Sensors Development with the Ability to Withstand Harsh Environments

2 years Progress Workshop

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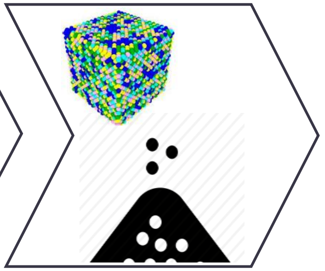
engionic, AIMEN

The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N° 958374.

Our contribution: To validate the developed materials and coating solutions by **embedding high-temperature, strain** and **electrochemical-based sensors** in three end user's cases

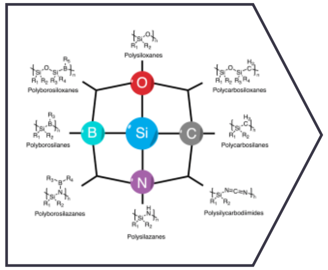
Materials Development



VTT aimen TECHNOLOGY CENTRE

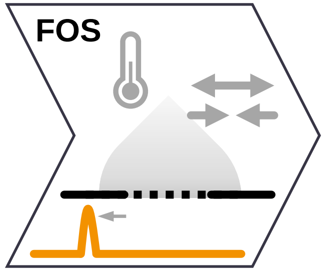
HESA – High Entropy Super Alloys

PDC – Polymer-Derived Ceramics

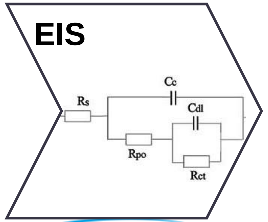


cea

Sensor Development



engionic Fiber Optics



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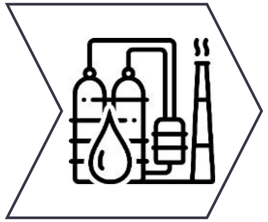
Use Cases

ArcelorMittal

Steel Use Case
- HESA-coating of FOS
-> strain, temperature measurements

Constellium

Aluminium Use Case
- PDC-coated furnace refractories with embedded FOS
-> temperature measurements



Tüpras

Petrochemical Use Case
- PDC-coated pipe component
-> electrochemical impedance measurements

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Preliminary results: Point-by-point inscription of FBGs in metal- and carbon-coated glass fibers, embedding in HESA material

Materials Development

VTT

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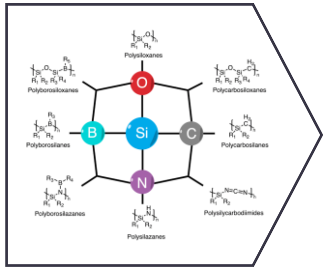

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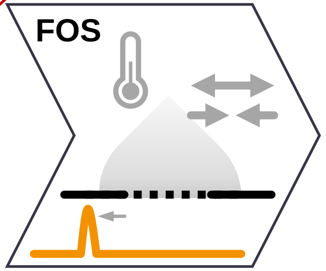

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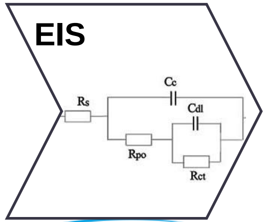

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Tüpraş

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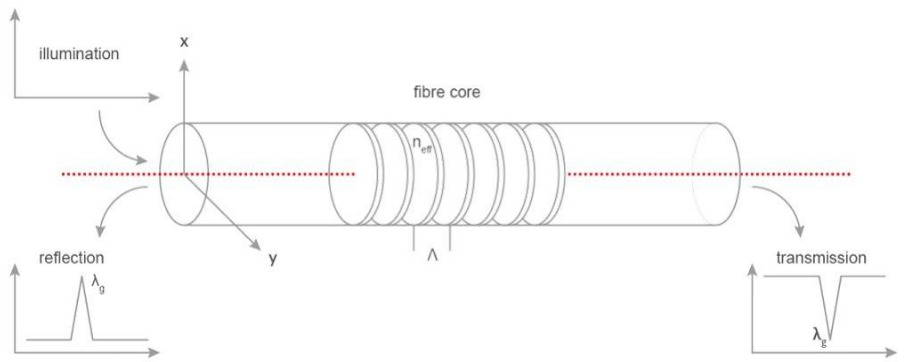
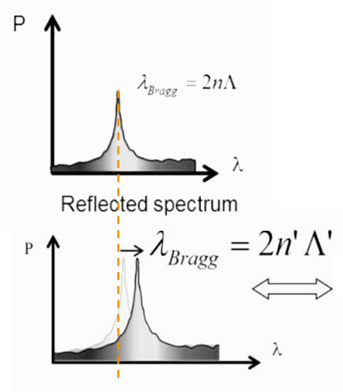
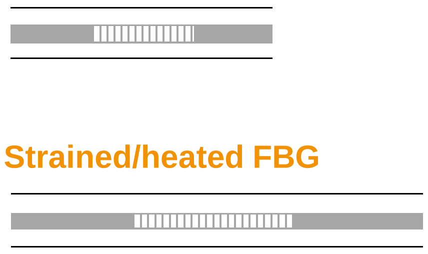
engionic Fiber Optics:
Point-by-point inscription of FBGs in glass fibers

Principle of the Fiber Bragg grating sensor



Details on measurement principle





- Fiber Bragg Gratings (FBGs) are **optical reflection gratings** that are inscribed in optical fibers
- A **periodic refractive index change** of the fiber core with the distance of Λ leads to a formation of a wavelength selective mirror at λ=2*n*Λ in the fiber core
- Strain and temperature changes cause a **change of the grating period** resulting in a change of the wavelength Δλ which is quasi linear over a large range
- Whatever physical quantity impacts the fiber expansion can be measured

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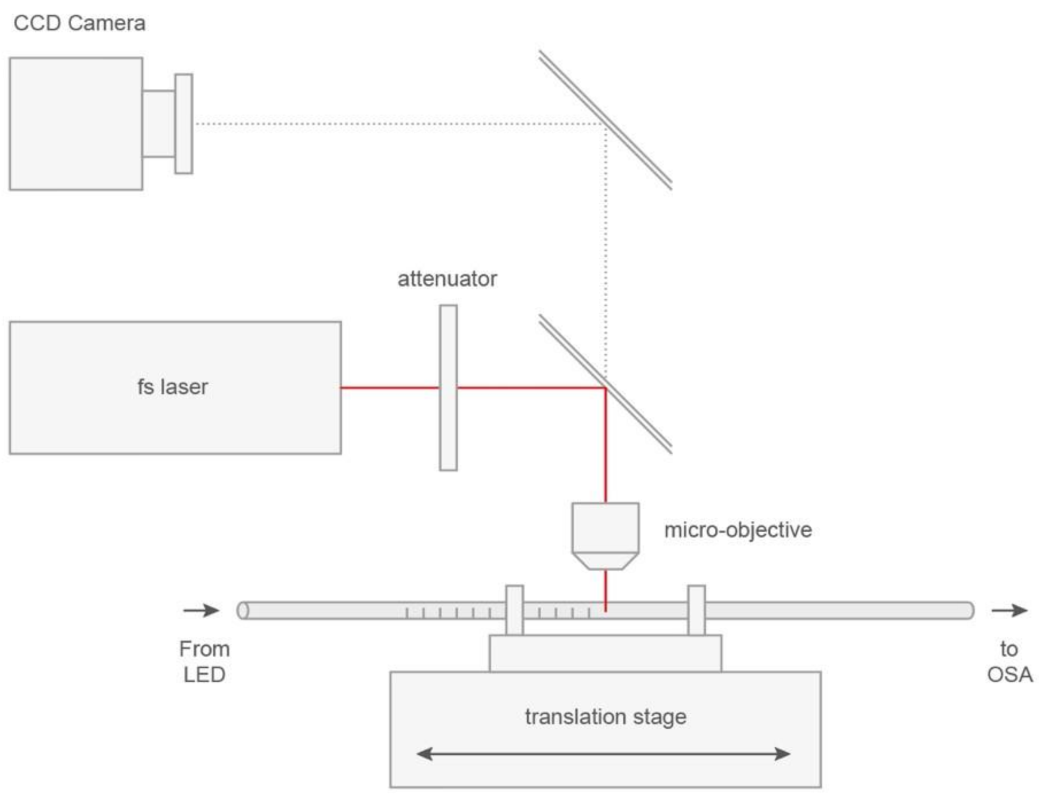
engionic Fiber Optics:
Point-by-point inscription of FBGs in glass fibers



Schematic of point-by-point FBG inscription setup

- Highly flexible **point-by-point inscription** without phase mask allows writing of any wavelength
- Writing **through the coating** is possible due to high transmission of typical coatings for IR light and low Laser intensity at coating
- Highly flexible **array configurations** with **distances** between a few mm and several km in **customized** fibers are possible

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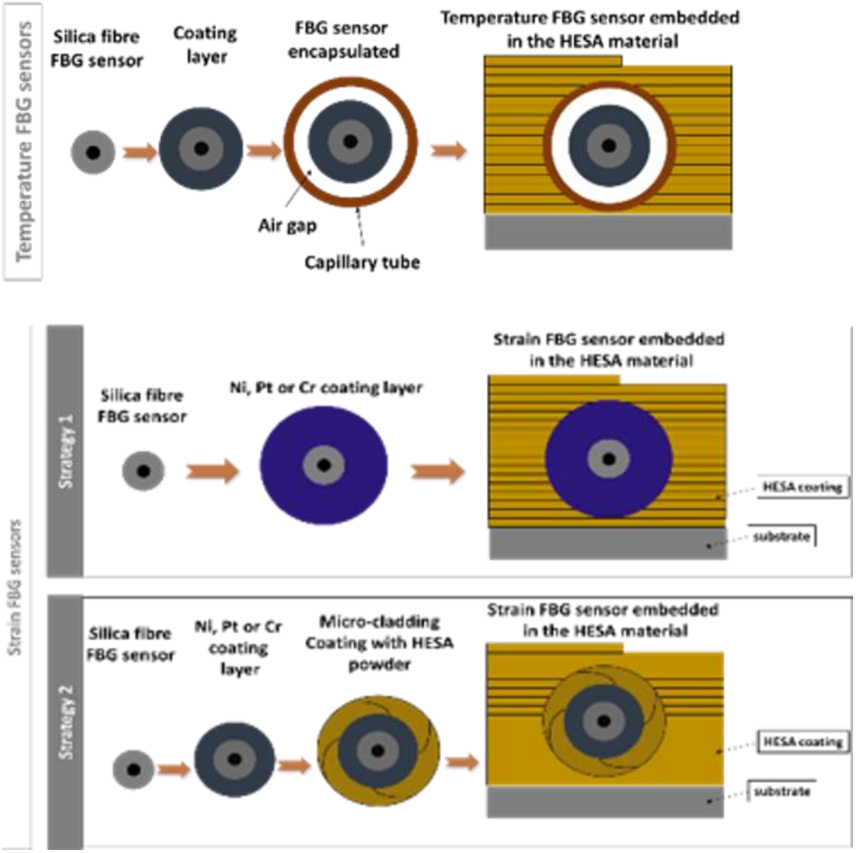
AIMEN:
Embedding glass fibres in HESA material

To use the FBG sensor in high temperature industrial environments a **robust mounting system** is needed.

Concept:

1. Removal of fiber polymer coating
2. Inscription of FBGs
3. Coating with metal
4. Embedding within High Entropy Super Alloy (HESA) material

For **temperature sensing**: optical fibre **loosely** mounted in tube
For **strain sensing**: optical fibre **mechanically bonded** to measuring object



Schematic of sensor mounting in HESA material

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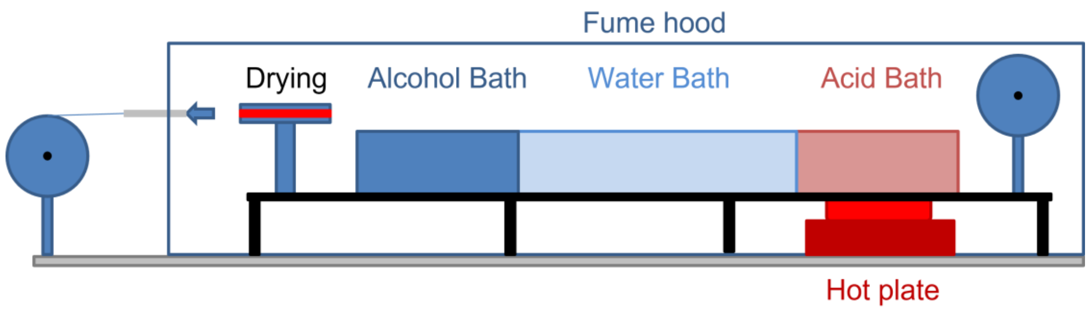
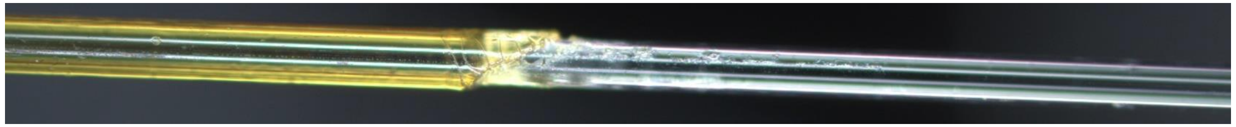
1. Removal of fiber polymer coating over long lenths



- Decoating of optical fibers over long length is difficult as the **fiber is brittle without coating**
- An apparatus for decoating fibers by **wet etching** was developed and set up
- First tests with polyimide-coated fibers were successfull
- The apparatus can be used for different types of coatings including metal-coated fibers with different acids for decoating



Schematic of fiber decoating setup, microscopic image of processed vs. coated fiber

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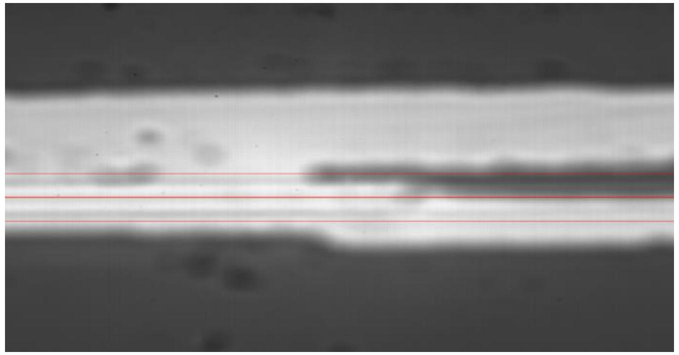
2. Point-by-point inscription of FBGs in carbon- and metal-coated glass fibers

Polymer-coated fiber | Carbon-coated fiber | Copper-coated fiber

- FBGs can be inscribed in polymer- and carbon-coated fibers without preparation
- Carbon-coated fibers absorb much more light, finding the core can be challenging
- Carbon coating may be damaged during inscription
- FBGs cannot be inscribed directly in metal-coated fibers, coating removal (etching) is required



Damage of carbon coating after FBG-inscription

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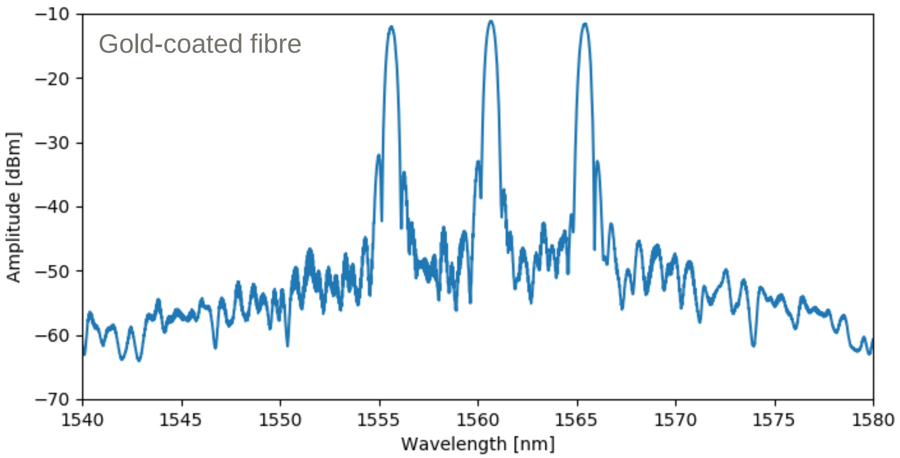
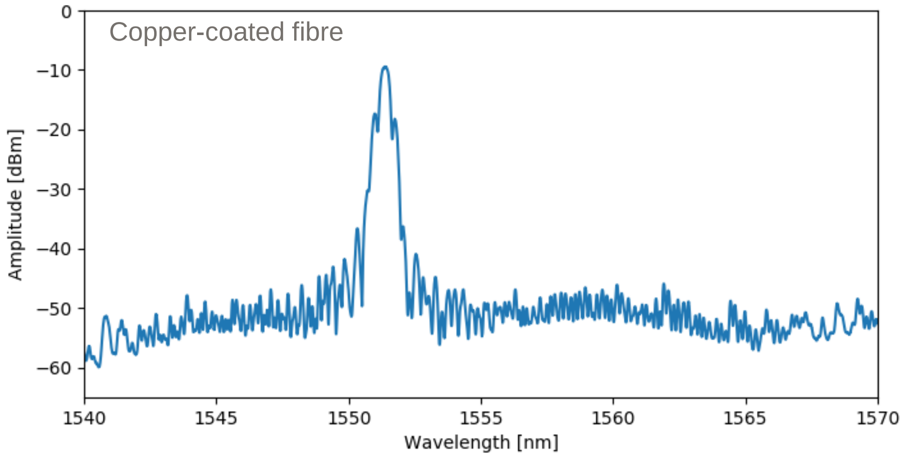
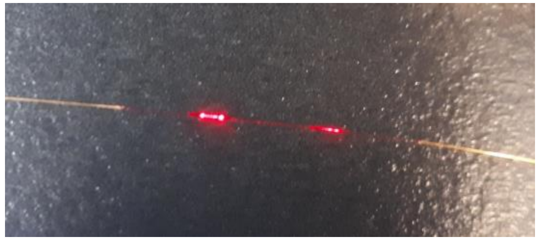
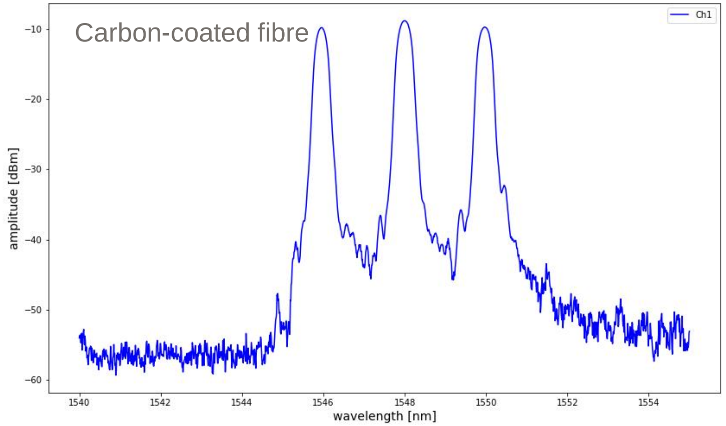
2. Point-by-point inscription of FBGs in carbon- and metal-coated glass fibers

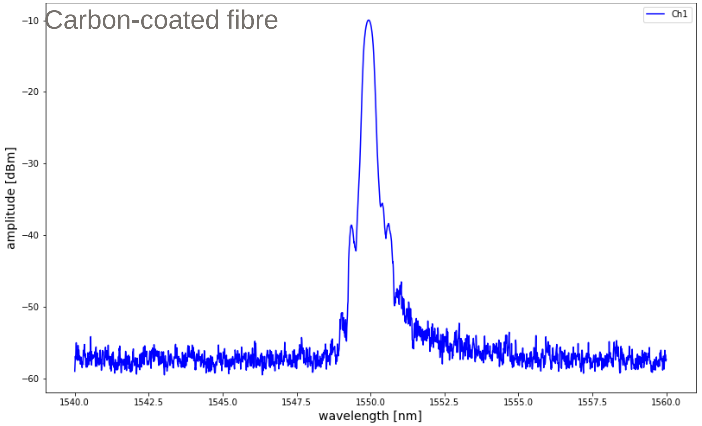




- FBG inscription in carbon-coated fibers is working well
- Inscription in metal-coated fibers is more difficult and time consuming
- Results show both coating materials are suitable for sensing applications







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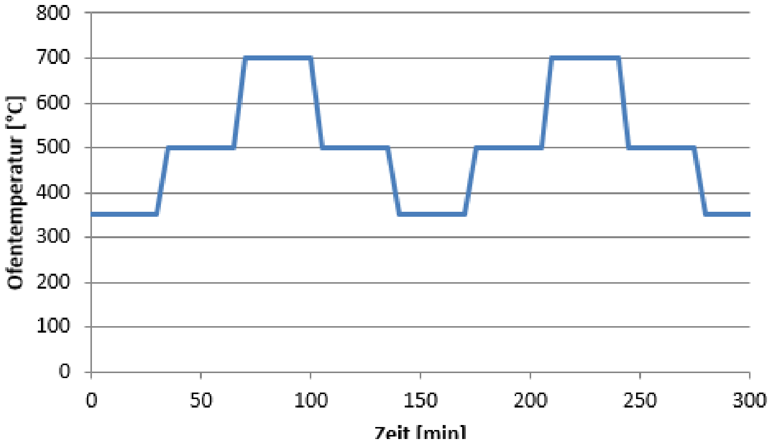
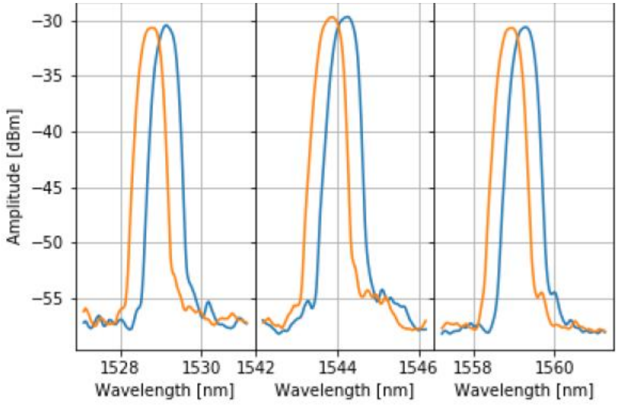
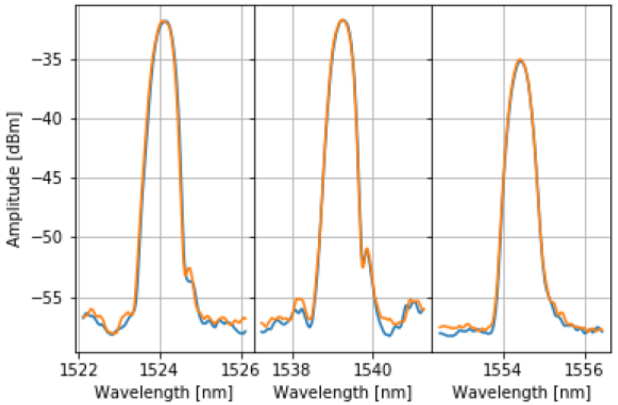
Sensor characterisation

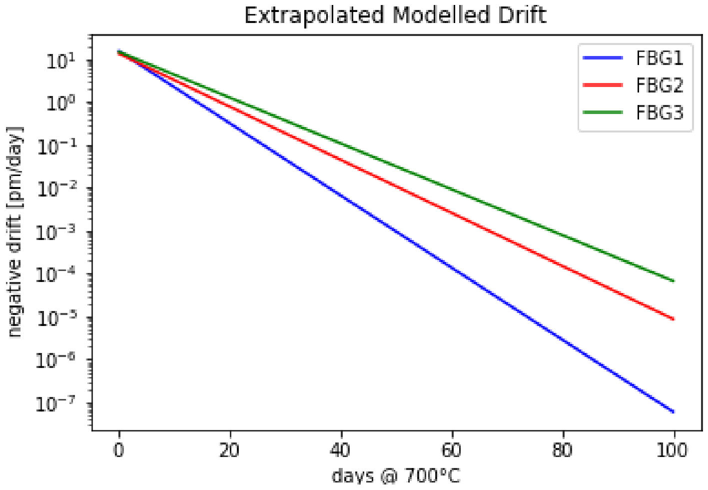
- ✓ FBGs are tested and optimised under high temperature conditions
- ✓ Measurements show a good thermal stability at high temperatures
- ✓ Biggest issue still not resolved: Drift at high temperatures that depends on:
  - fibre type
  - Inscription and annealing conditions

-> Can potentially be modelled to compensate drift









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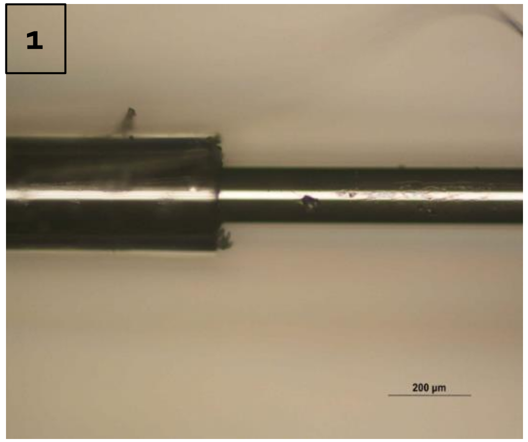
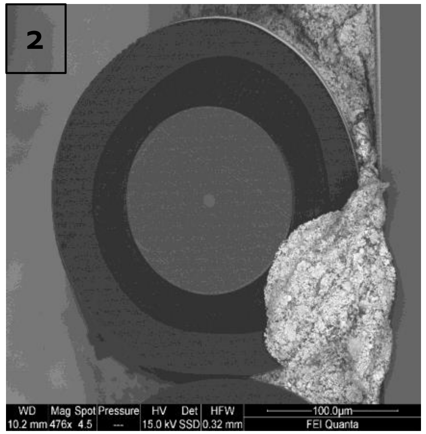
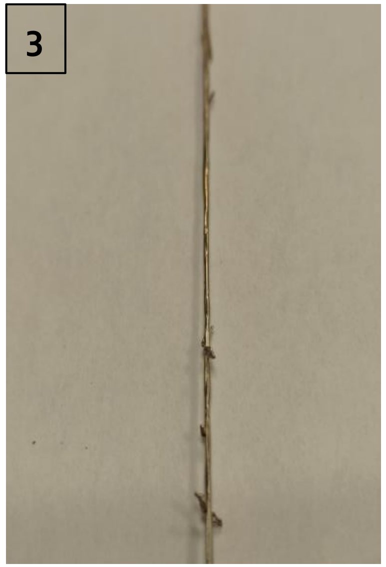
3. Coating with metal

The commercial C-coated optical fiber has a coating layer of a few nm of thickness protected by a polymer. The polymer doesn't resist T > 350°C, and the C-coating layer is not resistant enough in an industrial environment (very fragile). A metallic coating is needed to protect the (hermetic) C-coating layer. Ni is (a-priori) the best metal to re-coat optical fibers.







Images of commercial C-coated optical fibres.

1. fibre with and without polymer coating.
2. SEM picture of cross section.
3. Carbon fiber with Ni-coating.

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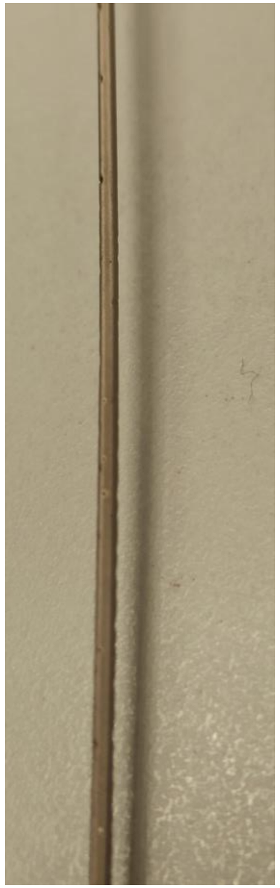
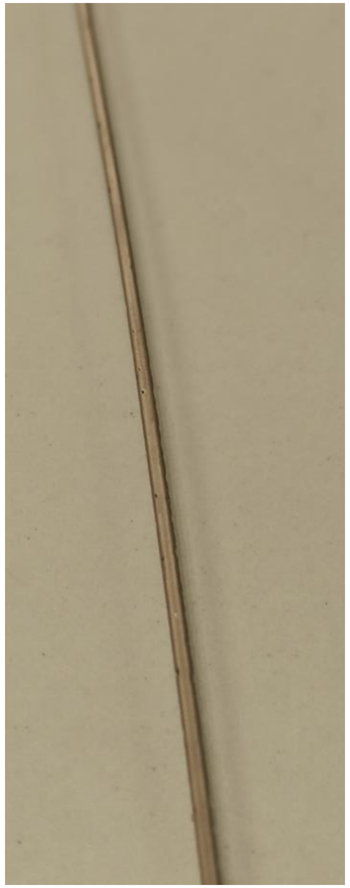
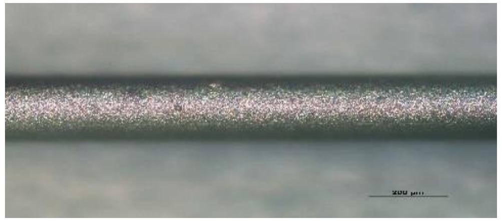
3. Coating with metal

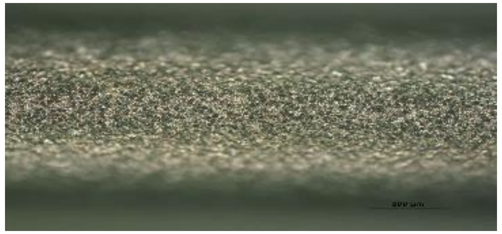
Metallic coating

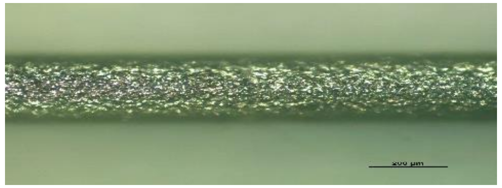
- A metallic nickel coating is applied to the FBG sensors using the electrodeposition technique
- FBG sensors are coated with different thicknesses between 500 µm and 750 µm, to withstand high temperatures
- Pictures on the right show examples of FBG sensors and fiber optics metallized and some images taken with magnification of their surface finish











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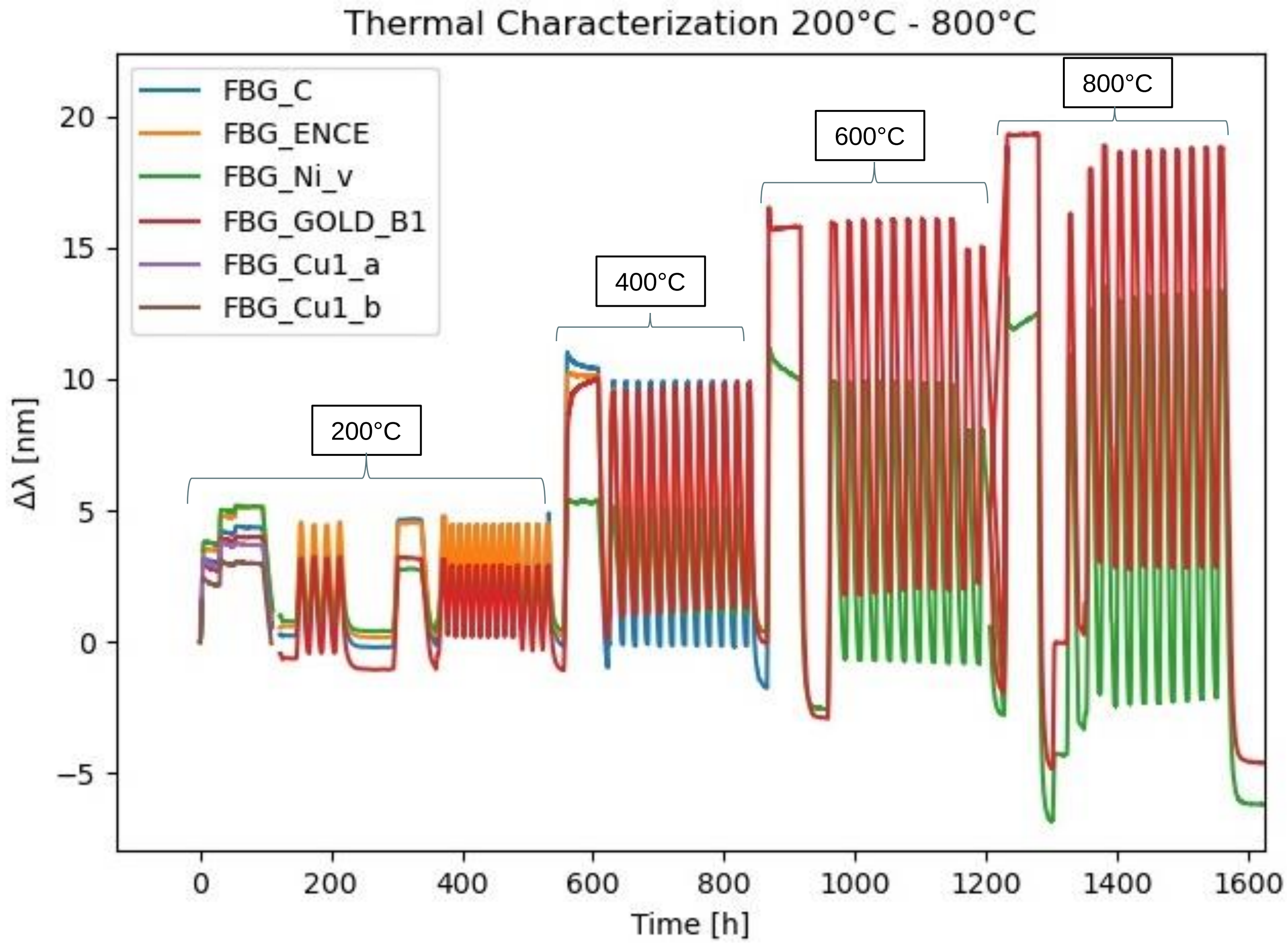
Sensor characterisation

Thermal fatigue tests

- An annealing process was applied above the cycle temperature and then cycled at the indicated temperature.
- Thermal test with the metal-coated FBGs were completed:
  - Fatigue tests at 200/ 400/ 600 / 800ºC
  - 66 days under thermal fatigue, 40 days under stable T
  - The thermocouple showed noise for T > 650ºC
- FBGs manufactured in Au-coated optical fibers as well as splicing standard FBGs to Cu-coated optical fibres showed more stable and reproducible responses

-> A new and improved batch of metallic coated FBGs will be thermally tested to compare results. New C-coated optical fibers will be tested.



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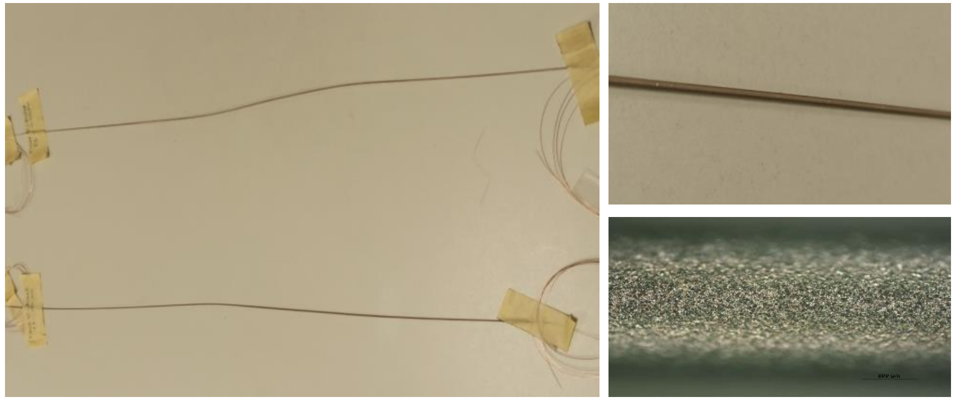
Outlook: 4. Sensor embedding

Concept

- Laser Additive Manufacturing (AM) of the metallic-coated FBG sensors
  - Embedding trials are in progress employing optical fibres with different Ni coating thicknesses



Some fibers with Ni-coating to be embedded by AM.

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Future Work WP6

Fiber optic temperature sensors

- validation of the reproducibility of the results
- Metallographic analysis of the FBGs tested under the thermal fatigue tests
- Develop a set-up and procedure to re-coat the C-coated optical fiber in a continuous mode.

HESA-embedded fiber optic strain sensors

- Trials of embedding of optical fibers with different thicknesses by AM testing new alloy materials.

Steel use case

- Visit the Arcelor facilities to find out how to prepare the sensors that will be installed there.

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Thank you

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