Improving distributed optical fibre sensing systems by specialty coatings on as-drawn fibres

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RISE Research Institutes of Sweden

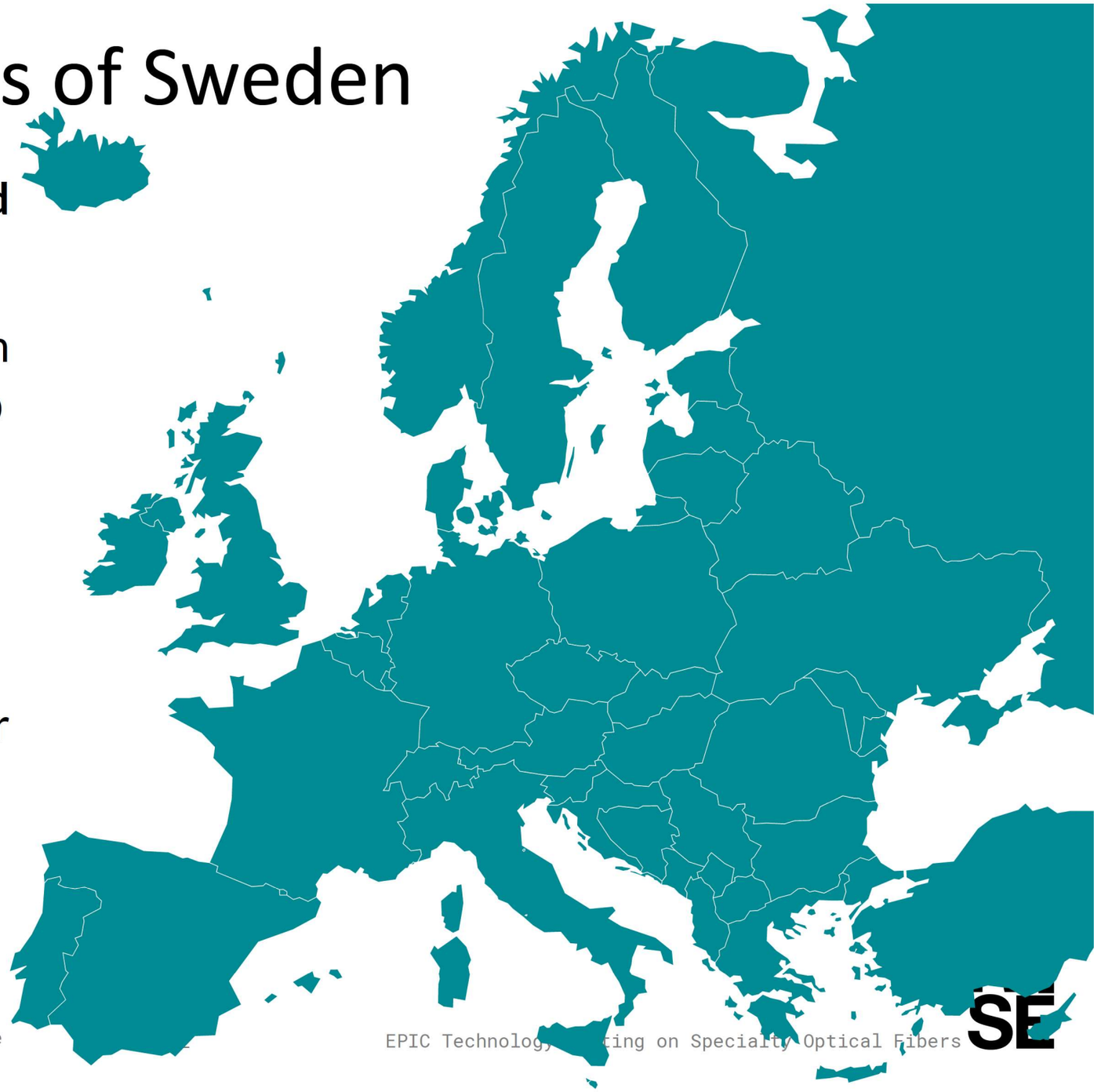
Cross-disciplinary research and innovation

The 4th largest institute of its kind in Europe, after Fraunhofer, CEA and TNO

Non-profit research institute

~3300 scientists and engineers active across different fields

Sites all around Sweden and in other countries (France, Norway, Belgium, US)



Fibre-Optics at RISE (~20 people)

Fiberlab in Hudiksvall

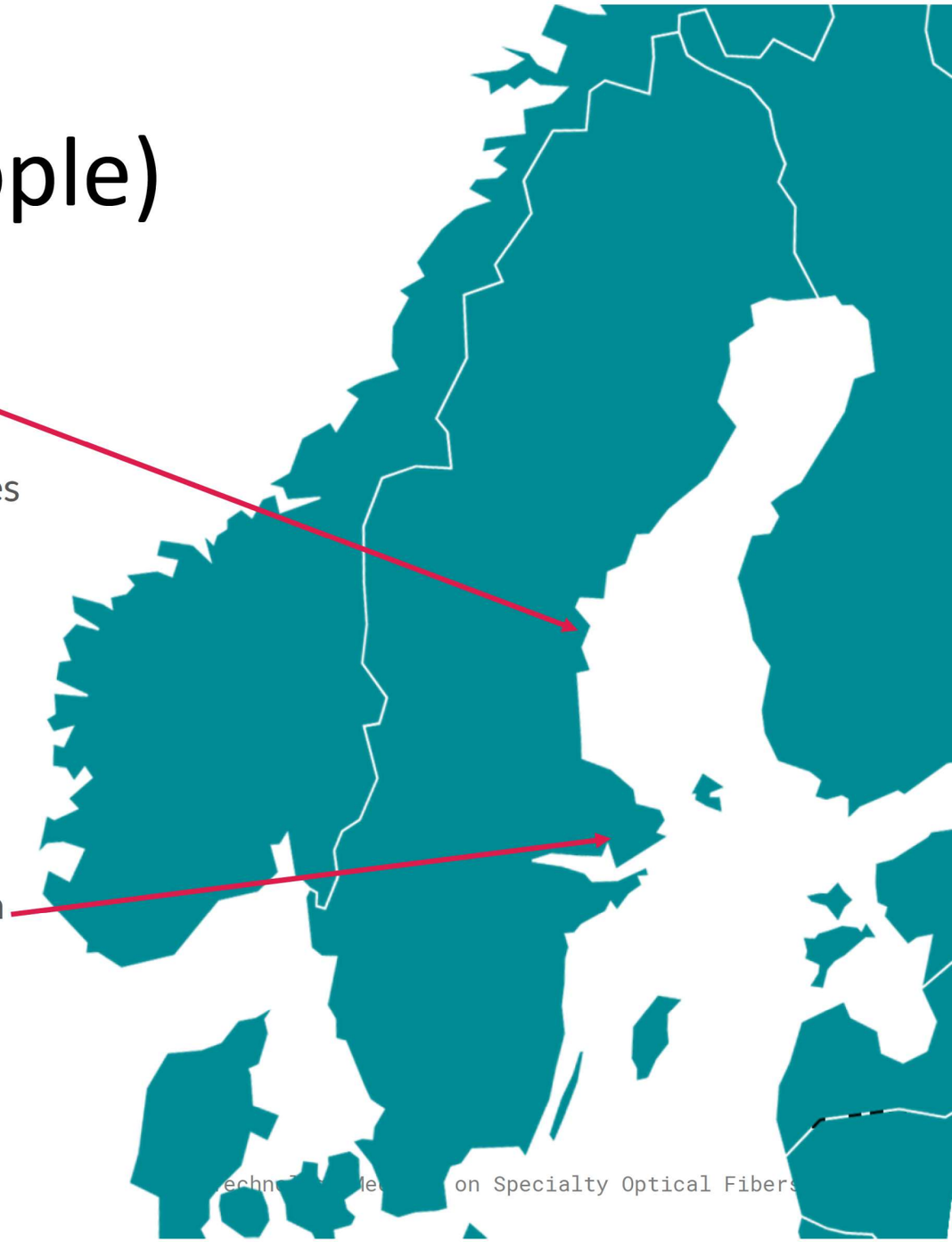
3 Draw towers (ISO 9001:2015)

2 Commercial Production of Fibres

1 R&D tower

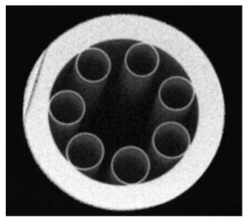
Fiber Optics and Photonics in Stockholm

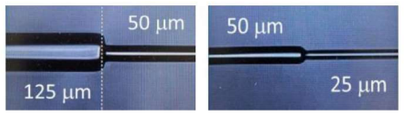
Design and deploy custom Fibre-Optic Sensing solutions and components

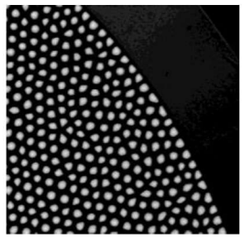


Core expertise at RISE fiber

Specialty fibre fabrication







Extreme geometries

Ultra-thin, Ultra-thick, Multi-hole, Multi-core, Thousands-of-cores, Hollow core, ..

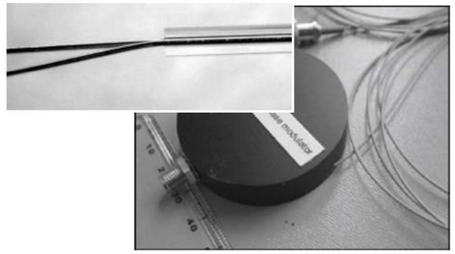
Fibres for harsh environments

Coatings, buffers and fibre designs for high/low temps and harsh chemistry

Custom functional coatings

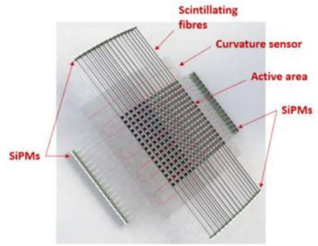
Carbon (conductive and hermetic), Magnetic, X-ray visible, Nano-composites, ..

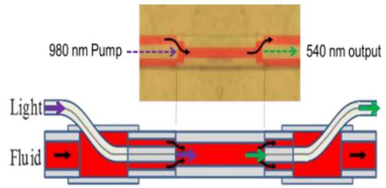
Fibre components and sensing

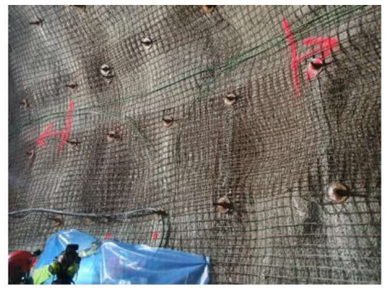


Fibre-optic components

Poled fibres, lab in a fibre (optofluidic devices), flexible scintillating fibres, …

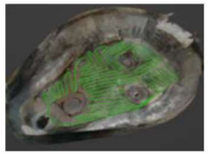


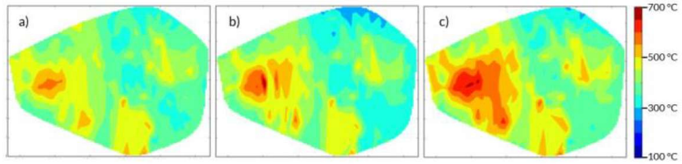




Deployment of tailored fibre sensing systems

Temperature, Vibrations, Strain, Pressure, Chemical,





Applications

Industrial Process

Monitoring in paper, steel production, Mining

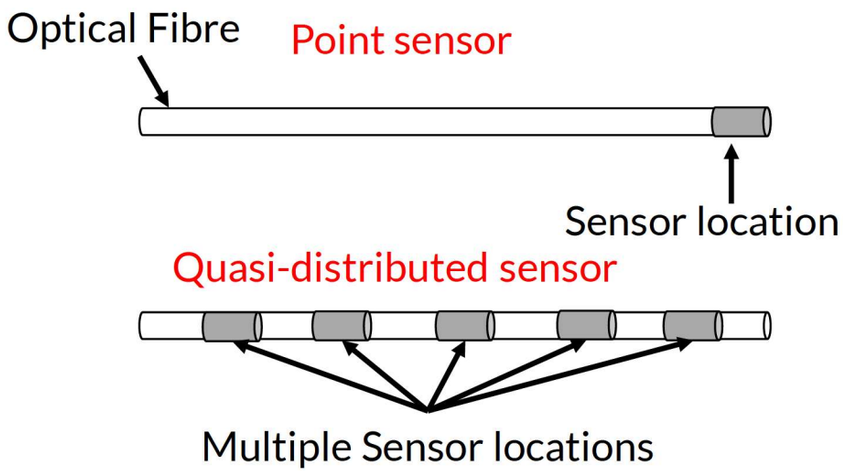
Manufacturing and medical

Fibres for power delivery, imaging, lighting, optofluidics, ..

Energy sector

Monitoring power cables, transformer components and Renewable Energy assets

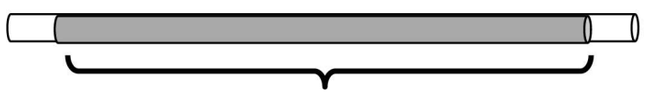
Exploiting the whole length of the fibre for sensing



Only one sensing measurement is obtained, e.g., Fabry-Perot sensors and single Fibre Bragg Grating (FBG) sensors

Many individual point sensors are multiplexed on the same optical fibre, e.g., Fibre Bragg grating (5-10 mm) every 1 metre over 100 metres

Fully distributed sensor

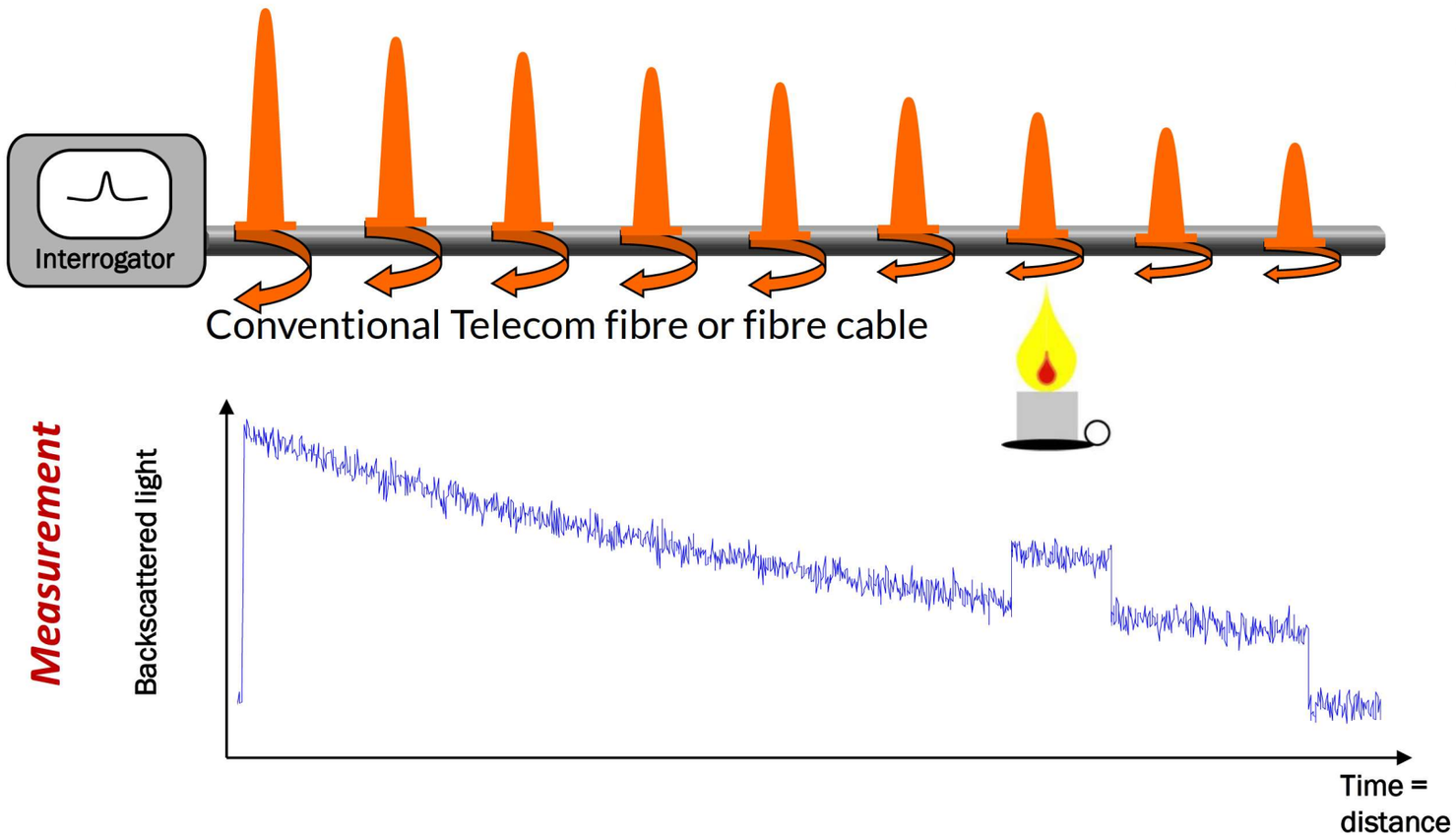


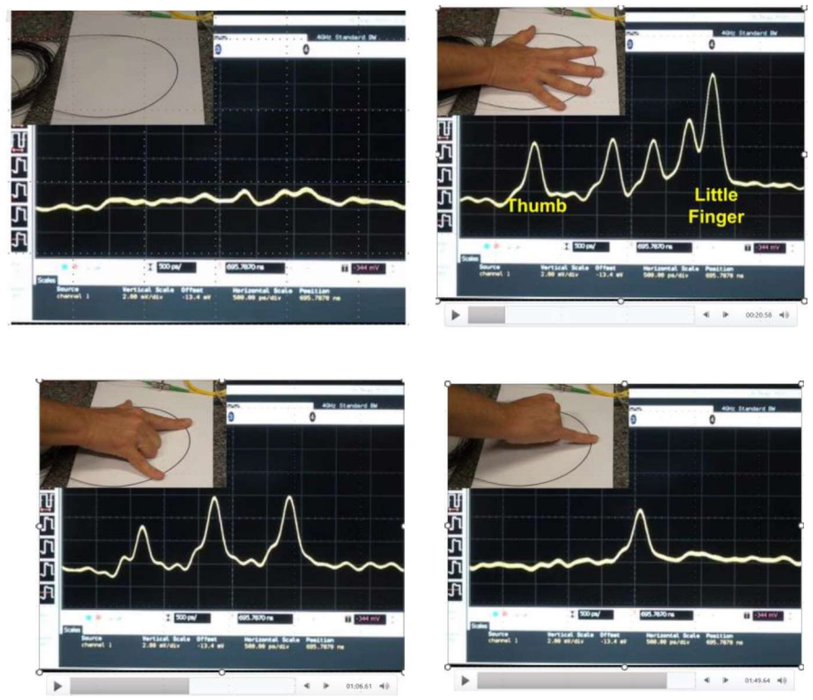
Continuous Sensing zone → 10s of km

The whole length of a conventional optical fibre becomes the sensing element; the sensing zone is given by the spatial resolution of the measurement.

Distributed Fibre-Optic Sensing: Sonar for fibres

- Light pulse launched in optical fibre
- Backscattered light along the fibre is measured
- A hotspot locally changes the backscattered light and can be located

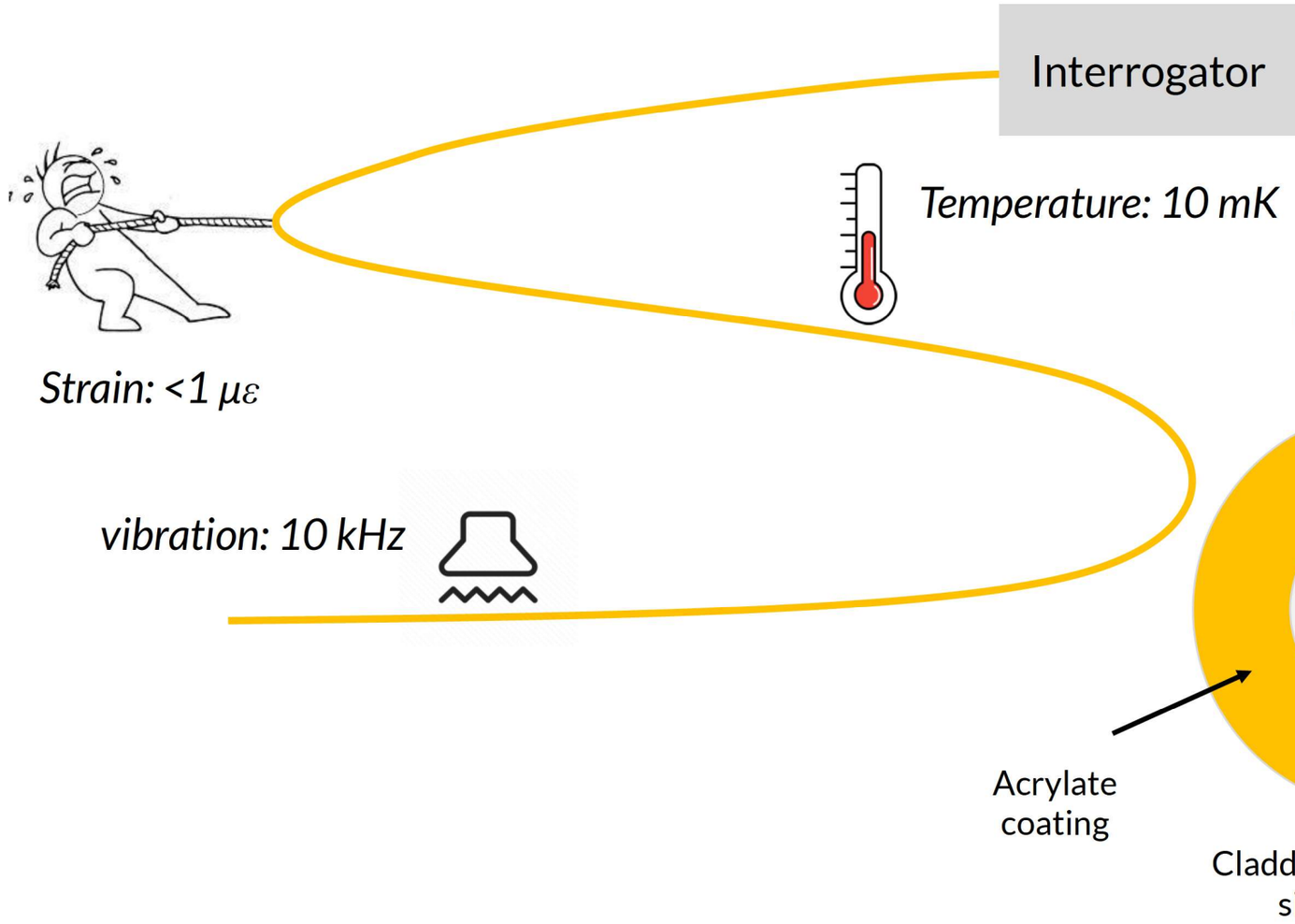




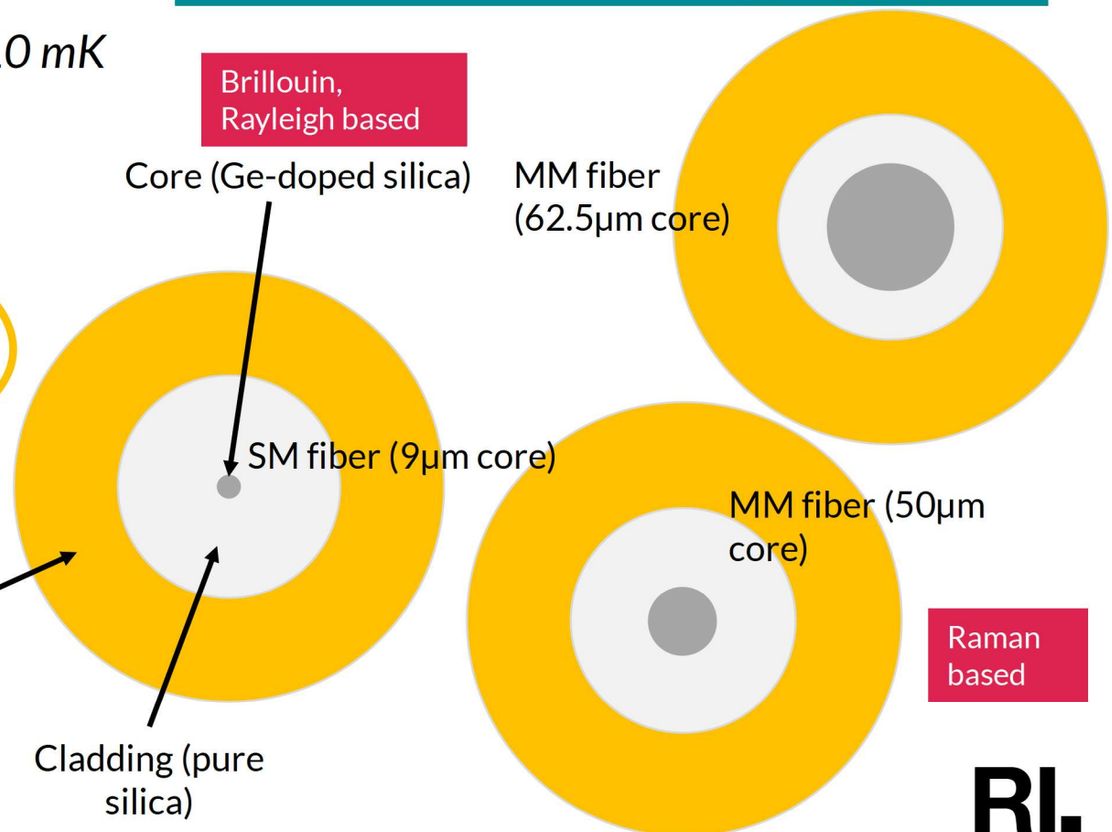
Courtesy: EPFL-GFO - Prof. Luc Thévenaz

Conventional DFOS system

Typical sensing performance of commercial DFOS system :
1.Range: 30 – 50 km
2.Spatial resolution: 1-2 metres
3.Measurement time: several minutes (static)



Conventional fibres (for sensing people)



Do we really need specialty fibres for DFOS then?

Conventional SMF and MMF

Proactive approach to DFOS: Use specialty optical fibres

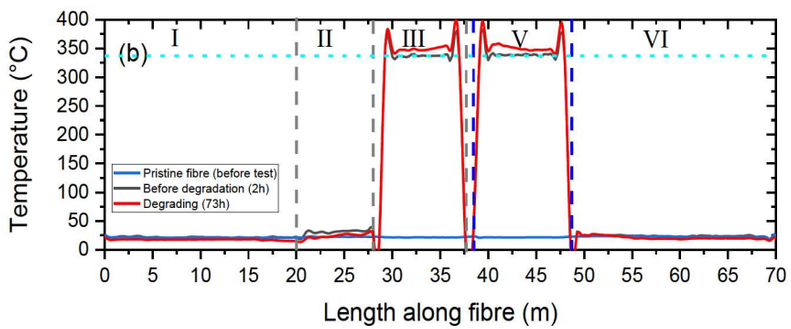
Temperature, strain, vibration

Other parameters

In ”normal” environment:

- Temperature < 70 ◦C
- Fibres in cables, not embedded (in most cases)

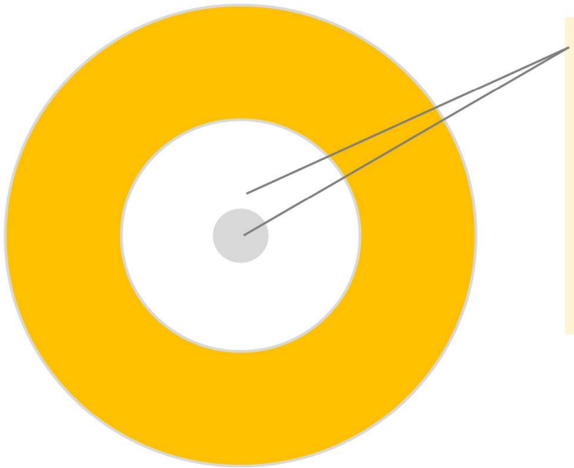
Less reliable measurements obtained using DFOS:



- In **harsh environment** (e.g., high-temperature)
- when the fibre is (badly) **embedded** in structures

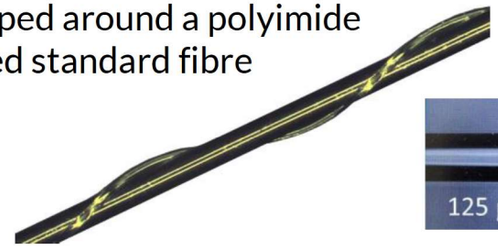
If one wants to measure **something else** than *strain*, *vibration* and *temperature* in a distributed way

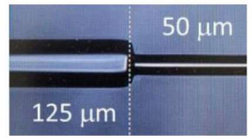
Specialty fibres: changing core/cladding structure

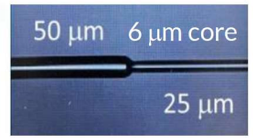


Core/cladding
- Numerical aperture
- Active/passive dopants
- Core/cladding geometry
- Core and cladding size
- Holes, hollow cores, geometry

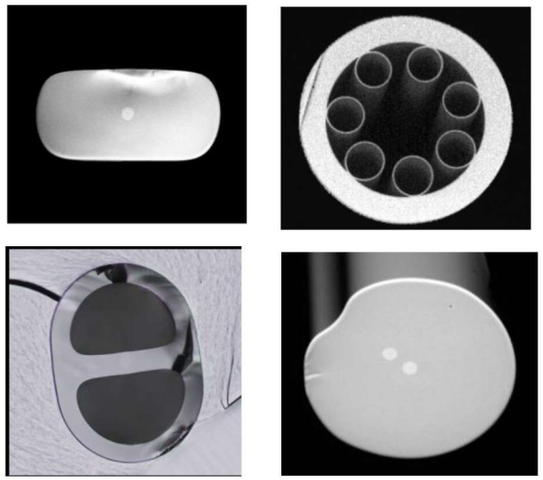
Ultra-thin 25 micron fibre wrapped around a polyimide coated standard fibre







Thinner fibres for better embedding in structures for monitoring purposes

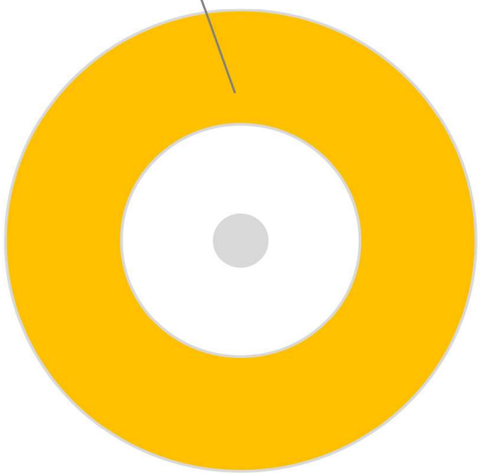


RISE fibres with modified core/cladding structures for distributed sensing

Changing the core/cladding structure tends to make the fibre (much) more lossy and less simple to handle

Specialty fibres: changing the coating material

Polyimide
Low index acrylate
Carbon
Silicone
Metals



Hermetic Carbon coating

Polyimide – high temperatures

Fluorescent coating

Biocompatible and visible under Xray

GO

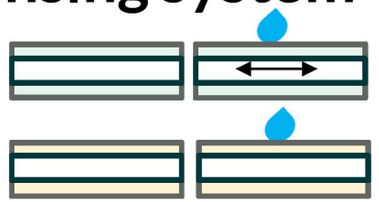
No change in the fibre geometry; ”standard” fibre with realtively low losses

Improving DFOS performance by coating
- High temperature measurement
- Reduce microbends, improve mechanical protection during embedding
- Hermetic/senstive to water or hydrogen
- Active functions

Use Case I: Photonhub prototyping project (field measurements)
Distributed fibre-optic humidity sensing system

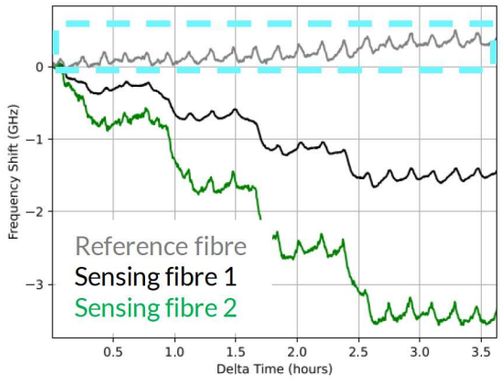
FIBERSIGHT

Enabler: Fabrication of a pair of special optical fibres, with hydrophobic and hydrophilic coatings on as-drawn fibres

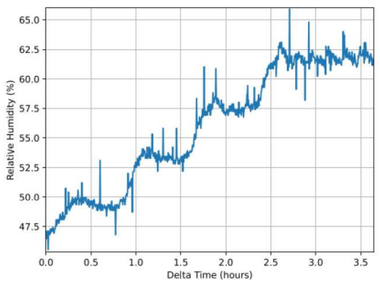


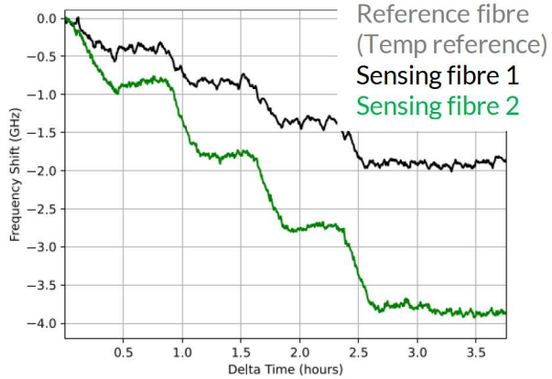
Sensing hydrophilic fibre coating

Reference hydrophobic fibre coating



Small drift of 0.2 GHz and spikes due to temperature variation during the test.





Real time monitoring for soil moisture and water leakages is being performed for 2 months at the Botanical garden of Lecce, Italy.

Humidity-induced strain measured on the hydrophilic and hydrophobic coated fibre measured by phase-OTDR

T. Neves, K. H. Tow, *et al.*, paper Th6.78, OFS28 *28th International Conference on Optical Fiber Sensors.*

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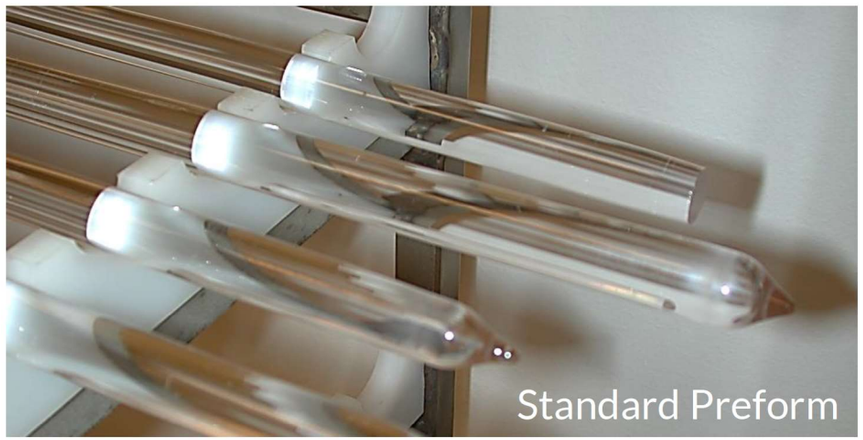
Towards more functionalisation using the coating



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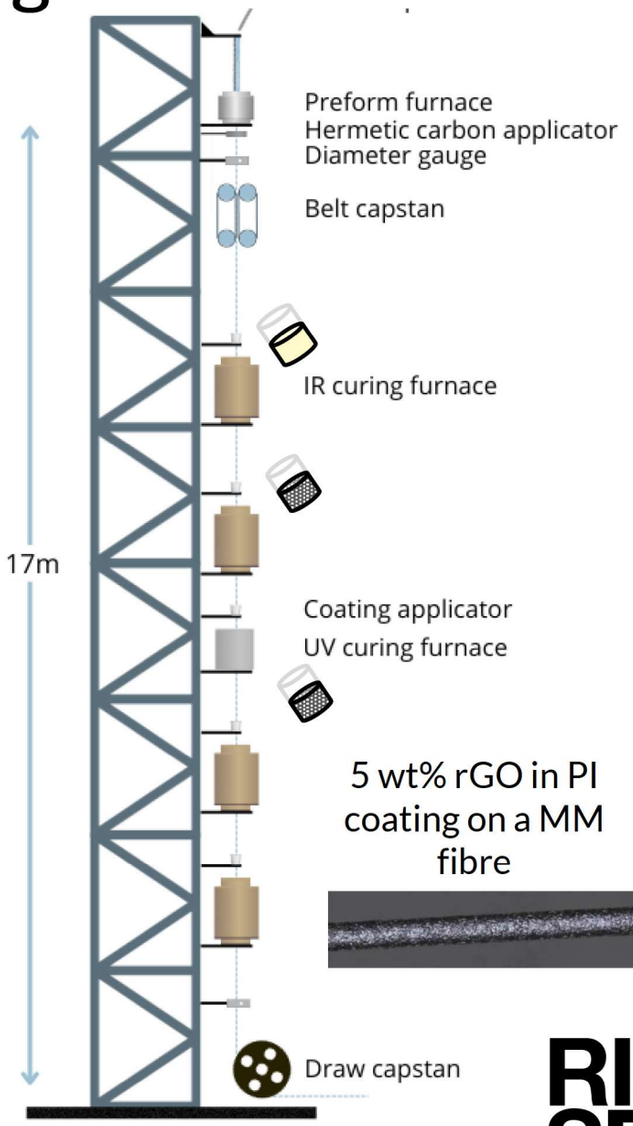
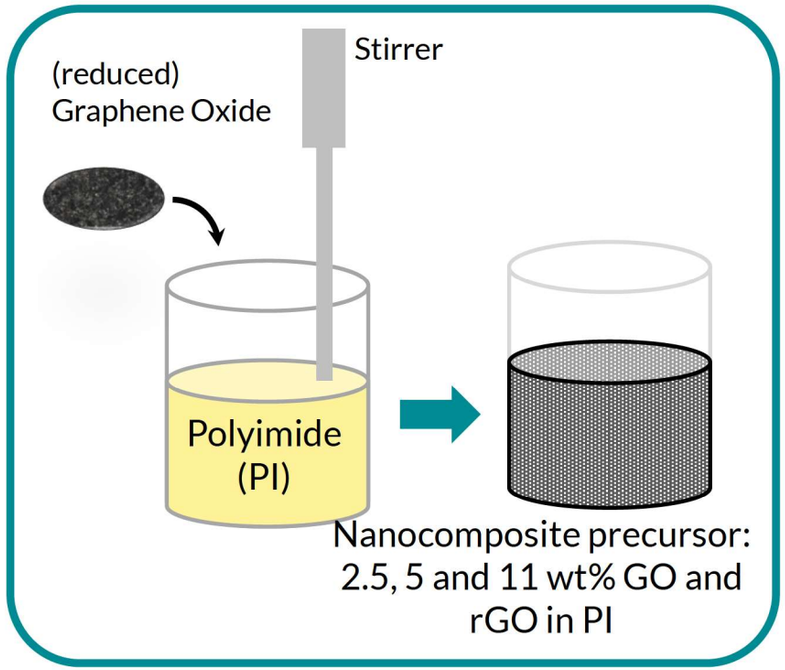


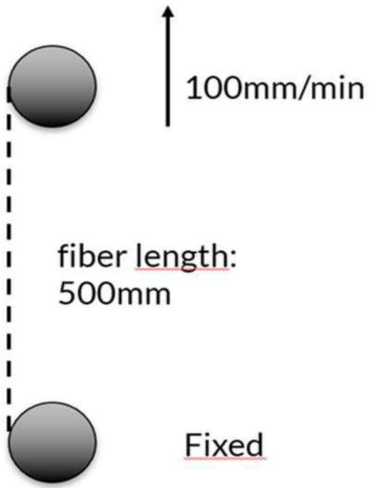


MMF with coating	Losses at 1300 nm (dB/km)
Polyimide-coated	2
Nanocomposite	3

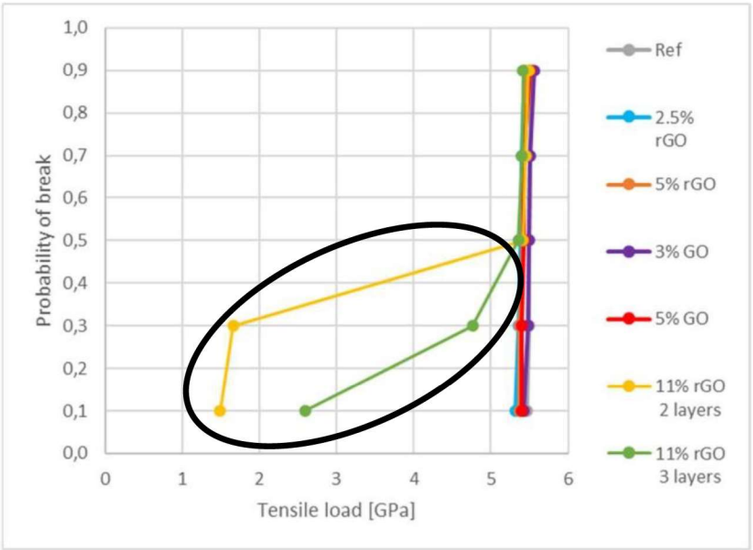
- Kilometers of such fibres can be produced in a draw tower process
- Comparable attenuation losses with PI-coated MMF

5 wt% rGO in PI coating on a MM fibre

Fibre testing: Tensile tests on pristine MMF and after ageing

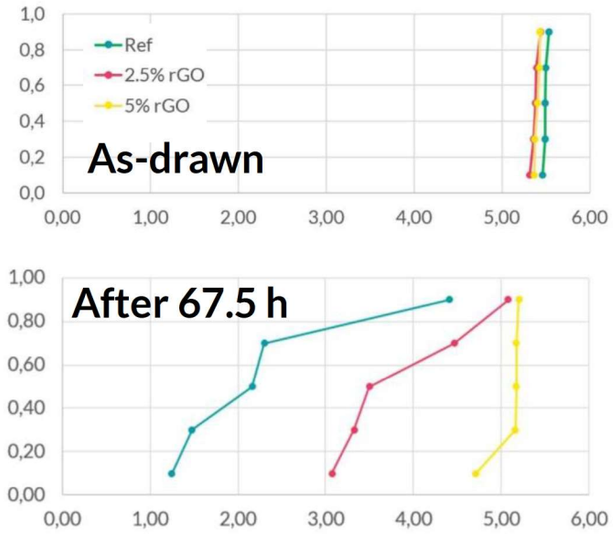


Tensile strength test of pristine fabricated fibre samples as-drawn



As-drawn NC fibers are as strong as PI-coated fibers without the NC layers, except for the 11wt% NC ones

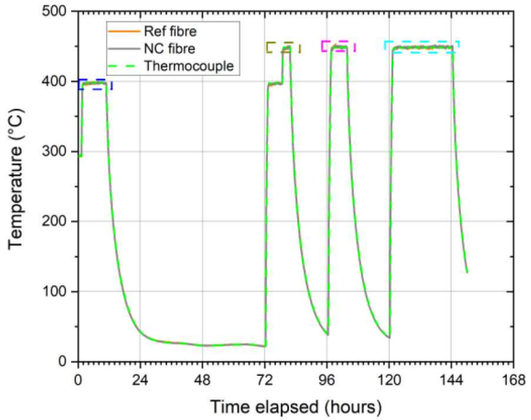
Tensile strength of fiber samples as-drawn (top) and after ageing at 370˚C in air for 67.5 hours

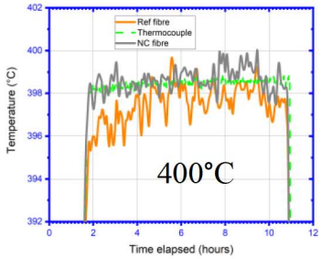


Fibre strength of the PI coated fibre decreased by 5 while negligible degradation of the 5wt% rGO fibre

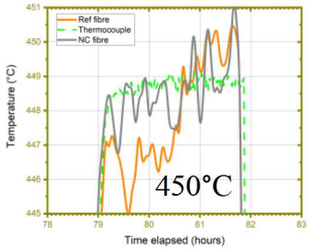
A multifunctional fibre for improved sensing performance in harsh environment

Less varying microbending losses during thermal ageing leading to more reliable distributed (high) temperature sensing data





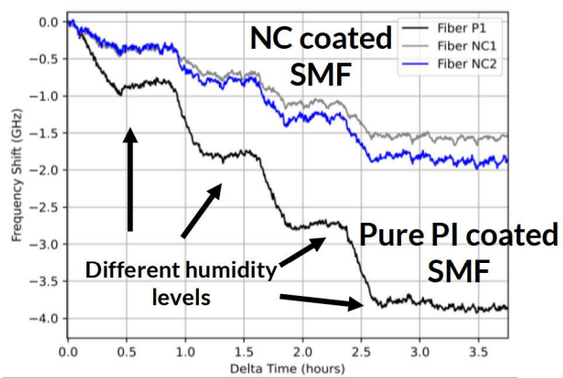
Ref start to degrade, NC ok

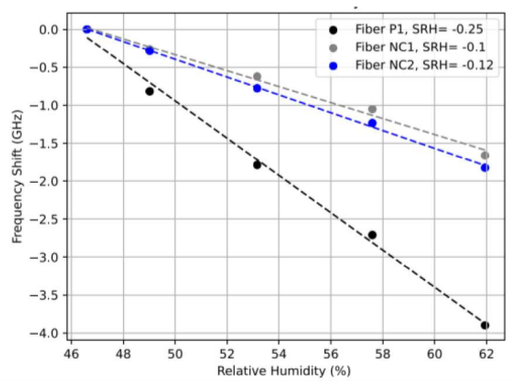


Both degrading, Ref more than NC

Improved mean temperature and standard deviation using NC-coated fibre

Reduction of the humidity-induced strain by a factor 2





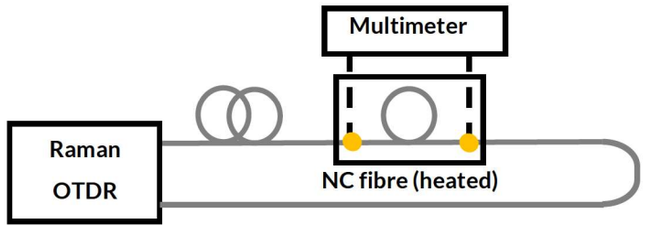
Ref 3 layer PI MMF

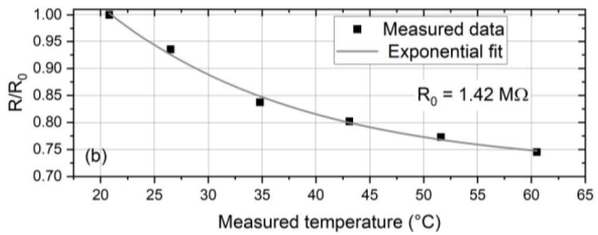
NC: 5 wt% rGO MMF

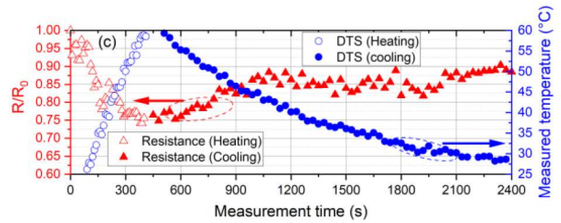
P1: Ref 3 layer PI SMF

NC 1: 5 wt% rGO
NC2: 2.5 wt% rGO

Exploiting the electrical conductivity of the NC coating for DFOS







- New sensing applications requiring active DTS, e.g., wind speed
- Better strain/temperature discrimination using light and electricity

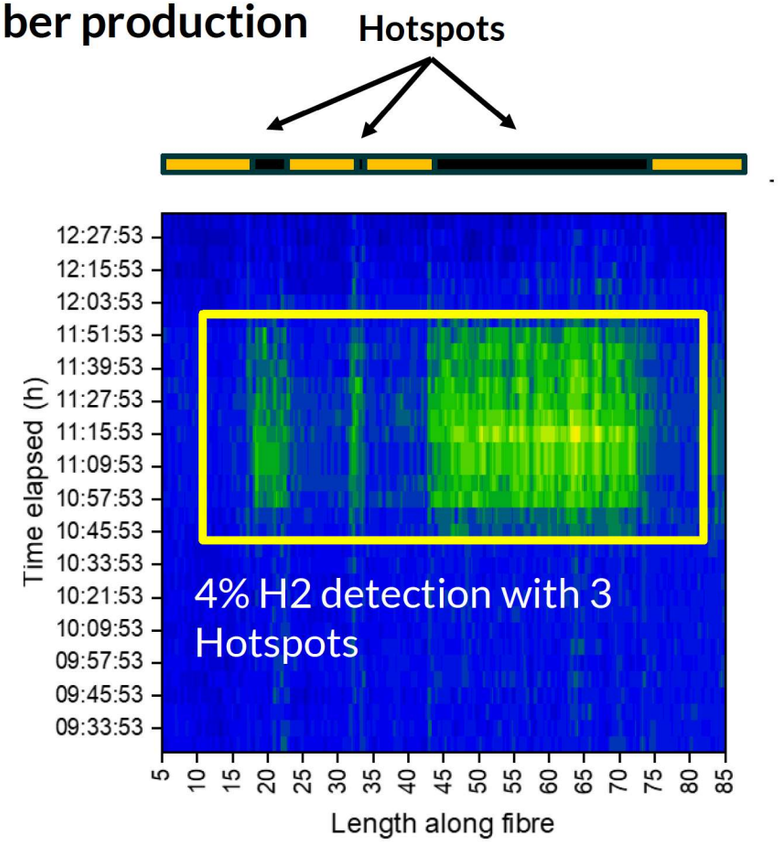
KH Tow, et al., Journal of Lightwave Technology (2024), DOI: 10.1109/JLT.2024.3405891

Use Case II: Photonhub Prototyping project: Hydrogen sensing for pipe leak detection (Proof-of-concept)

Enabler: Apply a hydrogen sensitive coating in-line on as-drawn optical fiber production

Hundreds of meters of fibre was produced, by RISE with fiber strength, optical performance, and coating quality evaluated.

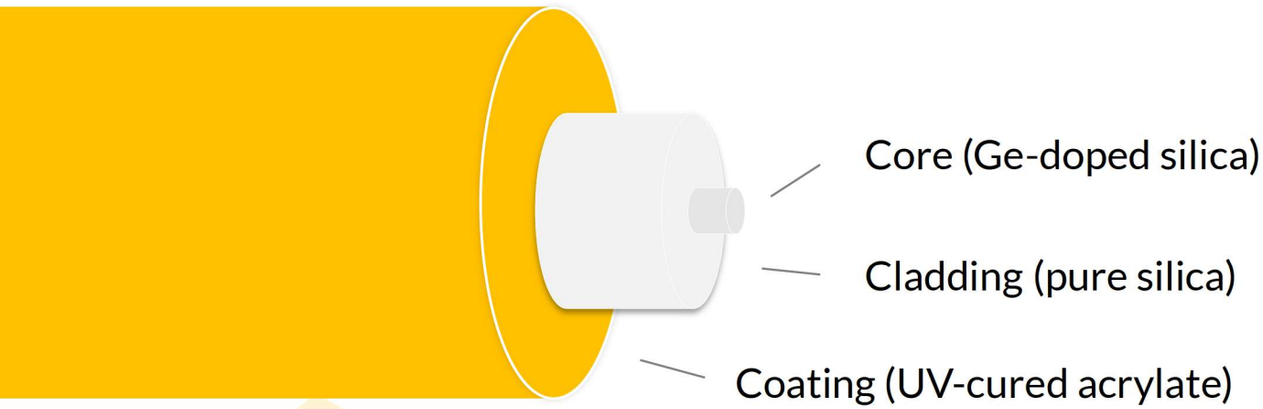
Distributed sensing and safe operation demonstrated in hydrogen test-bed at RISE



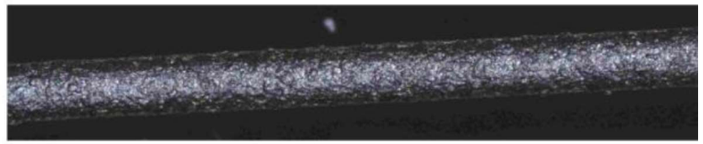
Hydrogen reacts with the coating and creates an exothermic reaction measurable by distributed Temperature Sensing

S. Alomari, K. H. Tow *et al.*, Distributed hydrogen sensing and leak detection using draw-tower fabricated optical fiber (SoTh1F.2), to be presented in August 2024 at Advanced Photonics Congress as invited talk

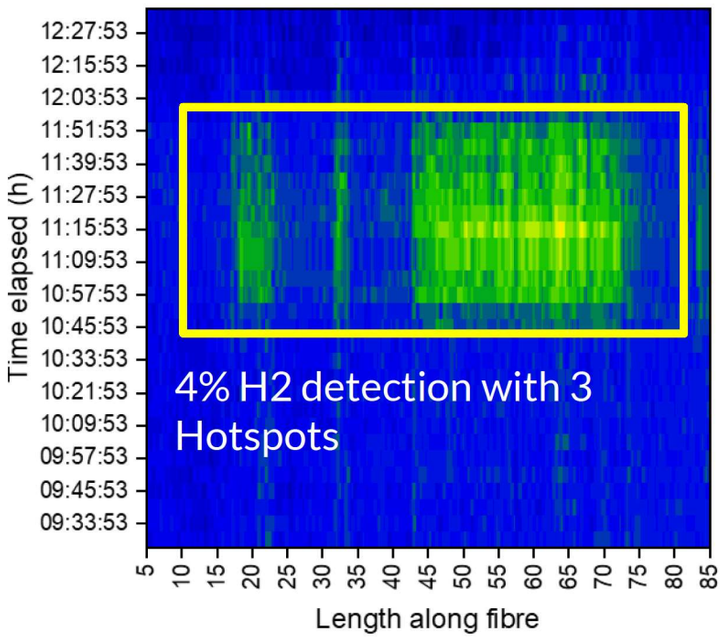
Main take-away messages



"The main purpose of the fibre coating is **NOT ONLY** to provide protection during manufacturing, installation, and use of the sensor, **BUT CAN ALSO ACTIVELY PARTICIPATE IN THE SENSING PROCESS**



Fibre material and sensing properties can be enhanced by adding graphene nanoparticles in the coating during the drawing process



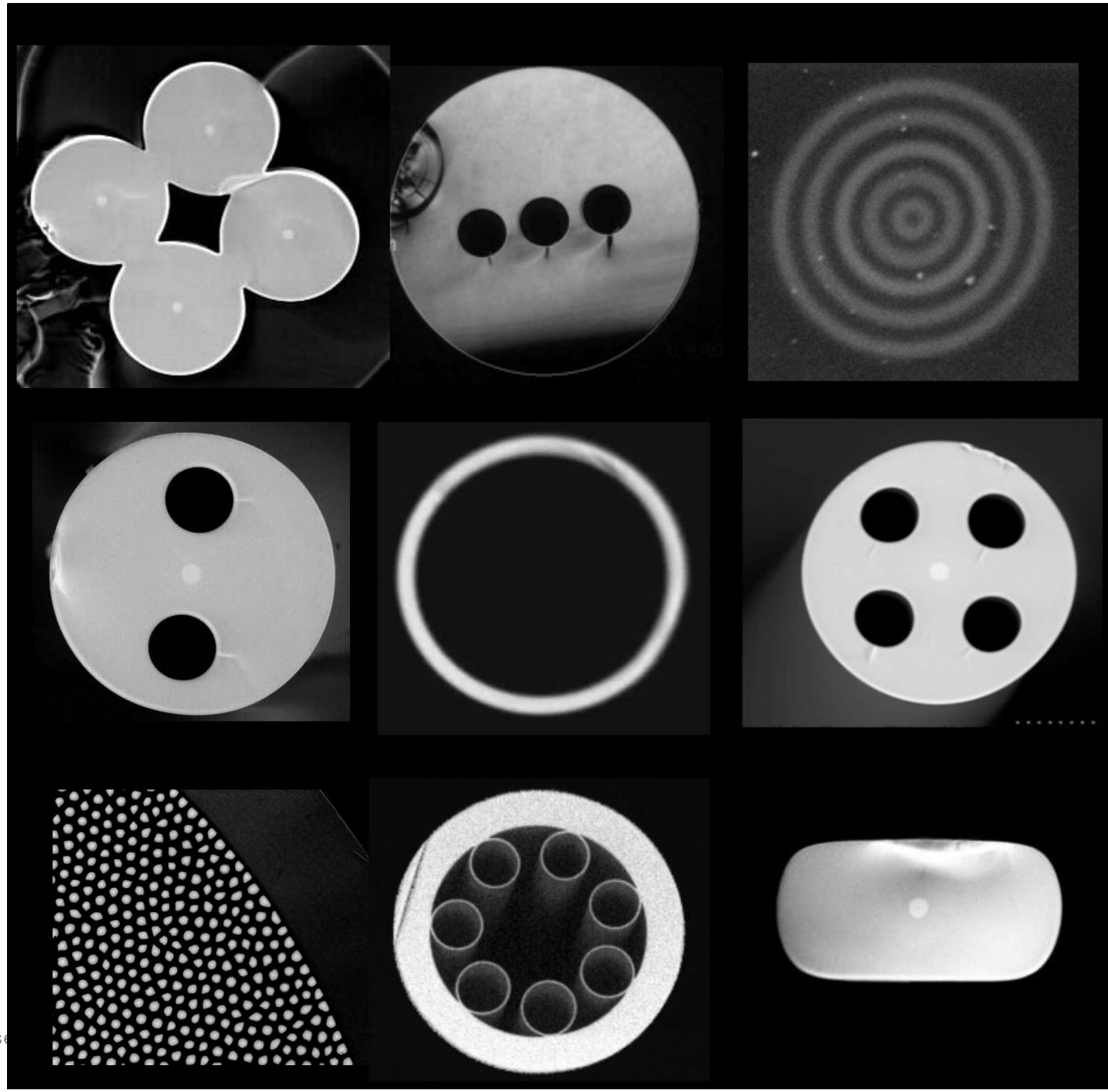
Development of new coatings paves the way to the measurement of new parameters in a distributed way

Challenges and opportunities

Challenge:
Improve the acceptance of specialty fibres by manufacturers of distributed fibre sensing systems →unlocking new applications

Opportunities for fibre manufacturers:
- Distributed Pressure Sensing
- Environmental monitoring: pollutants, chemicals, H_2, CO_2

Opportunities for others:
- Data compression, AI for data sorting and classification
- Development of short range, lower cost interrogators (PIC-based interrogators)



Want to collaborate with us on fibre and sensing projects

Fiber optic sensors and fiber optic solutions

A fiber optic sensor can often be used where conventional technologies fail, e.g. in explosive settings, in systems where you need numerous measurement points, or in applications where the sensor needs to be very small or of extremely low weight.

- Read more about our focus area Fiber optic sensors.

Fiber optic sensors are often used in process industry

Specialty optical fiber

Often a standard telecom fiber is not enough for fiber optic applications. Perhaps the fiber needs to take high temperatures, aggressive chemistry, or be miniaturized to fit in the intended application.

- Read more about our focus area Specialty optical fiber.

The optical fiber can be tailor made for each application.

https://www.ri.se/en/what-we-do/expertises/fiber-optics

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Want to learn more about innovation vouchers for companies?

Courses in fiber optics and nanophotonics

In the framework of PhotonHub Europe, RISE offers three courses in photonics and fiber optics

- Webinar: Fiber optic sensing and specialty fibers in Manufacturing and Industry 4.0 (two hour on-line training)
- Webinar: Nanophotonics intro – technologies and applications in Sustainable Environment & Energy (two hour on-line training)
- Specialty Optical Fibres for sensing applications in Industry (full day demonstration training on-site Kista/Stockholm)

Innovation support

7.4 million Euro is earmarked for eligible companies, for innovation projects within the PhotonHub framework. Experts, laboratory resource prototyping and test facilities across Europe are available to the projects

Read more about the funding support in our leaflet on PhotonHub Europ innovation funding.

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https://www.ri.se/en/what-we-do/projects/photonhub-europe-training-and-innovation-support-in-photonics