19-20 April 2023. Porto, Portugal

EPIC Meeting on Fiber Sensors
at HBK FiberSensing

EPIC
EUROPEAN PHOTONICS INDUSTRY CONSORTIUM

A Combined LPG-FBG Multi-sensing Platform for Simultaneous Measurement of Humidity and Radiation

20 April 2023

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CERN *(Conseil Européen pour la Recherche Nucléaire)*
The European Laboratory for Particle Physics

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- Founding convention ratified by the first 12 member states on 19/09/1954
- Today: 23 Member states, 12 Associate Member States, 3 Observer States (1 suspended)
- Mission:
  - perform world-class research in fundamental physics.
  - provide a unique range of particle accelerator facilities that enable research at the forefront of human knowledge.
  - unite people from all over the world to push the frontiers of science and technology, for the benefit of all.
  - train new generations of physicists, engineers and technicians, and engage all citizens in research and in the values of science.

Return to Member and Associate Member states

Scientific objectives

CERN's main objectives 2021-2025:
https://home.web.cern.ch/sites/default/files/2022-01/CERNS%20Main%20Objectives_0.pdf

Impact on society

The CERN accelerator complex and LHC experiments

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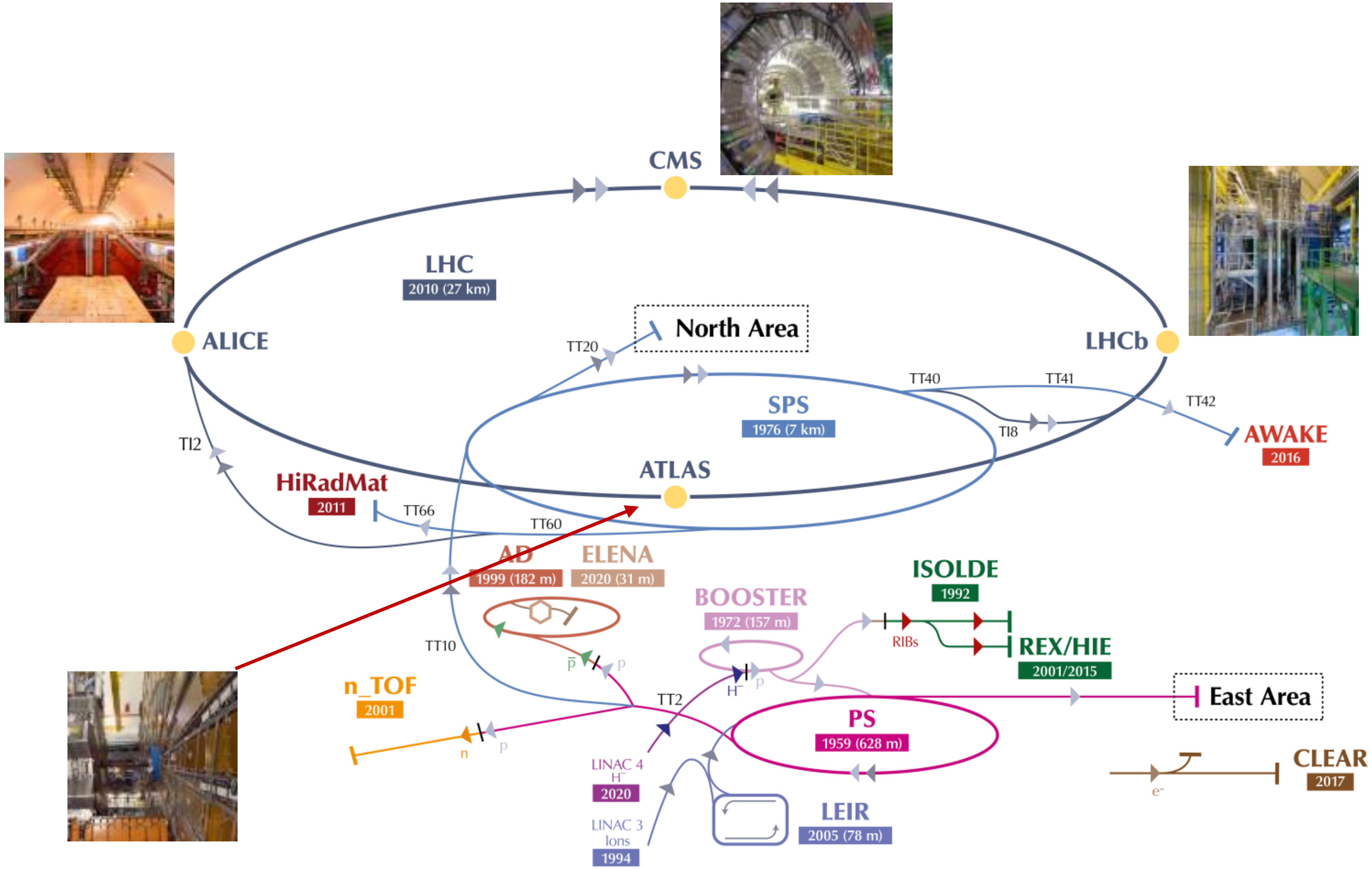
A huge playground for all possible engineering fields!...



Fibre Optic sensor applications at CERN

Optical Fiber Sensing and Applications at CERN

Tuesday 3 Sept 2019, 08:20 → 12:30 Europe/Zurich

31/3-004 - IT Amphitheatre (CERN)

Yacine Kadi (CERN), Diego Di Francesca (CERN)

Description Optical fiber based technologies provide unique capabilities. However, introducing them at CERN comes often with its own challenges. This event aims at reviewing the current status of most activities related to optical fiber sensing and application at CERN, as well as the ongoing and future developments.

https://indico.cern.ch/event/837593/

- Temperature monitoring
- Strain in metallic structures
- Strain in superconductive cryo magnets
- Distributed dosimetry
- (low) Relative humidity monitoring

- Beam imaging and monitoring
- Particle detection
- Structural health of civil engineer installations
- Structural health of large superconductors
- …

Relative humidity monitoring in high radiation fields

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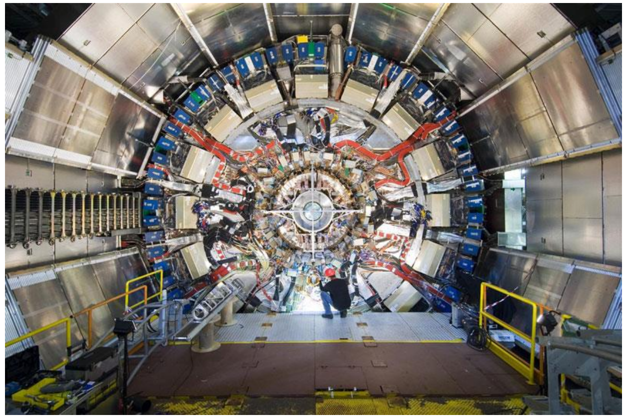

The heart of the experiments (e.g. ATLAS and CMS) is the Tracker Detector

- Silicon sensors accurately measure the traces and the origin of the particles emerging from the beam collision
- **High radiations** cause severe damage to silicon sensors unless constantly kept at T << 0 °C
- Powerful cooling systems are needed
- **The tracker and its services must be kept dry to avoid condensation: accurate sensing of low RH (below 5%)**

A CONTINUOUS THERMAL AND HYGROMETRIC CONTROL OF THE LOCAL ENVIRONMENT IS MANDATORY

Three generations of thermo-hygrometric FOS

1st generation based on ***Fiber Bragg Grating (FBG)*** *technology*:
- Investigations from 2011
- R&D completed
- Network of 72 T (commercial) + RH (custom Polyimide coated) operating in CMS since 2014

2nd generation based on ***Long Period Grating (LPG)*** *technology*:
- Investigations from late 2013
- Prototype installation in ATLAS in March 2019
- R&D being completed
- Includes local on-line measurement of absorbed ionising dose!
- Target complete installation (~80 measurement points) in ATLAS in 2024

THIS TALK

3rd generation based on distributed sensing by ***Phase-sensitive OTDR***:
- Investigations from 2017 in collaboration with EPFL (L. Thévenaz)
- R&D generated a Spin-off by a young startup
- Presentation by T. Neves yesterday

Typical FBG performance (~10 μm thick PI coating)

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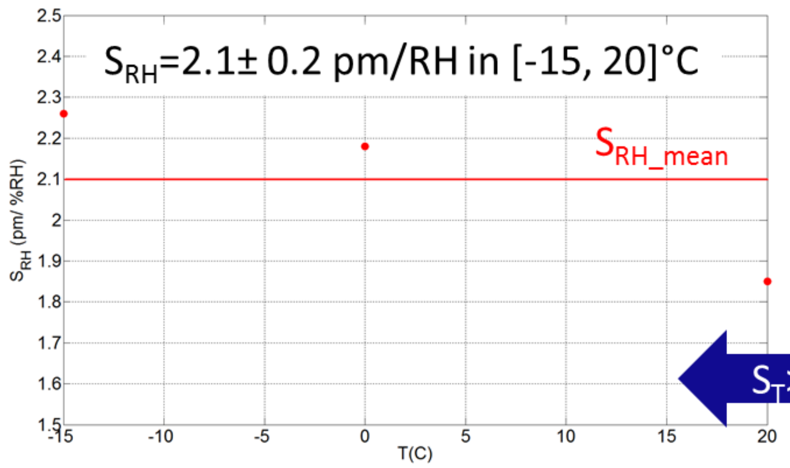
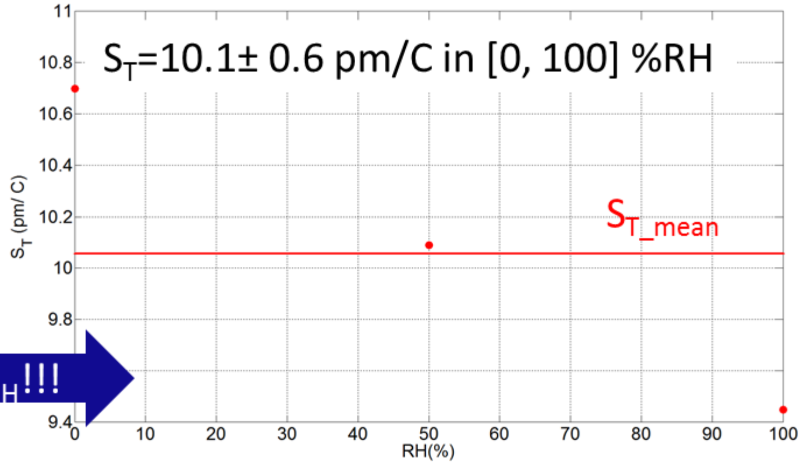
Relative Humidity Sensitivity



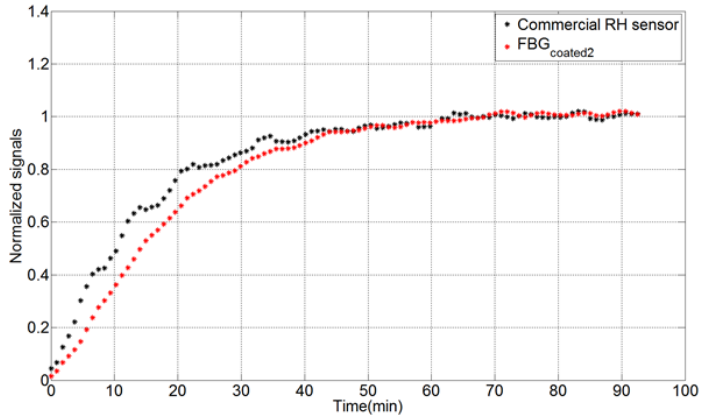
Temperature Sensitivity



$S_T >> S_{RH}$!!!

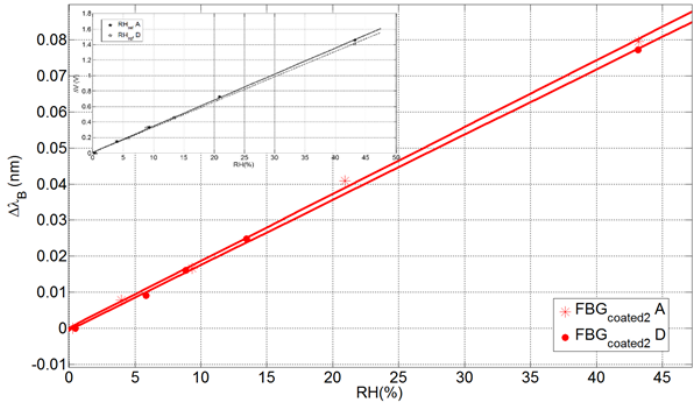
Response Time

$t_{response}$ of a few seconds, comparable to commercial miniaturized sensor



Hysteresis

~ 1.6 %RH, comparable to commercial miniaturized sensor



Not bad and fully comparable with the best miniaturized analog RH sensors available in the market.

But not enough to measure precisely RH values below 5% and Dew Points below -40 °C

Radiation Hard Humidity Sensors for High Energy Physics Application using Polyimide-coated Fiber Bragg Gratings Sensors

G. Berruti, M. Consales, M. Giordano, L. Sansone, P. Petagna, S. Buontempo, G. Breglio, and A. Cusano (Sensors and Actuators B: Chemical, 2012)

TiO_2 functionalised LPG: a powerful RH sensor

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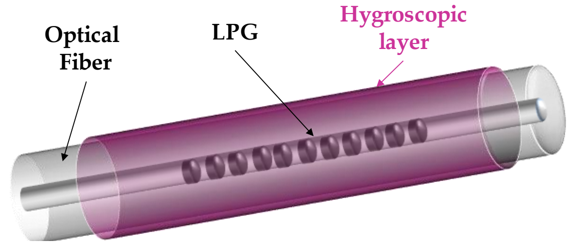
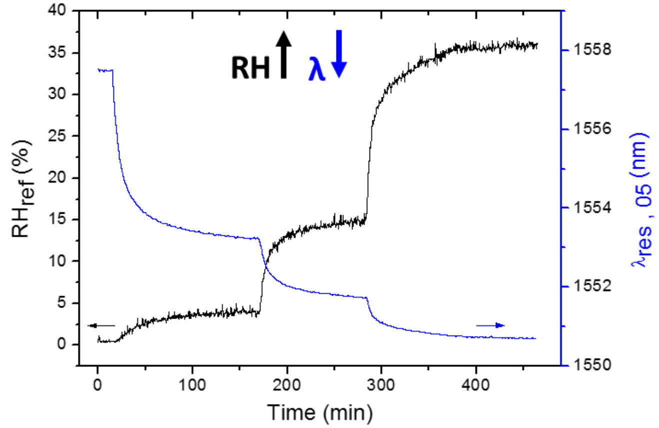


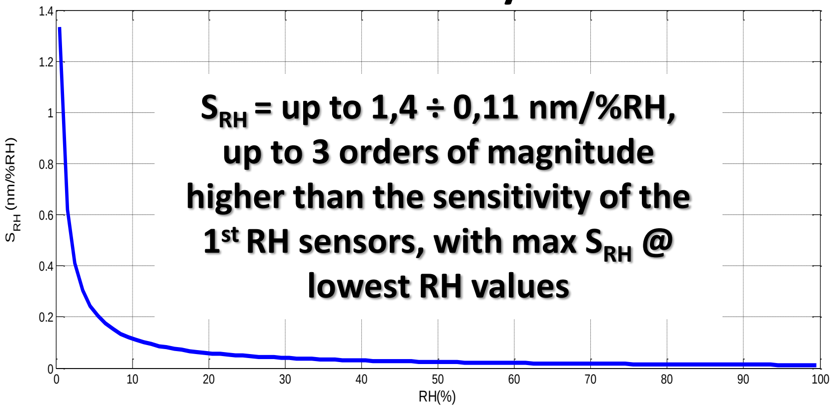
Integration of nano-scale TiO_2 overlays

Moisture absorbtion/desorption by the coating → Modification of coating RI → Spectral variation of attenuation bands

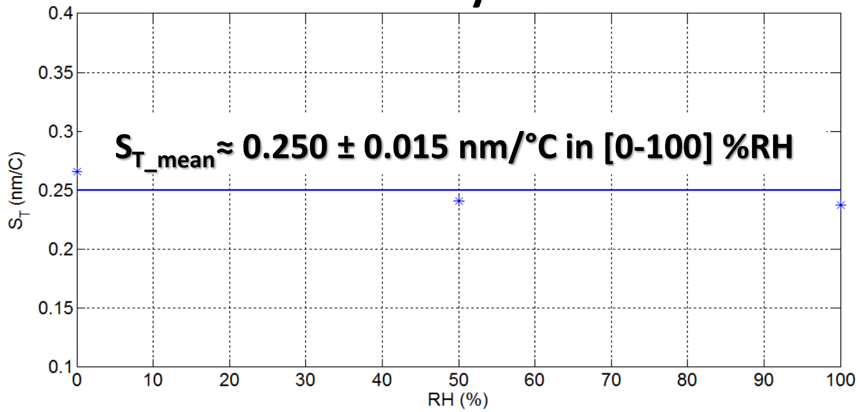
Typical response at 25 °C



RH sensitivity Curve



T sensitivity Curve



Even if poor T compensation is applied, a <u>T reading error of ± 1 °C corresponds to:</u>

- **7-10 %RH error** for *coated FBG based RH sensors*
- **0.2÷2 %RH error** for *coated LPG based RH sensors*

Typical declared behaviour for commercial RH sensors (ONLY AT 25 °C):

- RH Accuracy=± 2÷3 %RH in the range [10-80]%
- RH Accuracy=± 3÷5 %RH in the range [0-10]%
- Hysteresis not included (typ. ±1 %RH)

July 15, 2014 / Vol. 39, No. 14 / OPTICS LETTERS
Nanoscale TiO_2-coated LPGs as radiation-tolerant humidity sensors for high-energy physics applications
Marco Consales, Gaia Berruti, Anna Borriello, Michele Giordano, Salvatore Buontempo, Giovanni Breglio, Alajos Makovec, Paolo Petagna, and Andrea Cusano

A Comparative Study of Radiation-Tolerant Fiber Optic Sensors for Relative Humidity Monitoring in High-Radiation Environments at CERN
Volume 6, Number 6, December 2014
IEEE PHOTONIC JOURNAL

LPG cross-sensitivity

TiO_2-coated LPGs are extremely sensitive to RH variations

But Cross-sensitivity is a common problem for FOS

- All LPGs are by definition also sensitive to **strain**: this can be solved by a well designed package
- All LPGs are also very sensitive to **temperature** variations: this requires signal deconvolution via a twin uncoated sensor
- Today we are only able to write “good quality” LPGs by Excimer Laser on B/Ge-doped fibre: this makes them sensitive to **radiation (Total Ionising Dose, TID)** too!
- However, **FBGs written by Femtosecond Laser on rad-hard fibre are NOT sensitive to radiation** and can be used to remove the effect of radiation from the LPG signal (at least waiting for the first Femto-laser LPG to appear on the market…!)

A combined LPG-FBG multi-sensing platform

Assuming to eliminate the effects of strain by a proper package design, we remain with three measurands to be deconvoluted from the signal of a TiO2 coated LPG written by Excimer Laser on B/Ge-doped fibre:

1. **T**
2. **TID**
3. **RH**

- An **uncoated FBG written by femtosecond laser on rad-hard fibre** will only produce a T-dependent signal
- A second **uncoated FBG written on B/Ge-doped fibre** will produce a signal sensitive to T and TID
- Finally the **TiO_2-coated LPG** signal is dependent by all three measurands

Combining the information from the three sensor packaged together, we obtain the reading of all three measurands at the position of the multi-sensor platform.

Packaging (strain free FBGs and pre-strained LPG)

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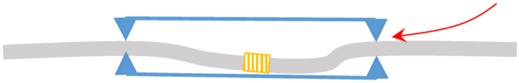
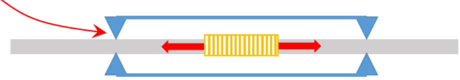
FBG: strain-free mounting

LPG: pre-strained mounting

“clamping” points

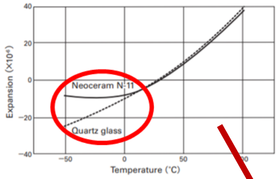




When correctly “clamped” the FBG only feels its own local strain

When correctly “clamped” the LPG feels both its own local strain AND packaging deformations

Thermal expansion

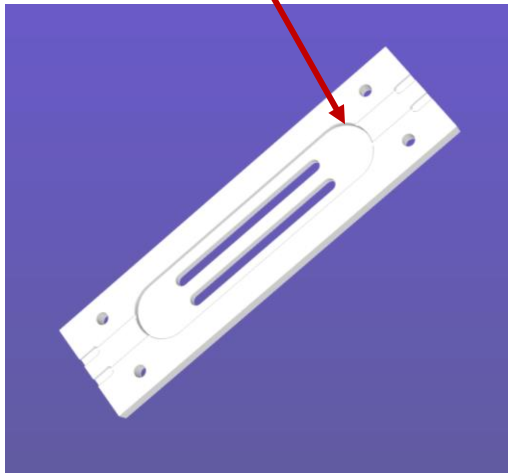


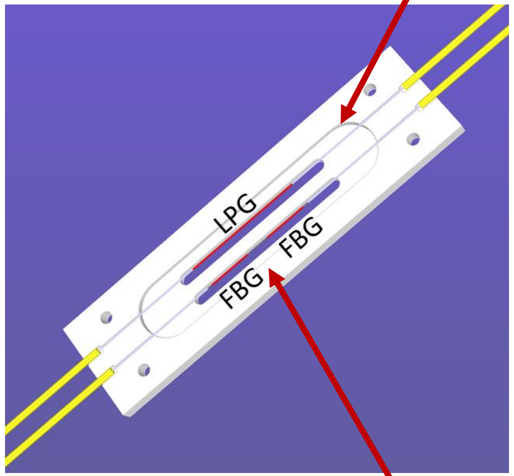
Neoceram N-11
CTE very close to SiO_2

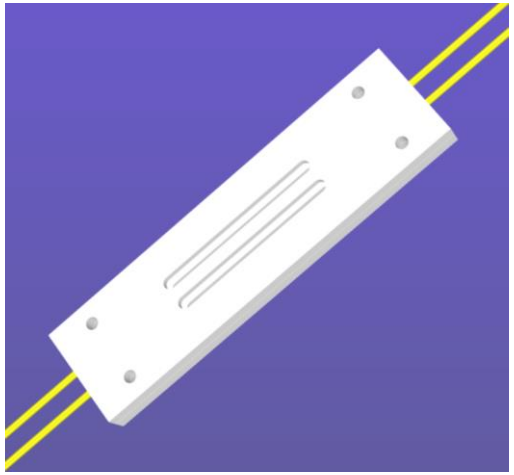
Pre-strained / strain-free installation

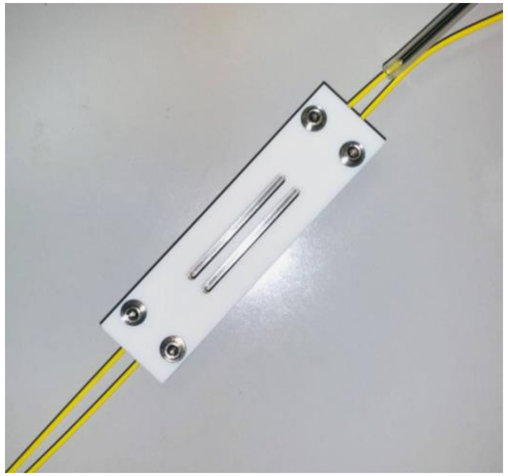
Clamping
Gluing

Tightening







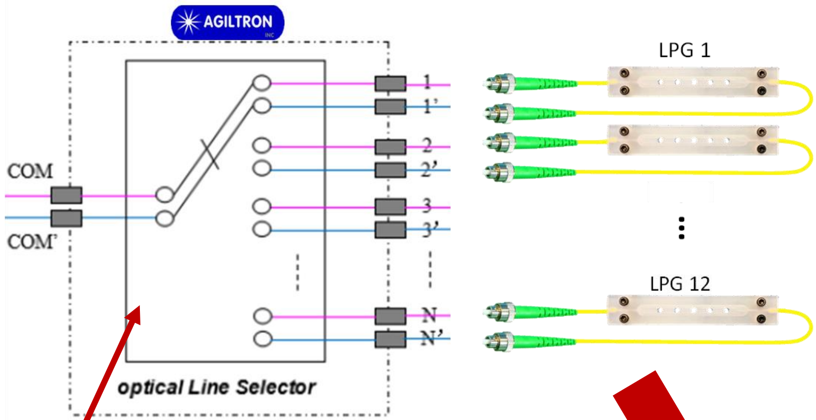


Two FBGs spliced next to the other

Multiple sensor interrogation

Hyperion si155:

- Wavelength range: 1460-1620 nm
- Number of channels: 4
- Wavelength accuracy: 1 pm

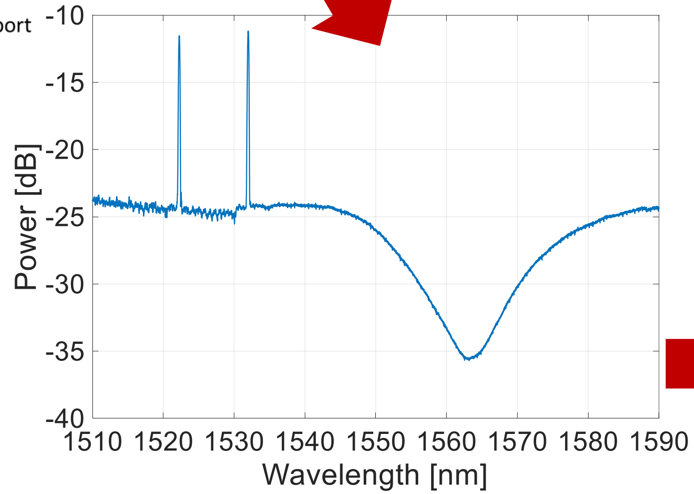


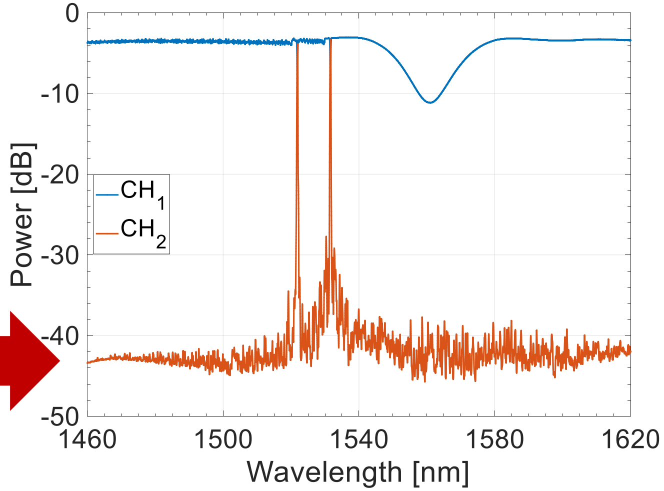
Self-align dual 1x12 switch :

- Operative range: 1460-1620 nm
- Fiber: SMF-28 fiber
- Connectors: FC/APC on each port

Opto-mechanic optical switch

Broadband Fiber Optical Isolator





Signal deconvolution algorithm

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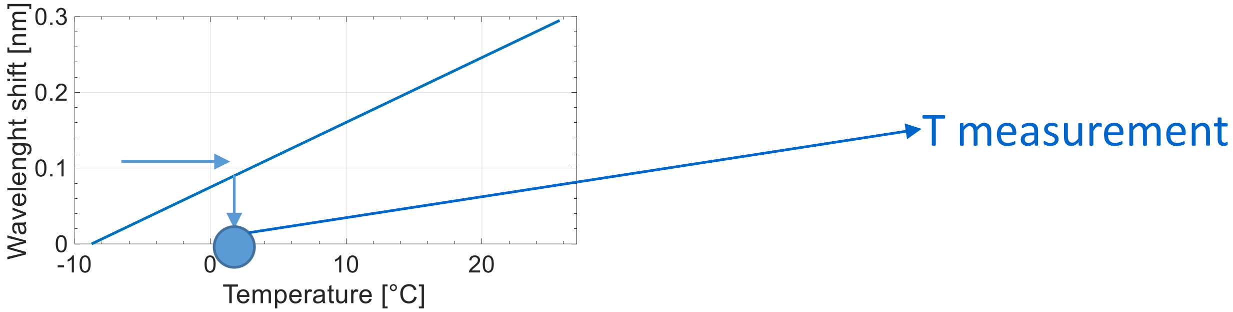
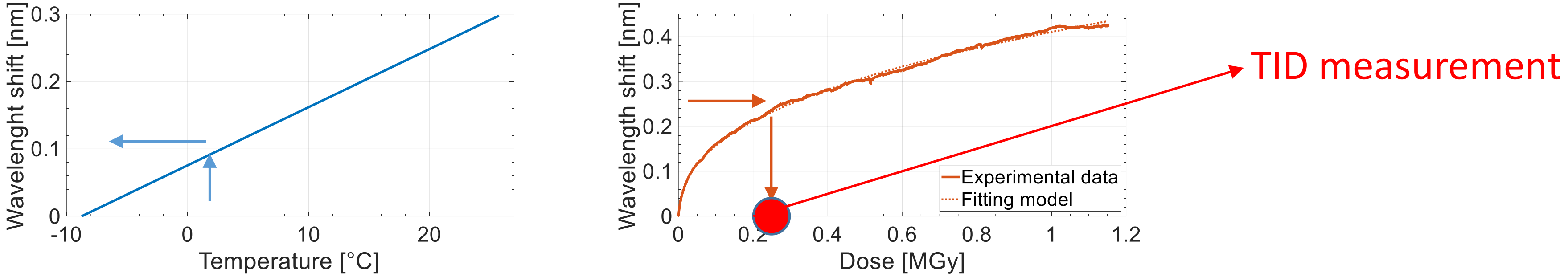
1. Get the value of T from the first FBG (on rad-hard fibre, sensitive only to T): $\boldsymbol{\Delta\lambda_{total} = \Delta\lambda_{T}}$

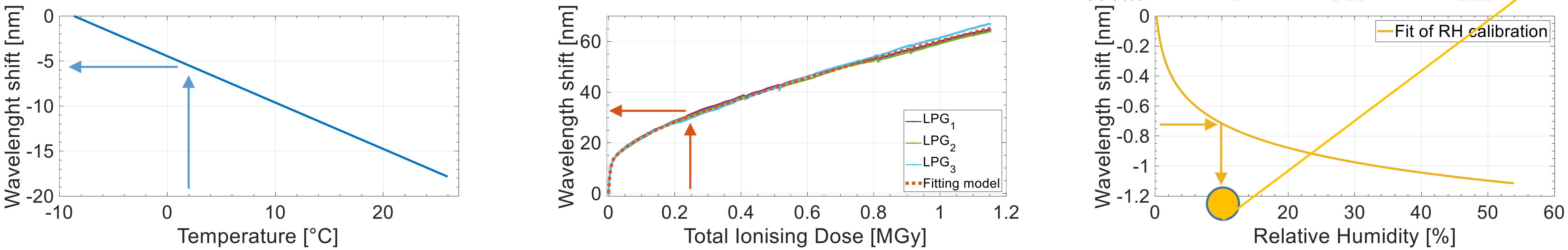


2. Compensate the T effect obtained from the first FBG on the second FBG (sensitive to T and TID), thus calculating the radiation-induced change: $\boldsymbol{\Delta\lambda_{total} = \Delta\lambda_{T} + \Delta\lambda_{TID}}$



RH measurement

3. Compensate the effects of T and TID on the LPG response to derive the RH value: $\boldsymbol{\Delta\lambda_{total} = \Delta\lambda_{T} + \Delta\lambda_{TID} + \Delta\lambda_{RH}}$



CONCLUSIONS

- LPG sensors, though still very late on the market, exhibit very high sensitivities and can be functionalized to become highly sensitive to RH by a thin (~100 nm) TiO_2 overlay
- They do survive very high radiation doses but at the moment the only reliable production requires UV writing on B/Ge-doped fibre, which makes the LPGs sensitive to TID as well
- By combining them with suited FBG written with different technologies it is possible to isolate the RH signal while providing in parallel a direct measurement of T and TID
- The measurement algorithm can of course be fully automatised
- The concept can be easily extended to other measurements of interest
- Are LPGs soon to make their *début* on the commercial market?
- Is it possible to update existing femto-second laser production facilities for the production of LPG?