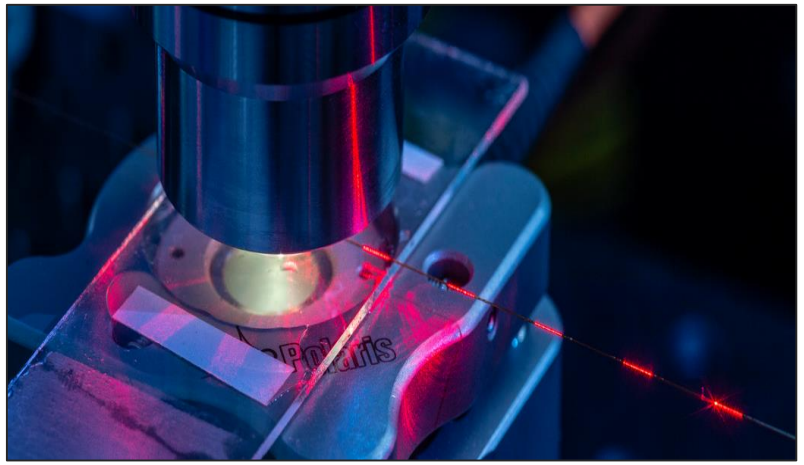


Fiber Sensing Solutions at CEA List for Harsh Environments and SHM Systems

CEA List LSPM *Lab. Systems and Photonic for Monitoring*

Guillaume Laffont, guillaume.laffont@cea.fr

EPIC Porto meeting, April 20th, 2023

LSPM Lab. Systems and Photonic for Monitoring

The Team

30 Researchers

Lasers, OFS, Bragg, 3D printing for Photonic
Ultrasonic guided wave, Algorithm & Tomography
Instrumentations, Embedded Systems, SHM

Main Equipments

3 Platforms

Sachems, FemtoBragg, TowerBragg

Sachems

Acoustic Emission fiber-based system, Impact, DAQ,

FemtoBragg [3 laser Labs]

KrF, Co2, 4 femtos →1030/800/515/400/266/248 nm
Txwo Photon Polymerization 3D printing system

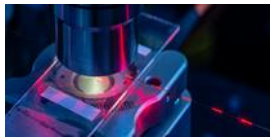
TowerBragg [CEA/CNRS/Univ Lille]

Draw tower, MCVD/OVD, Automated Bragg station

LSPM Team/Equipment Topics

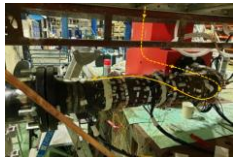
Lasers Processes & Innovative Sensors

Advanced Photonic devices, Start up *Myriad4Sensing*
3D printing for photonic, Biosensing
Tranducers (PZT, Bragg, Rayleigh)



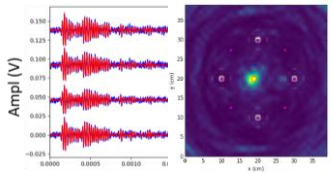
SHM for Harsh Environment

High T°, Radiations, Integration, Testing
Energies, Oil & Gas, Aero, Nuclear Energy, Defense



Data Processing for Monitoring/SHM

Active/Passive Tomography, Acoustic Emission
High speed optical spectrum analysis (Bragg sensors)

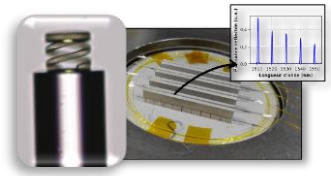


Embedded Instrumentations

Electronic and Embedded IA codes, Monitoring systems
Autonomous and Communicating sensors nodes

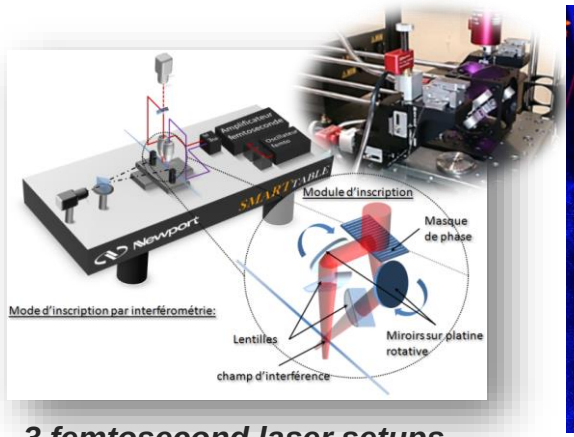
Monitoring For Additive Manufacturing

In situ machine monitoring, SHM
Temperature/Strain/Acoustic, Metal/Ceramic/Glass

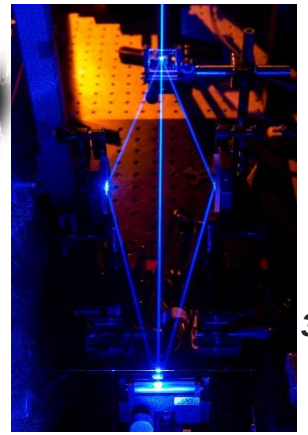


FemtoBragg platform

Writing platform for Fiber Bragg Gratings and amplified Rayleigh
Femto/Nanosecond lasers, 3D printer for Photonic mini/micro-component



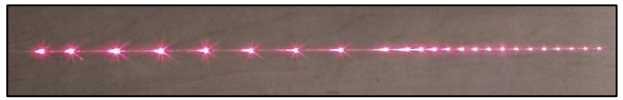
3 femtosecond laser setups
Direct writing on all kind of fibers
Silica glass, Sapphire rods



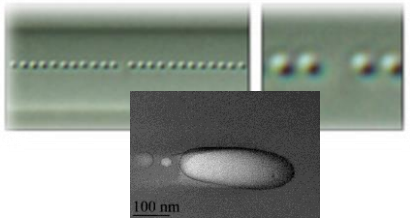
Excimer laser (KrF)
Talbot interferometer

3D printer for Photonic components
Two-Photon Polymerization
Glass structures / Polymer

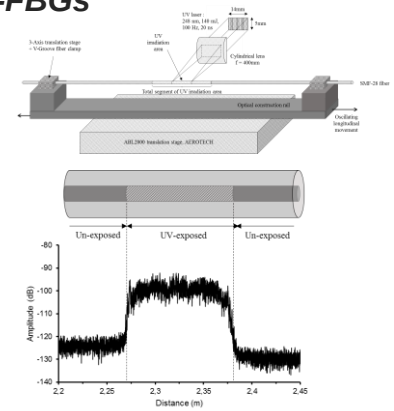
Optcal Fiber Sensors (FBGs, Rayleigh)
dedicated to Harsh Environements Applications



Array of λ-mux PbP-fs-FBGs



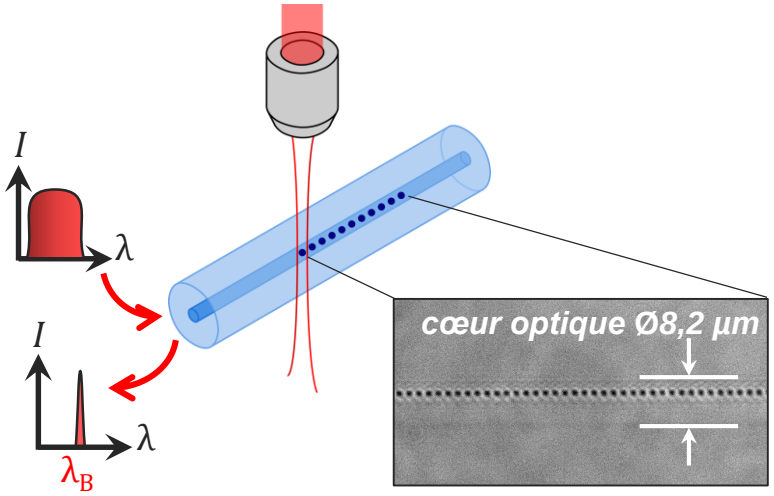
Diffracting FBGs
(spectrometers)

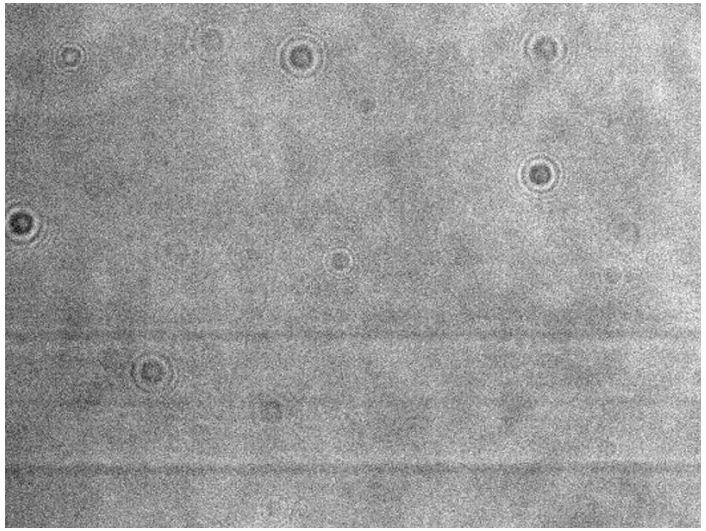


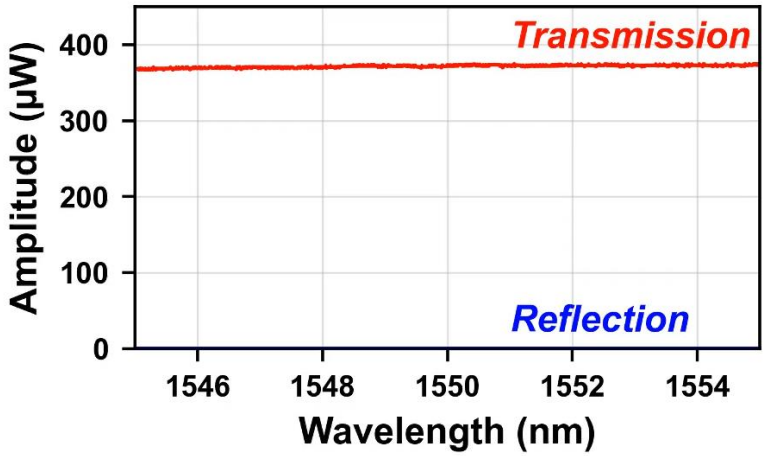
Amplified Rayleigh probes

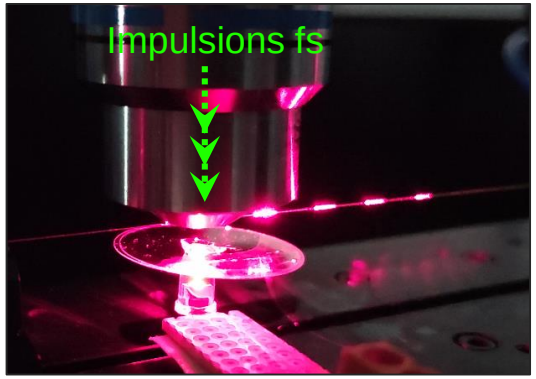
- FBGs and Rayleigh sensors for harsh environments (T°>1000°C, Cryogenic, Radhard)
- Pilot line dedicated to 3D printing of Photonic structures (Glass)
- « Lab-in-Fiber » concept: FBGs, Fabry-Perot cavities, waveguides

Femtosecond Fiber Bragg Grating – Direct laser writing





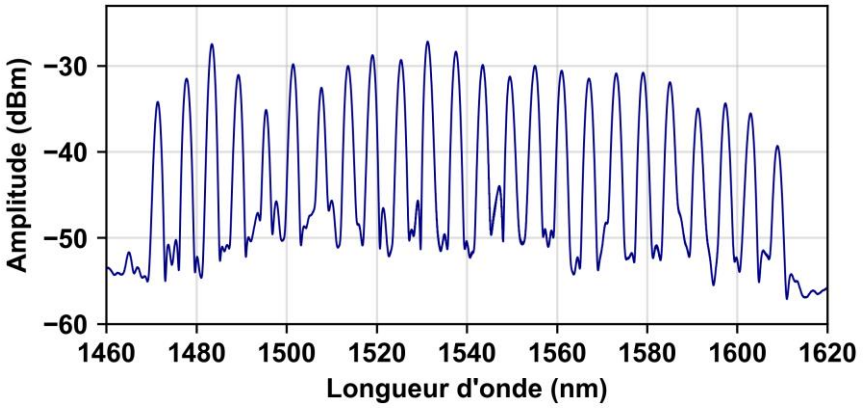


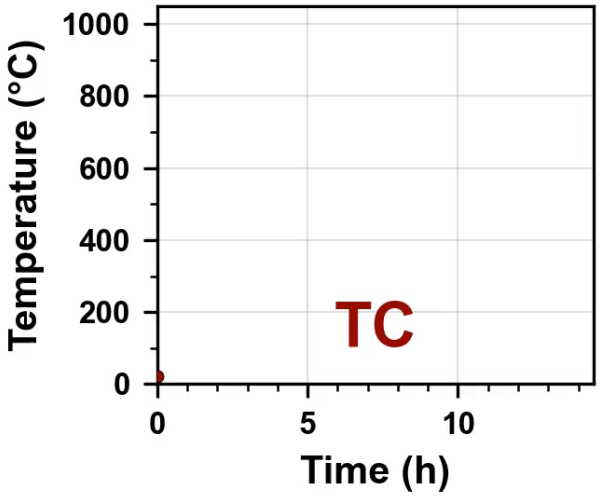


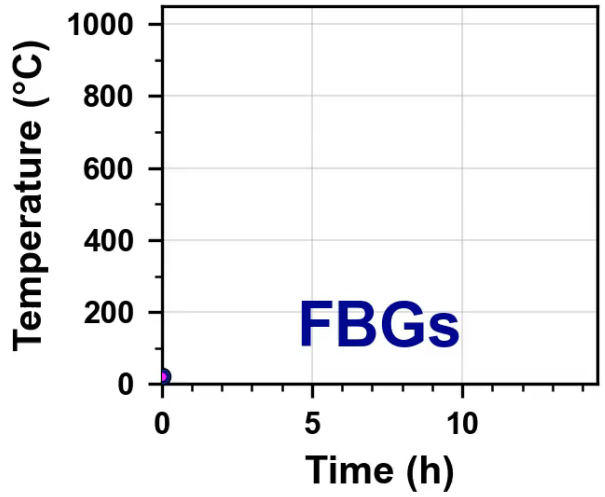
In any kind of optical fibers
Silica, doped silica, aluminosilicate, sapphire rods, etc…

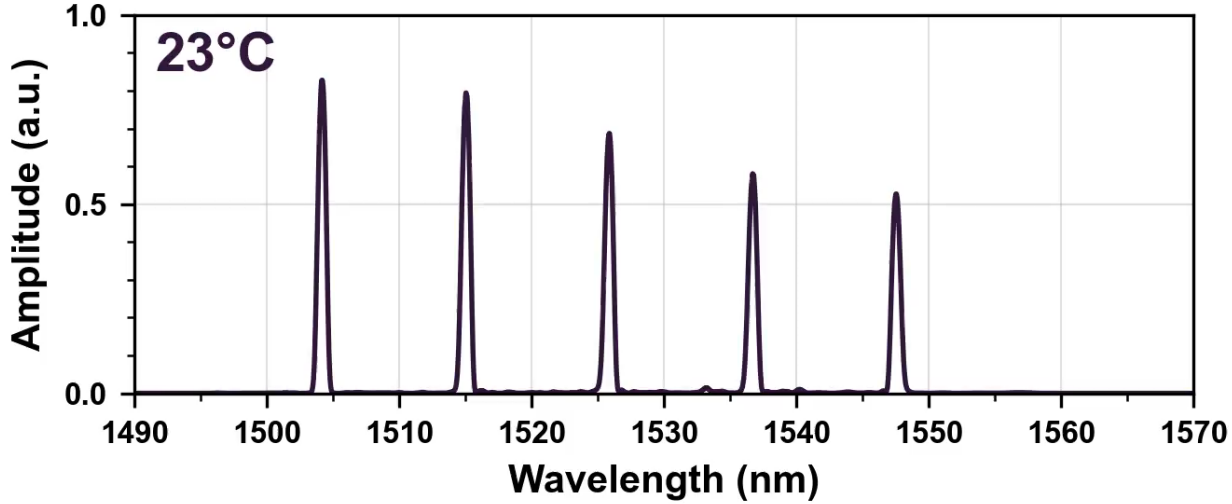
But also in planar substrate

Multipoint temperature sensing with type III femto-FBGs





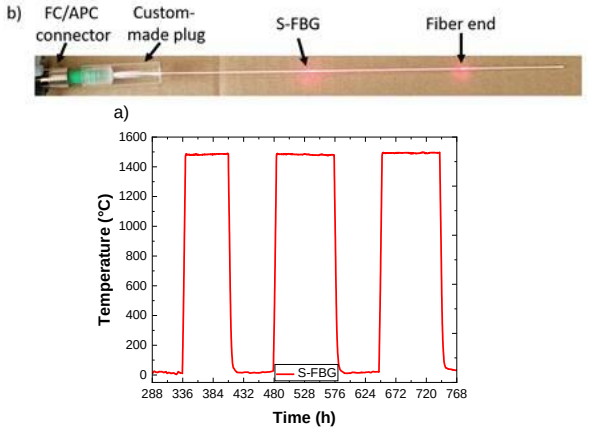




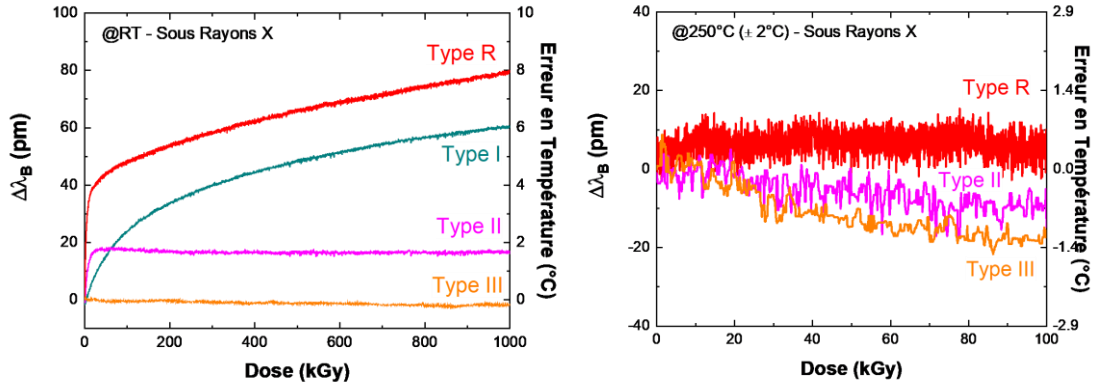
Harsh environment monitoring with fs-FBGs

Sapphire FBGs

- Mesurements @ 1500°C

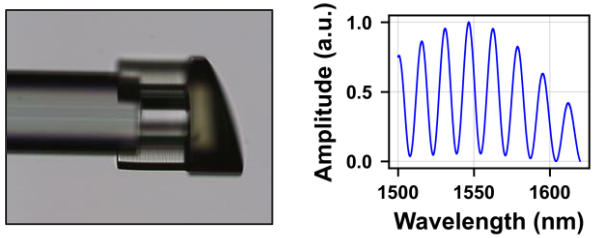


FBGs under ionizing radiations

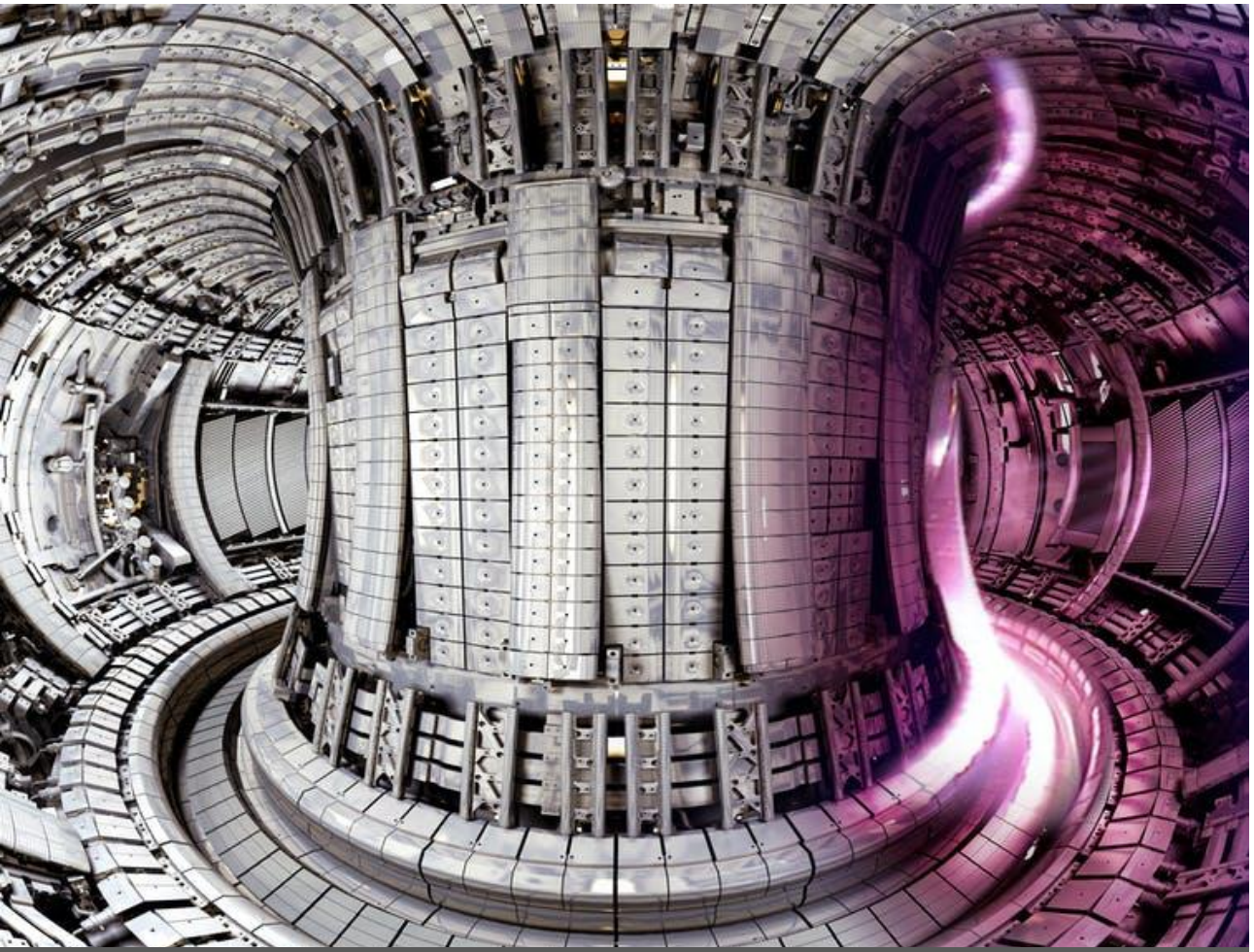


Fabry-Perot tip sensors

- 3D printed silica FP cavities (TPP)



Fusion and Tokamaks



TOKAMAK WEST (CADARACHE, FRANCE)

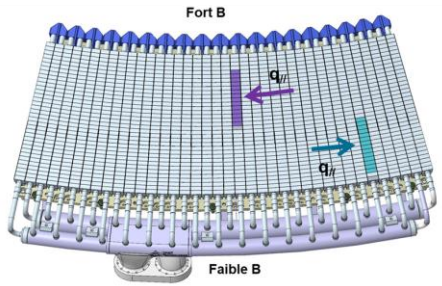
THERMAL DIAGNOSTIC IN A TOKAMAK >800°C

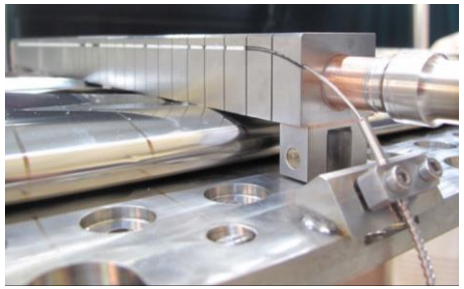
INSTRUMENTED W-BLOCKS OF A DIVERTOR'S SECTOR

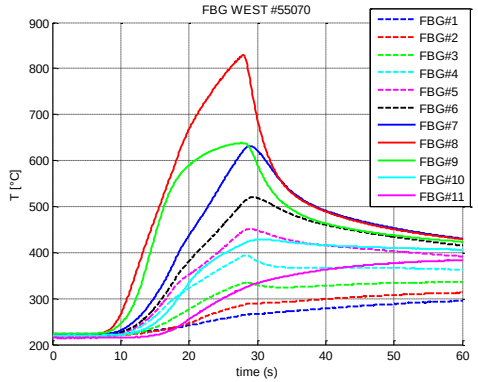
Heat flux 5 MW/m2, Sun surface ~60 MW/m2, On the beach 0.001 MW/m2

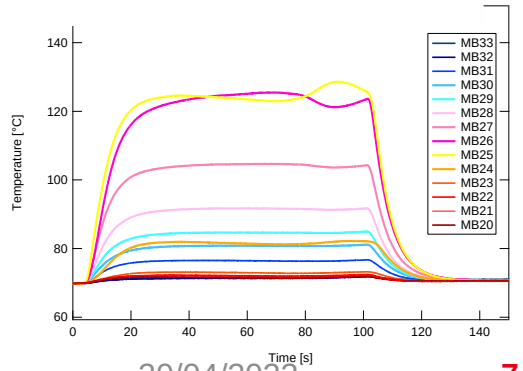
FULL INSTRUMENTATION

Packaged FBGs, Feedthrough, Remote line, System/Soft to the control room









Structural Health Monitoring for Aircrafts

Health Monitoring For Aeronautic

Structural Health Monitoring

Instrumentation Of Composite Structures
Instrumentation Of Aircraft Engine

Ultrasonic guided wave tomography (active/passive)
FBG as ultrasonic receivers
Dedicated FBG monitoring system (~MHz)

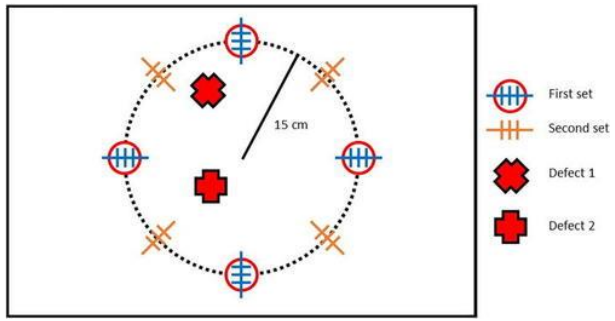
Femtosecond FBGs and Aircraft engines
Packaged Temperature/Strain probes with femto FBGs
Infiber pressure transducer (FP, FBG)

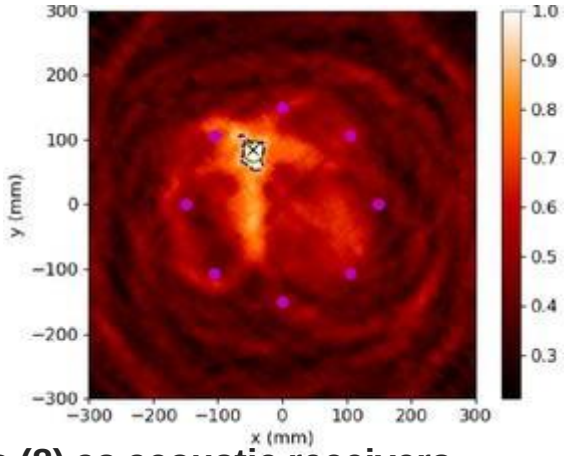
SHM – Passive Tomography with FBGs for Damage Detection

Passive Tomography (Aircraft, Pipe for Oil&Gas/Nuclear)

- Method coming from the geophysic domain (sismic wave monitoring)
- Make use of the ambient noise in the structure
- The structure creates its own probe signal, no need for PZT transducers
- Probe signal = Elastic guided wave @ ultrasonic frequencies

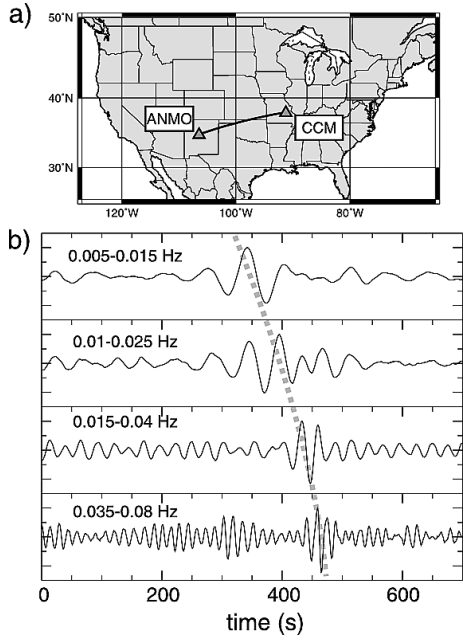
- **λ-mux FBGs are used as acoustic receivers at ultrasonic frequencies**
- **Dedicated multichannel FBG monitoring system operating under development**

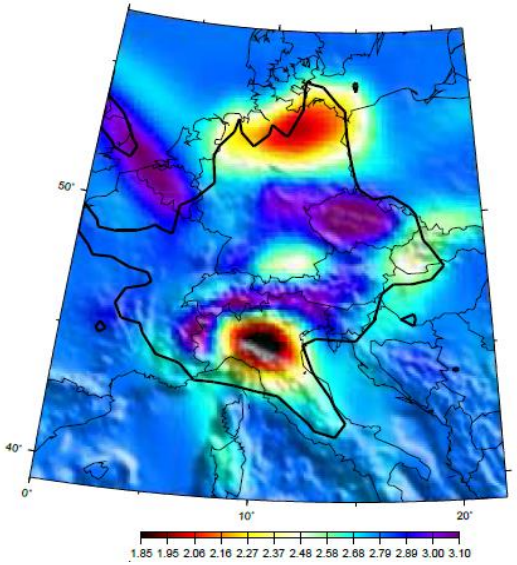




Passive tomography with only FBGs (8) as acoustic receivers

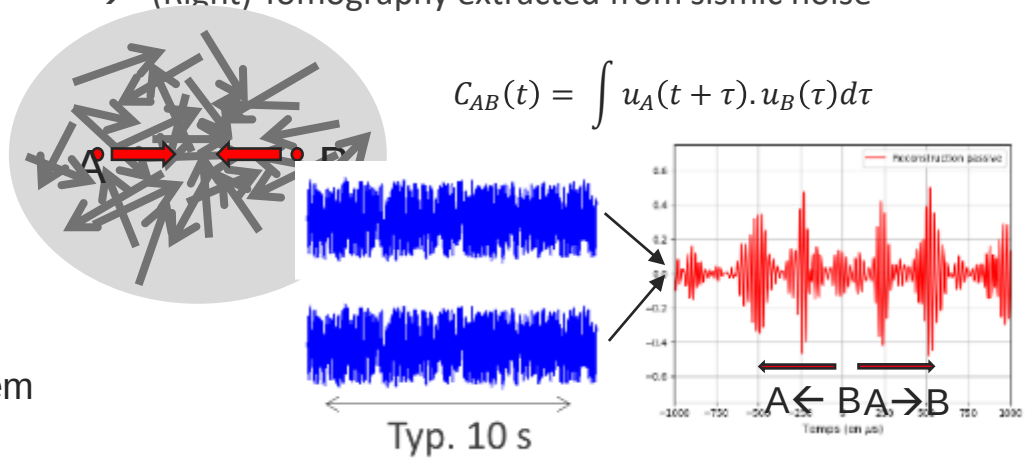
- Synthetic damage (pair of magnets) detection in a CFRP composite panel
- λ-mux FBGs interrogated at 1 MHz with home-made transimpedance/system
- Noise = compressed air flow moving randomly across the panel



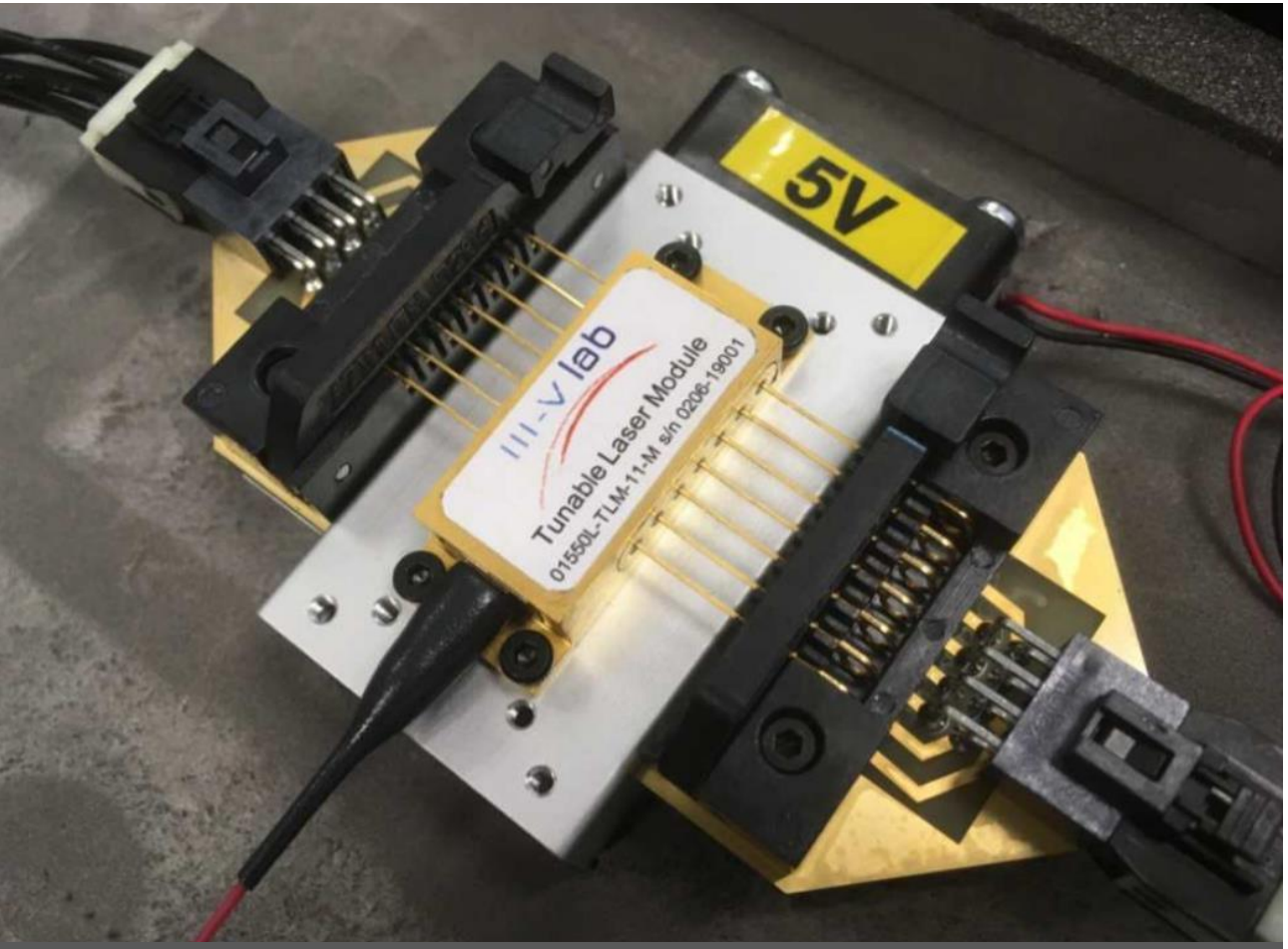


→ (Left) Rayleigh waves identified after thousands km
→ (Right) Tomography extracted from sismic noise

$$C_{AB}(t) = \int u_A(t+\tau).u_B(\tau)d\tau$$



FBG monitoring systems – From lab to embedded versions



Towards FBG interrogators

FBG MONITORING SYSTEMS

For Strain/T°/Vibrations mapping

For elastic guided waves (ultrasonic frequencies)

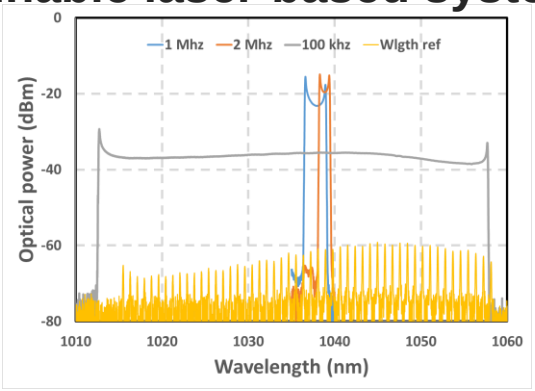
Related topics

- Passive demultiplexing
  - AWGs, Micro rings, Edge filtering
- In-fiber etalons for Wavelength Referencing
- Wavelength tunable systems
  - Fiber lasers
  - Vcsel and microring-based/Vernier III-V laser
- Compact spectrometers
  - FBG as diffracting element for compact spectrometer

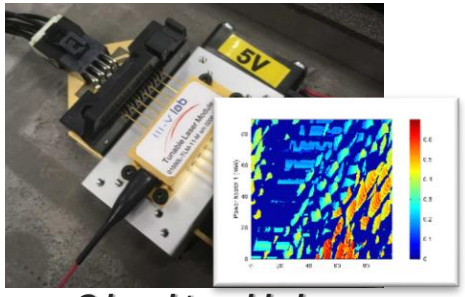
FBG monitoring systems – From lab to embedded versions

Accuracy < 0.1 pm @ 10 Hz
Rate 1 kHz
6 channels in parallel
Absolute wavelength referencing @ each sweep (every ms)
Spectral range 70 nm @ 1.5 µm
< 10 fm drift after 400 h | std dev < 32 fm | ΔT = 6°C

Tunable laser-based system

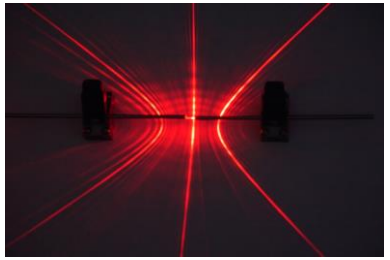


III-V tunable laser

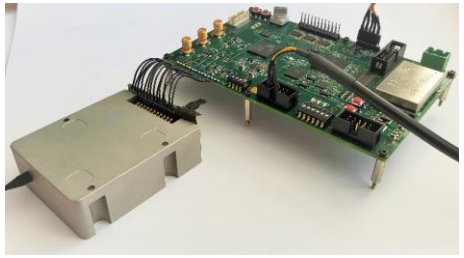


C band tunable laser
III-V Lab and CEA List/Leti

Compact spectrometers



Case 1: Femto FBG as diffracting element
Operation either at 850 nm or 1550 nm

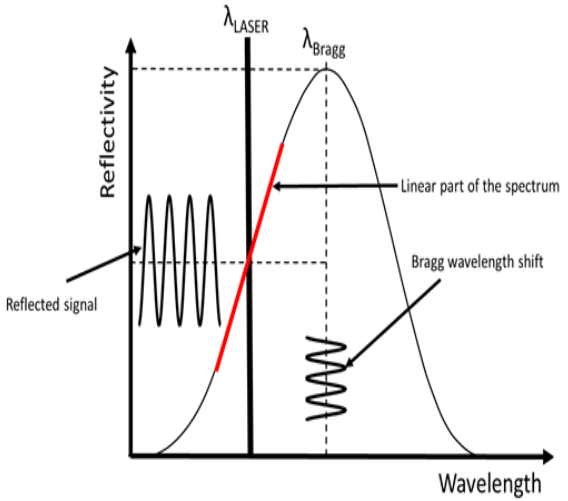


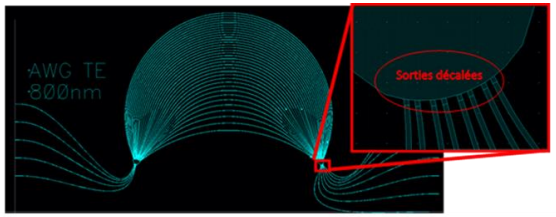
Case 2: T grating and CCD @ 1550 nm
To be embedded in airborne test vehicle

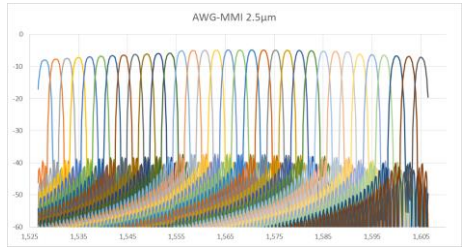
FBG monitoring systems – From lab to embedded versions

Compact monitoring system for λ-mux FBG acoustic receivers in SHM systems

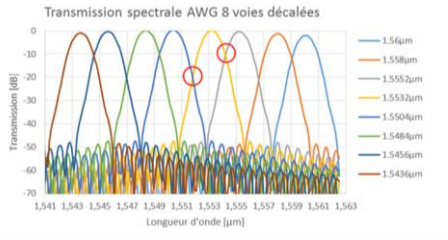
- Array Waveguide Grating customized for sensing needs (edge filtering)
- AWG Si/SiN developed through a collaboration between CEA List and Leti
- CEA patented



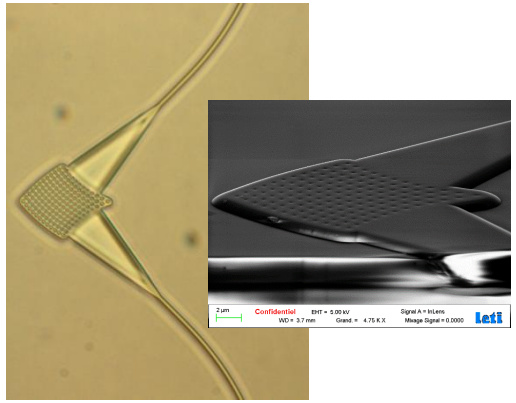


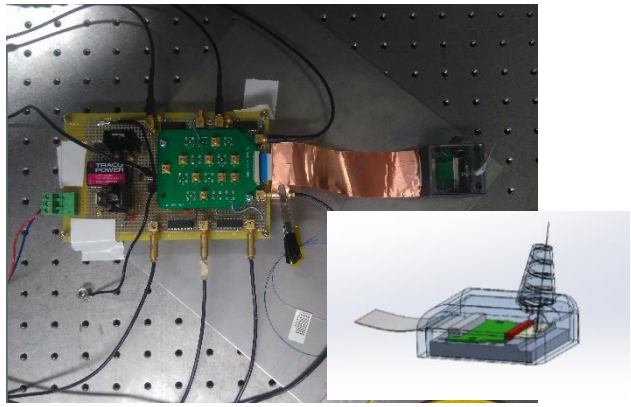


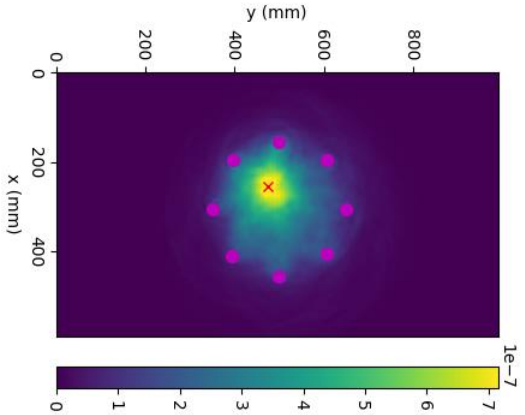
Demux *Telecom*



Demux *Sensing*







Active/Passive Tomography for damage detection in composite panels

FBGs = acoustic receivers

and PZT = emitters

To conclude – Ongoing activities on …

- **New high T° smf fibers, multicore fibers, High T° coatings**
- **Innovative femtosecond FBG sensors and amplified Rayleigh probes**
  - ... Silice fs-PbP-FBGs and innovative calibration method up to >1000°C
  - ... Sapphire fs-PbP(LbL)-FBGs up to 1500°C
  - ... And even FBG-based biosensors
- **Femtosecond FBG writing and automated writing stations**

- **Growing activity on embedded FBG monitoring systems**
  - ... using Photonic Integrated Circuits such as III-V tunable laser, tunable Vcsel or DFB lasers but also passive components (Array Waveguide Gratings Si/SiN, Microrings)

- **Application fields: Aerospace, Space launcher, Oil&Gas, Hydrogen, Nuclear energy, Defense**

- **Start up end of 2023 on High T° femtosecond FBGs**