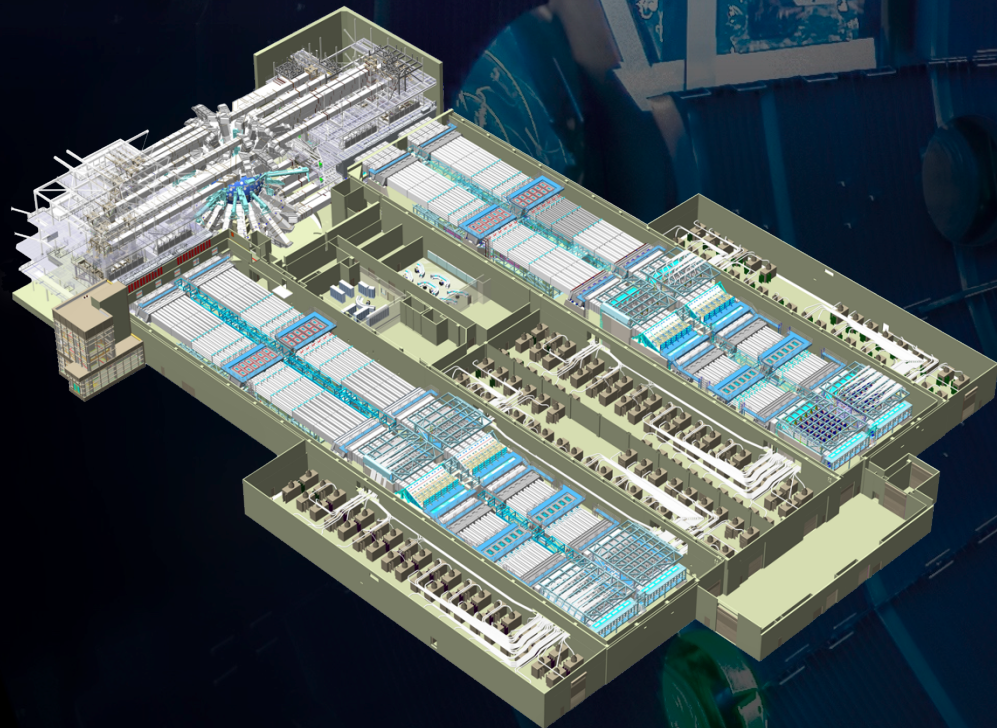
1

2 Fibers for High energy Lasers

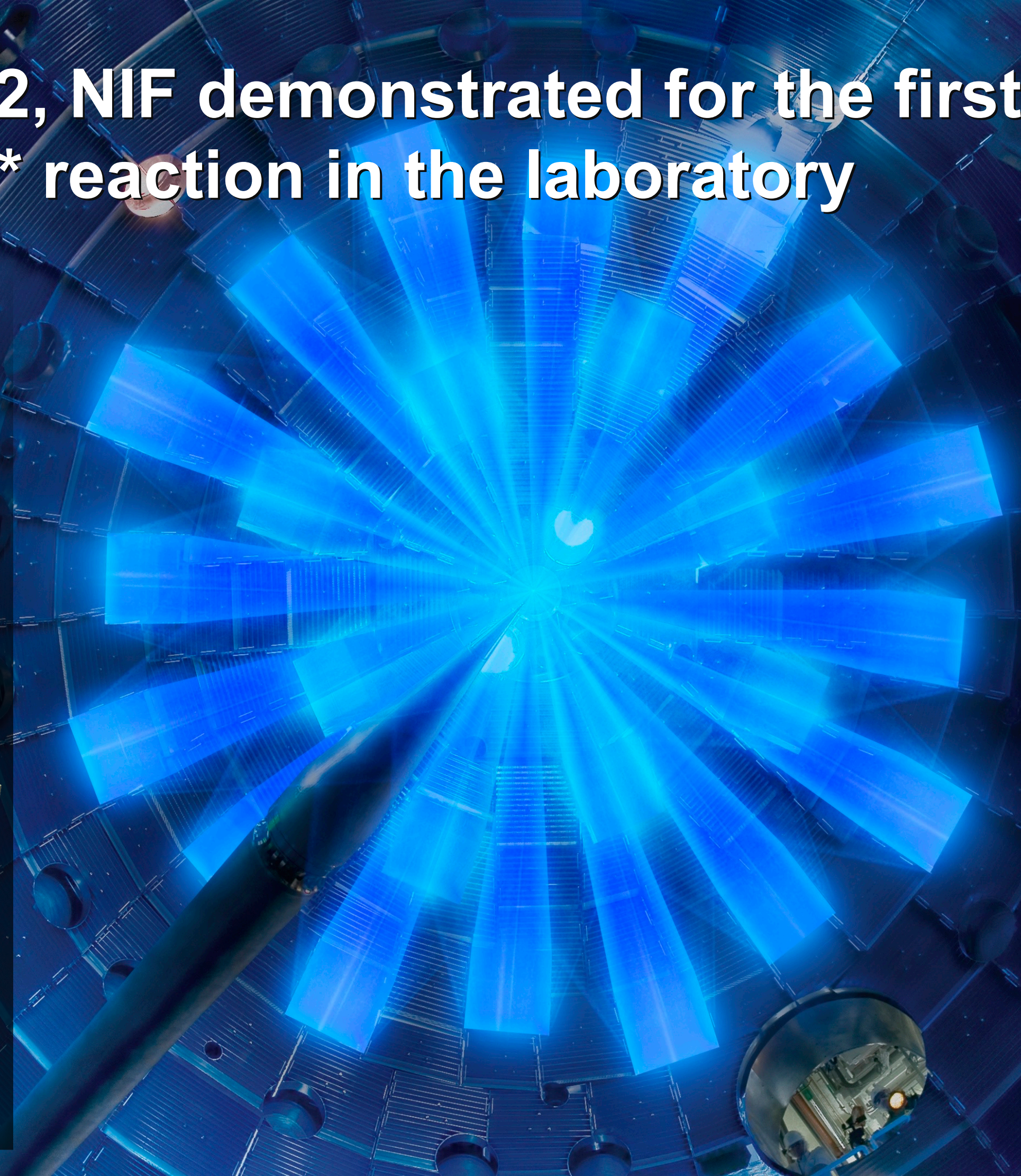


On Dec. 5, 2022, NIF demonstrated for the first time an igniting fusion* reaction in the laboratory

NIF Laser
on 12/5/2022
delivered
2.05♦ MJ UV
440 TW
Peak power ~4 ns

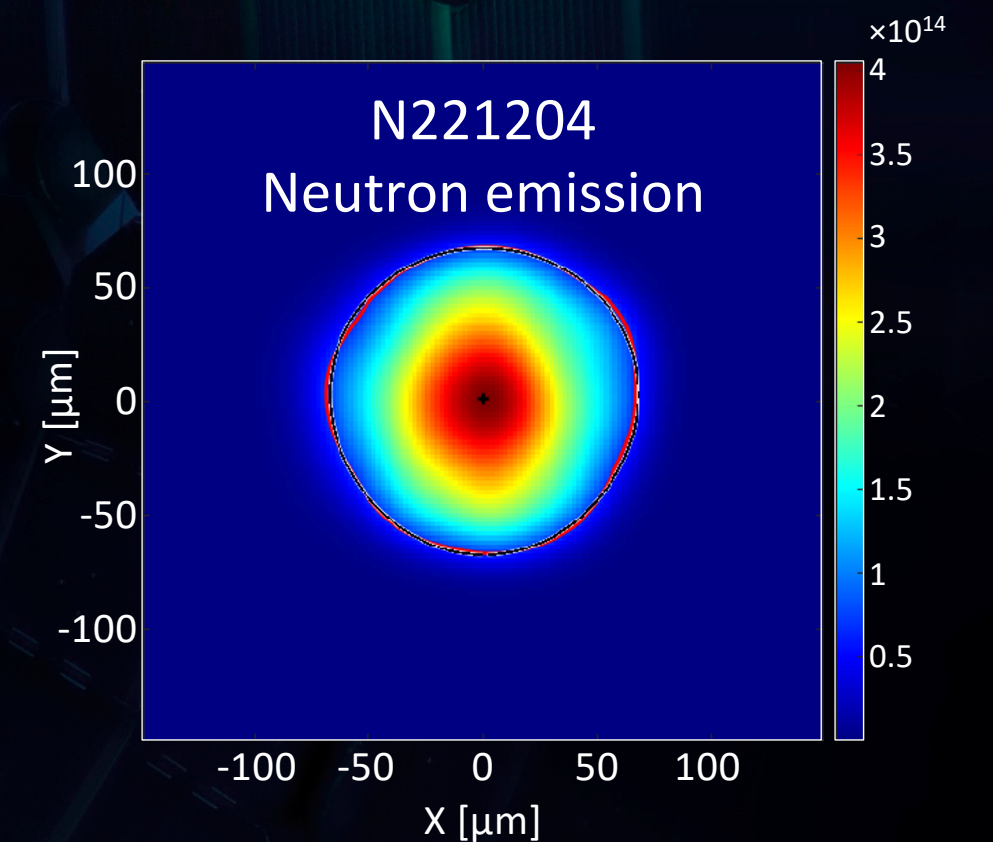


♦ The NIF laser was not designed to be efficient and uses about ~300-400MJ from the grid



Energy Output
From 12/5/2022 Experiment

>30,000 trillion watts (30 PW)
~3.15 MJ with $G_{\text{target}} \sim 1.5^*$
for ~100 ps



Fusion plasma ~100 μm
Temperature ~130,000,000 K

* Exceeding 1997 NAS definition
of Fusion Ignition

Exail's unique expertise in specialty optical fibers is a key for NIF's performance

➤ Exail fibers are used in the world's most energetic laser

- Exail's radiation-hardened UV fiber is used in the high-radiation environment of the NIF target bay to transport samples of the pulse power delivered to the target
- Exail Dual-stage Mach-Zehnder modulators are also used for precise pulse shaping in the Master Oscillator



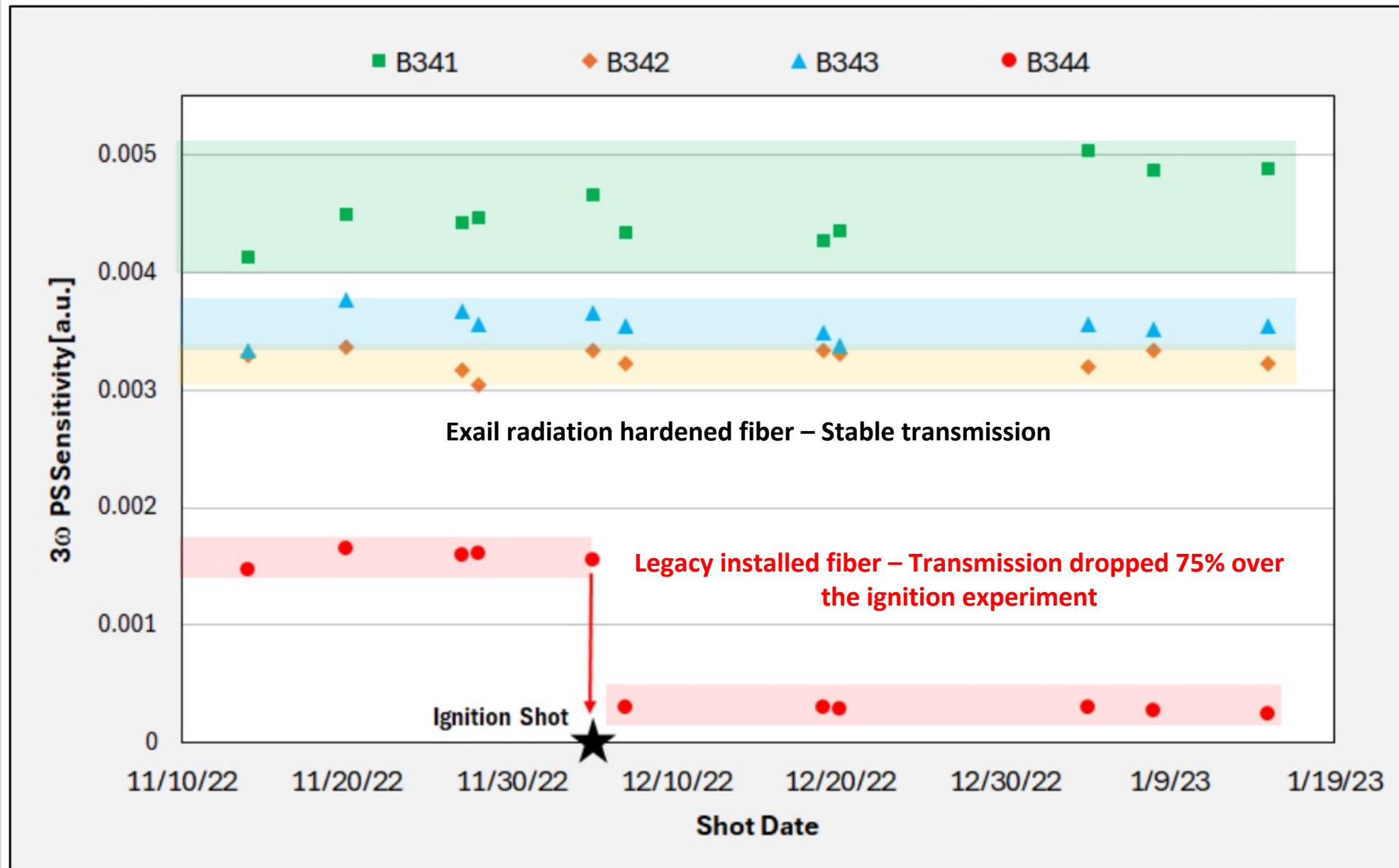
192 Beams, 2.2 MJ Energy, 500 TW Power

Laser Diagnostics & Pulse Shaping

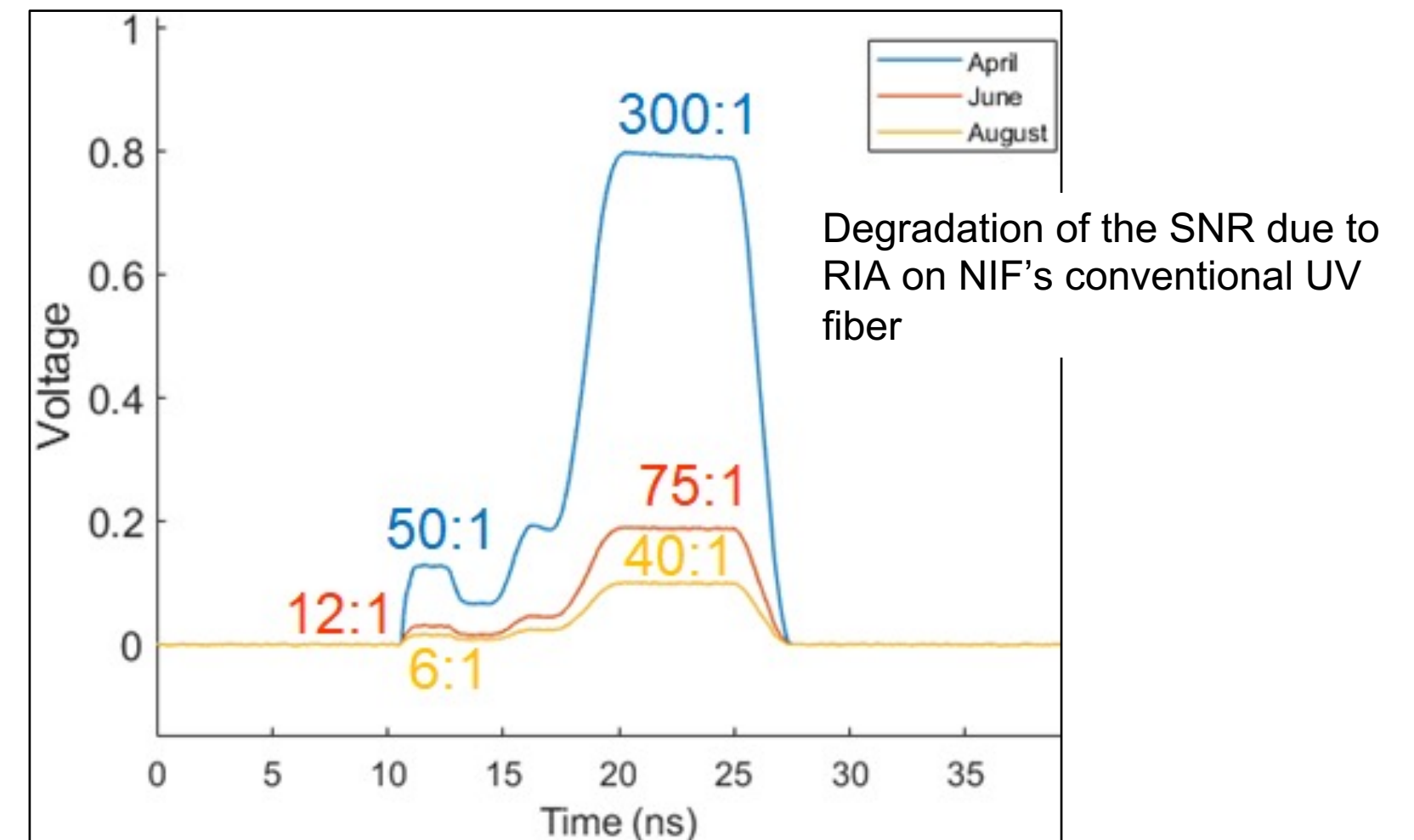


Substantial sensitivity improvement realized with Exail UV rad-hard fiber

All the 3 ω optical fibers were refurbished with Exail radiation tolerant fiber (top), 1 with legacy fiber (bottom)



- Offline analysis of beamline sensitivity indicate a range of transmission losses from initial fiber installation (2010-2011) through 2021 up to 30x
- Based on preliminary testing, Exail's fibers should be robust to many 100's of MJ of yield. !!!



All existing 3 ω power sensor beamlines have been retrofitted with Exail fiber
Deployment of additional sensors planned over the next few years

Examples of Most recent awesome Success

1

2

3

Sensing in HARSH environment

Enhancing the adoption of metal-coated optical fibers in the nuclear field



Awesome Radiation Hardened fibers

> 25 years experience in rad-hard fibers

- joint-research laboratory with Laboratoire Hubert Currien 

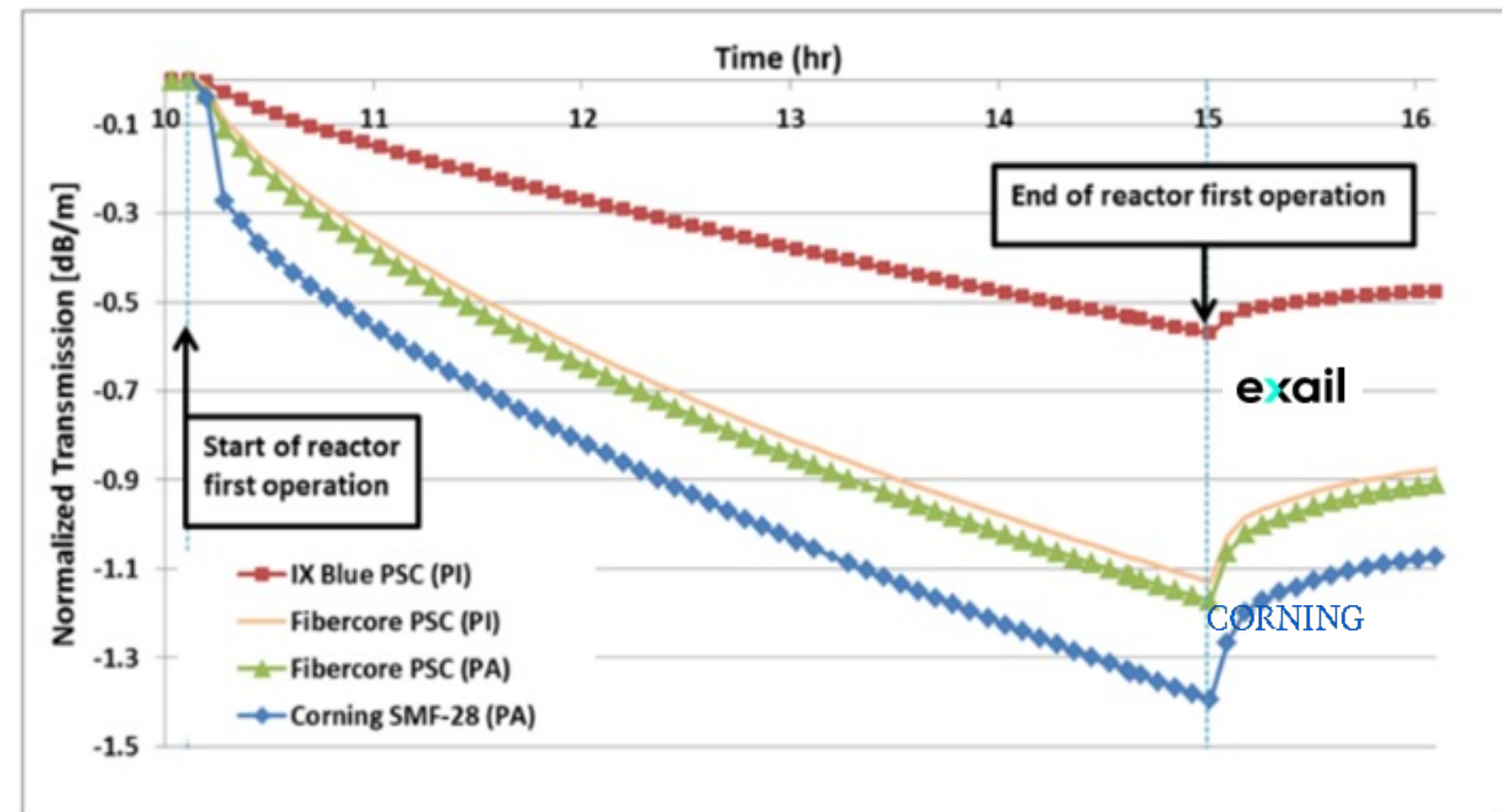
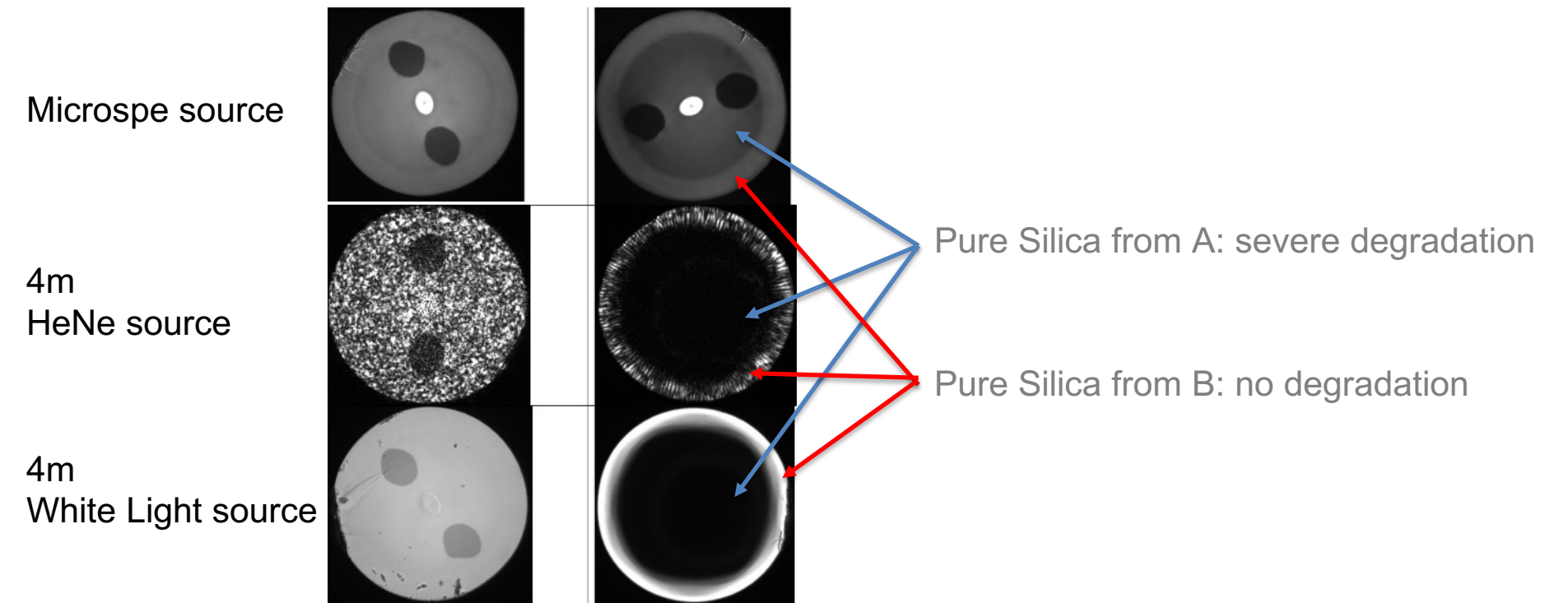
> Pure Silica Core is not enough !

- Measurement in Nuclear reactor
 - Exail: 2x better RIA than competitive PSC fibers
 - RIA : 0,55 dB/m RIA @4MGy @ 1550 nm

> Large choice of standard Rad-Hard fibers

- Three Grades:
 - Radiation Tolerant
 - Rad-hard
 - Super Rad-hard
- From UV to 2 μ m
- SM & MM

> Custom fibers from preform to fibers



From "[Characterization of radiation hardened fibers in a research grade nuclear reactor](#)"

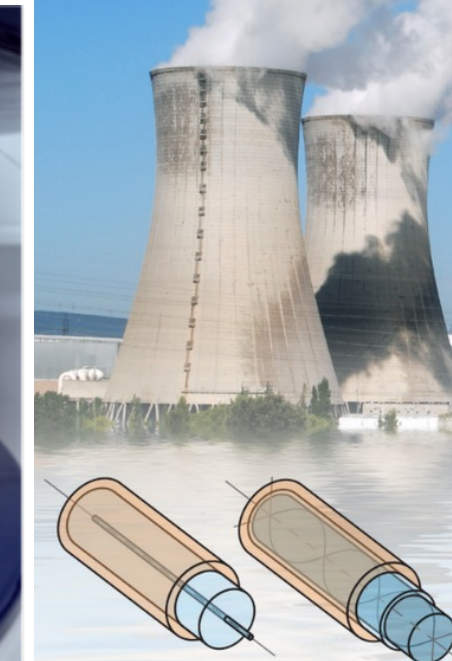
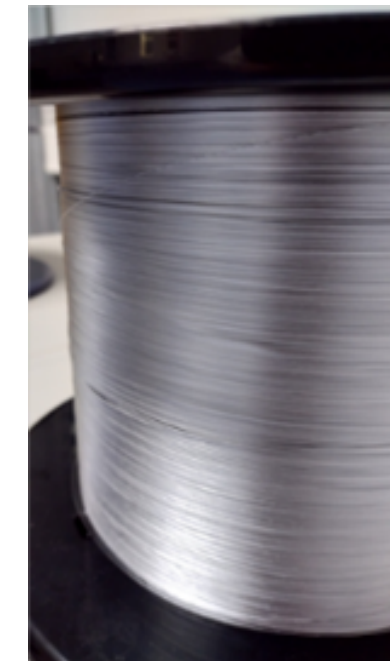
Exail offers Coatings for Harsh Environment

- > From 350 to 2100 nm
- > From 40 to 650 μm cladding
- > From 2 to 600 μm core
- > SM, MMSI, MMGI

- > **High Temperature Acrylate Coating**
 - +150°C long term operation

- > **High Quality Polyimide Coating**
 - Ideal for temperature sensing
 - +300°C long term operation
 - Low outgasing for space applications
 - Fully qualified for volume production
 - SMF suitable for FBGs femto inscription
 - No coating defect
 - Ex: 2000 FBGs with 10 cm spacing

- > **Metallic / Carbon coating**



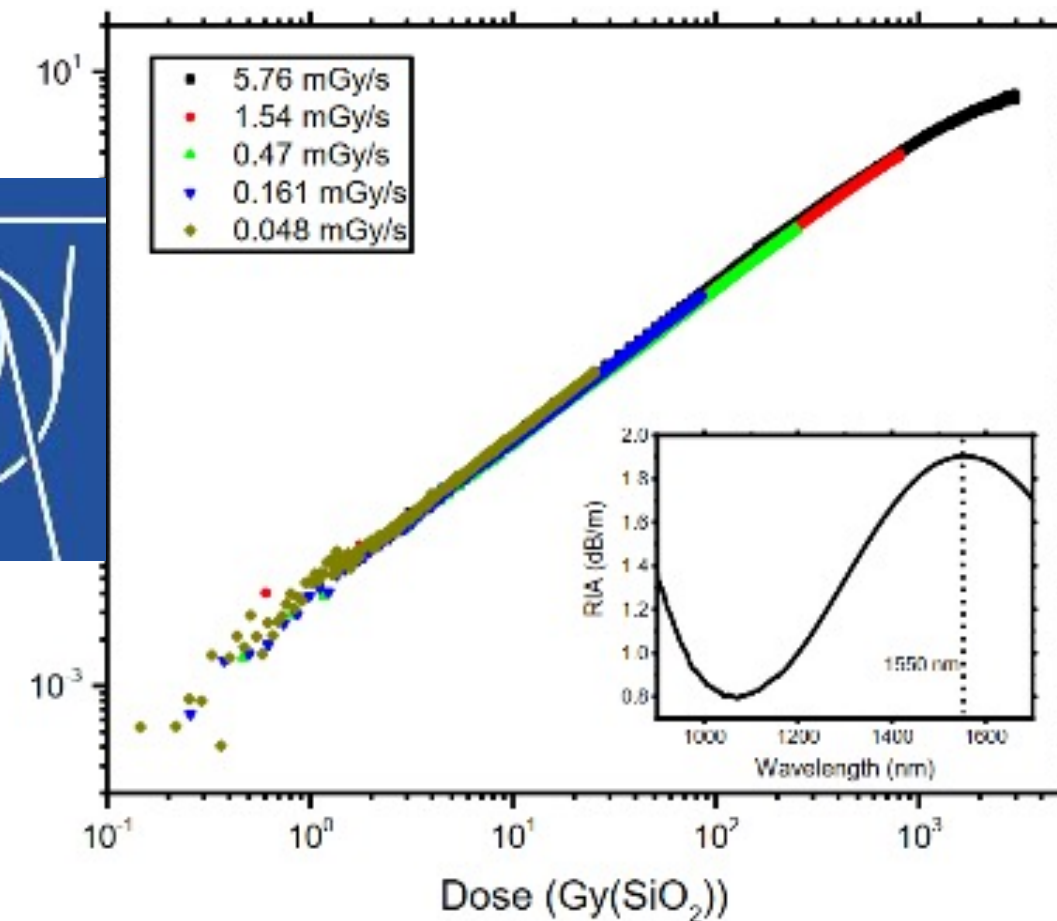
Coating

Max. temperature

Acrylate (Telecom Type)	85°C
Acrylate (High Temperature)	150°C
Polyimide	300°C
Aluminum	400°C
Carbon+Copper	600°C

RAD-SENSE fibers for dosimetry

- **Selected chemical composition to enhance fiber sensitivity to radiation**
- **Point sensing**
 - Optical configuration: Light source → Sense fiber → Pwmtr
 - Single punctual dose measurement
 - RIA with high resolution (m dB) & dynamic range (>50 dB)
- **Distributed sensing**
 - OTDR based measurement – single ended
 - Dose received along the fiber
 - Spatial resolution ~1 m
 - Limited optical budget (~ 15 dB) of the OTDR
 - Ex: *already deployed in CERN in the Proton Synchrotron Booster and Proton Synchrotron.*
- **Advantage of an all-fibered solution**
 - Ability to deport the measurement unit out of irradiated dose
 - Radiation Induced Attenuation (RIA) increases linearly with the cumulated dose, up to moderate dose levels
 - Limited dependence of the RIA to the dose rate and T°





We delight in

- Collaborating with R&D Labs
- Working on Technology transfer to the field !
- Industrializing Process
- Making Cutom design

exail

