



INESCTEC
TECHNOLOGY & SCIENCE
ASSOCIATE LABORATORY
PORTUGAL



Blue Photonics - optics and sensors to monitor the ocean

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FROM KNOWLEDGE GENERATION TO SCIENCE-BASED INNOVATION



Research and Technological Development | Technology Transfer and Valorization | Advanced Training | Consulting | Pre-incubation of Technology-based Companies

✔ **Monitoring the Ocean**

✔ **Photonics at INESC TEC**

✔ **Physical sensors**

✔ **Chemical sensors**

✔ **Biological sensors**



high demand for a diversity of sensor technology capable of operating in marine like environments, providing critical information in multiple dimensions: understanding the evolution of water quality, evaluating the impact on biodiversity, assessing the integrity of operating vessels and infrastructures



Optical fiber Sensors for environmental awareness

• Main features

- Remote real time monitoring
- Multiplexing ability (multipoint, multiparameter)
- Electromagnetically passive
- Immunity to electromagnetic interference
- Suitable for harsh environments
- Low weight, reduced dimensions

Photonics for sensing

Physical parameters

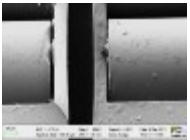
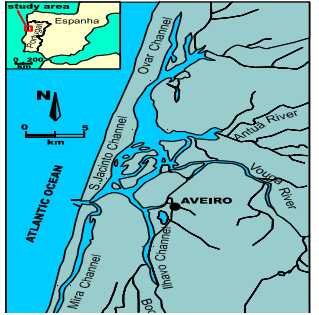
- Temperature sensors
- Strain and deformation
- Vibration

Chemical Parameters

- Dissolved Carbon Dioxide
- Dissolved Oxygen
- Methane
- Hydrogen

Biological parameters

- Toxins
- Bacteria



Physical sensors:

- Environmental monitoring
- Structural health monitoring
- Remote interrogations
- Electric current sensors



PROTEU – Real time monitoring of Temperature at Ria de Aveiro



Multi point Temperature sensing

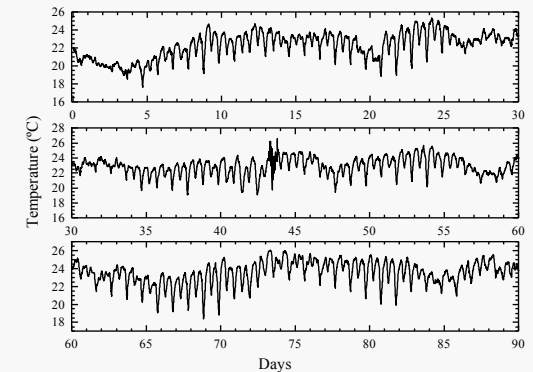
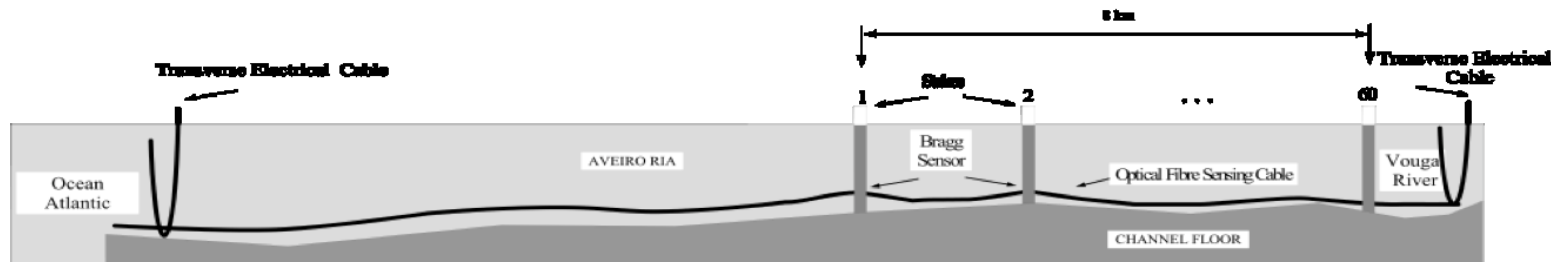
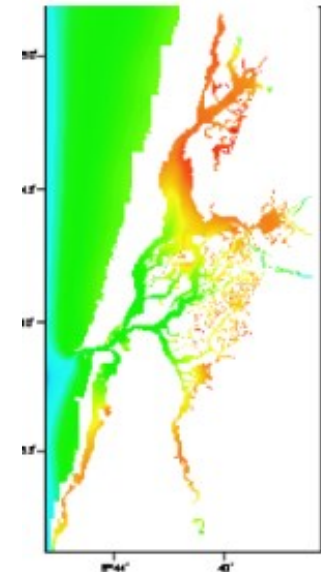
10 km; 19 sensors. 0,1 °C resolution

GSM communication: real time data

Continuous operation ~2years



Data stored in database for feeding theoretical models.



Optical fiber sensors for physical parameters

Well established technology (HBM Fibersensing)

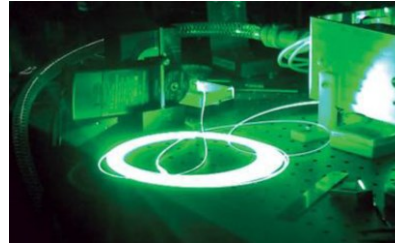
Strain

Temperature

Acceleration/vibration

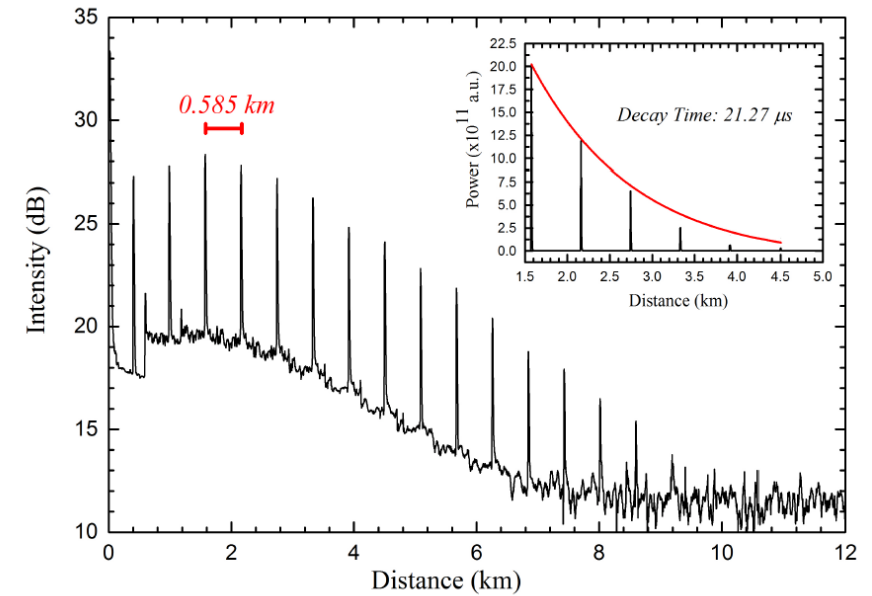
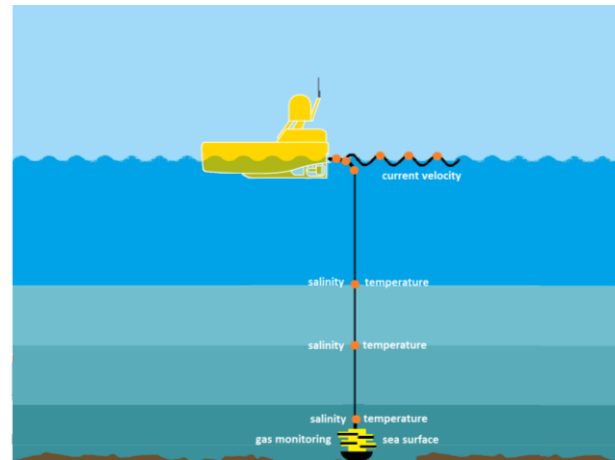


- Optical fibers enable: multipoint or distributed sensing
- Typical range is in the 10'km
- Special techniques can extend the range over 100 Km



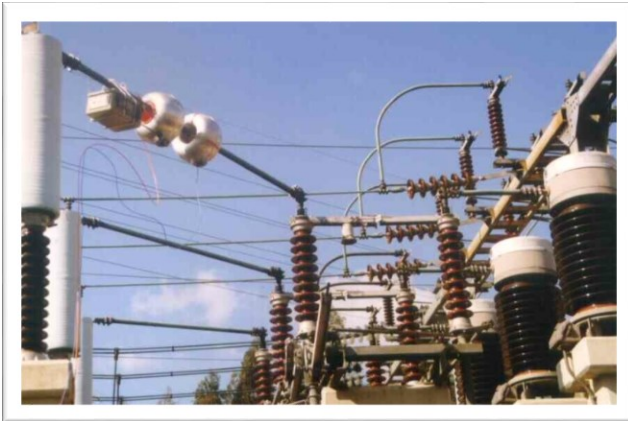
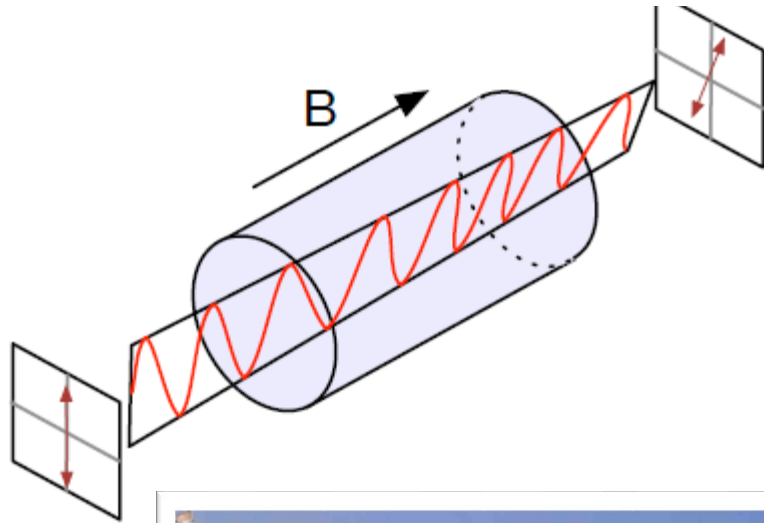
Structural health monitoring

Environmental monitoring



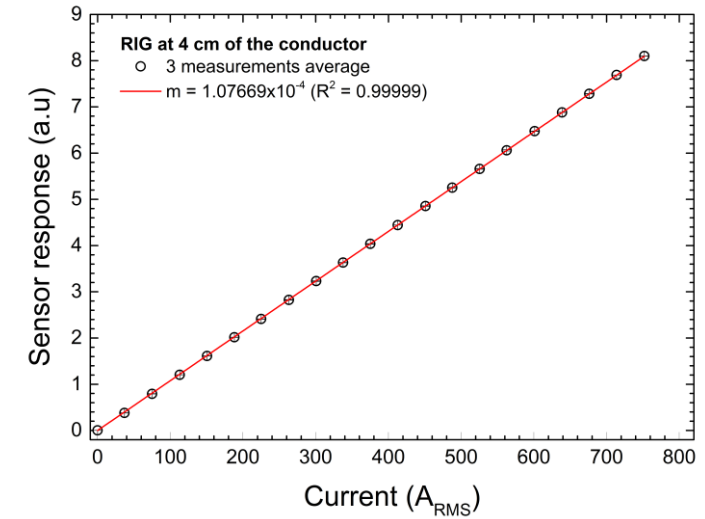
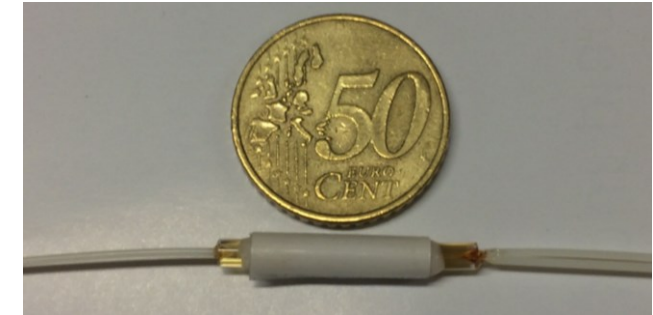
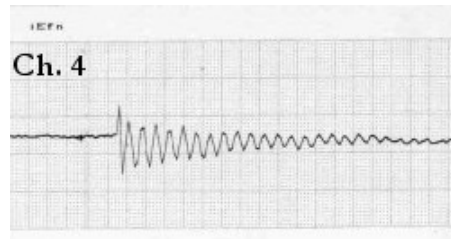
Optical current sensors

Faraday Effect $\theta_F \propto B \cdot V(\lambda, T)$



Small footprint
Large bandwidth
Large dynamic range
Dielectric

Ideal for operation in
corrosive environments

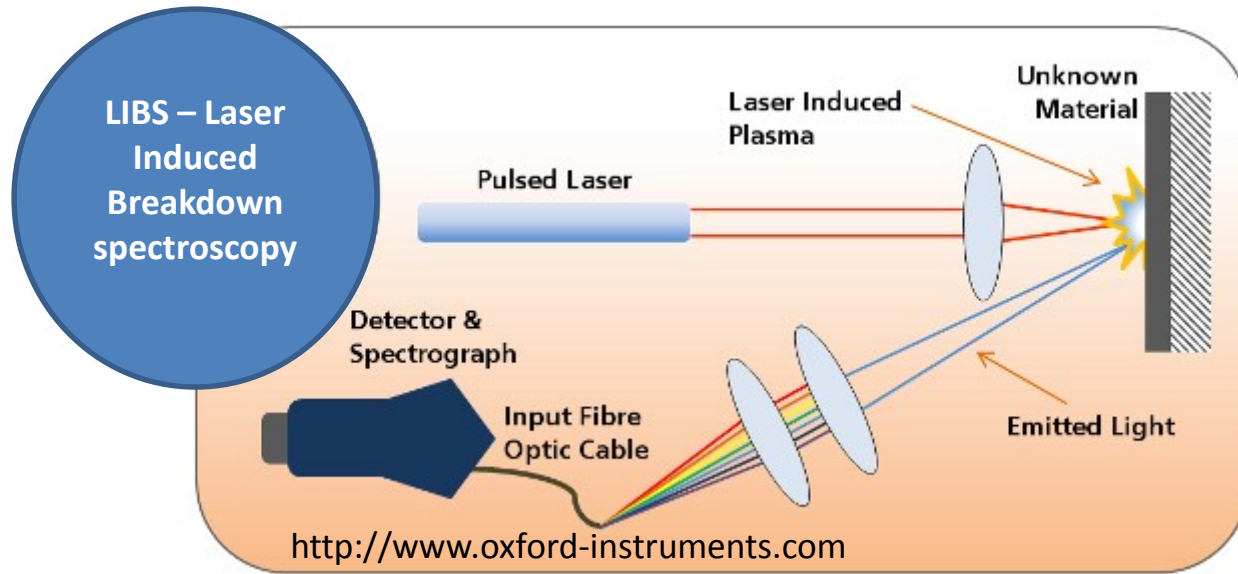


Chemical sensors:

- LIBS
- Corrosion monitoring
- Optrodes and low cost optoelectronics
- Microfluidics
- 3D monolithic optofluidics

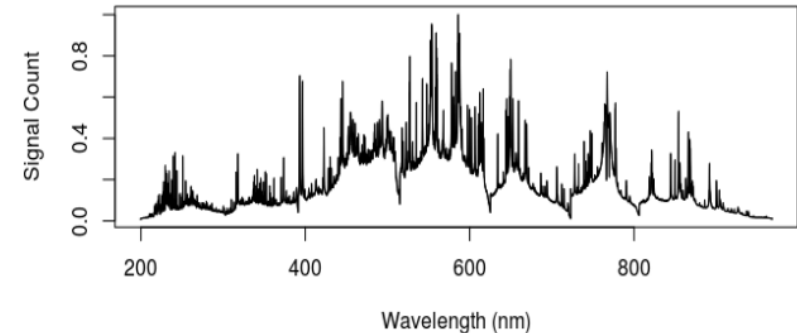
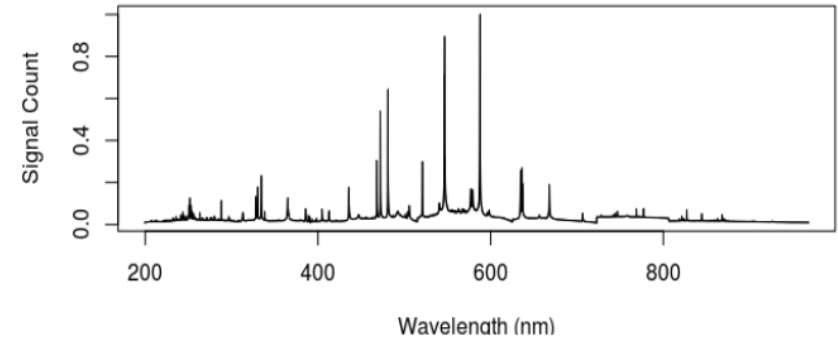


LIBS: Real Time element analysis



- High energy ($> \text{MW}/\text{cm}^2$) laser pulse (ns)
- Breakdown of material generates a plasma
- Accelerated electrons have broadband emission $\sim T$ of plasma
- Cooling down :Atomic emission lines from constituent elements observable.

Spectra of pure element

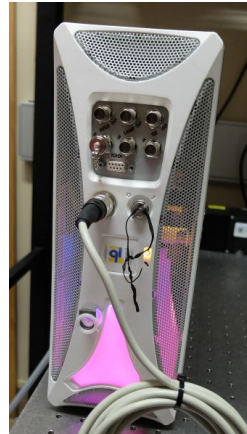
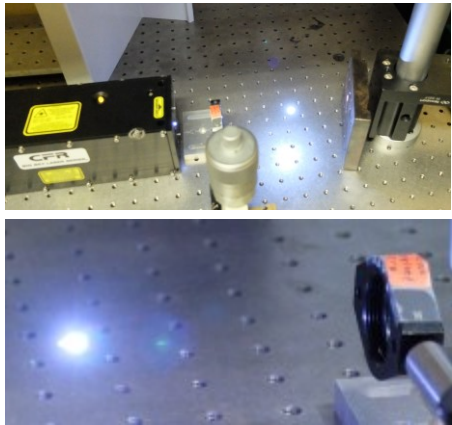


Spectra of complex material

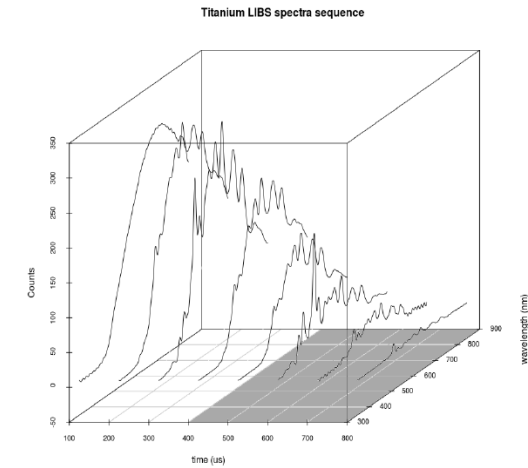
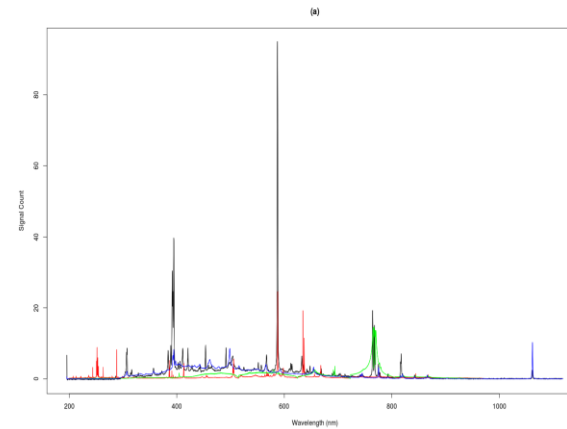
Fibers in LIBS

CFR200 Quantel systems LASER:

- Parametrization of Laser Energy
- Pulse rate
- Detection gating
- Plasma features



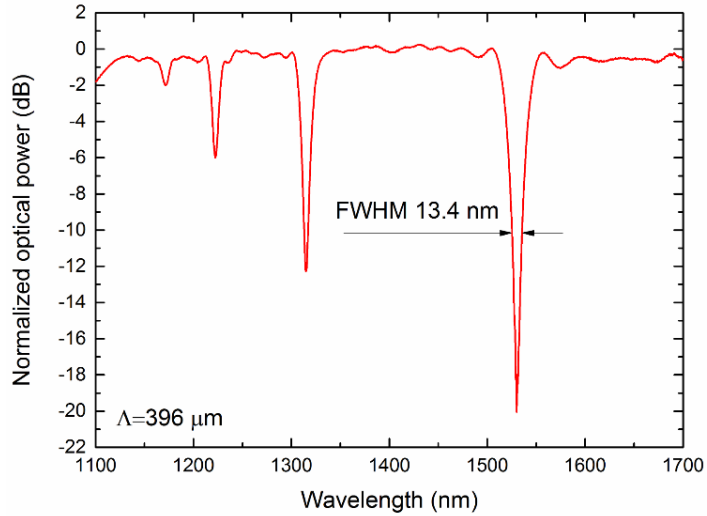
Granit: Potassium, Silicon and Aluminum



Mineral Dynamic LIBS Fingerprinting (Tensor Data)

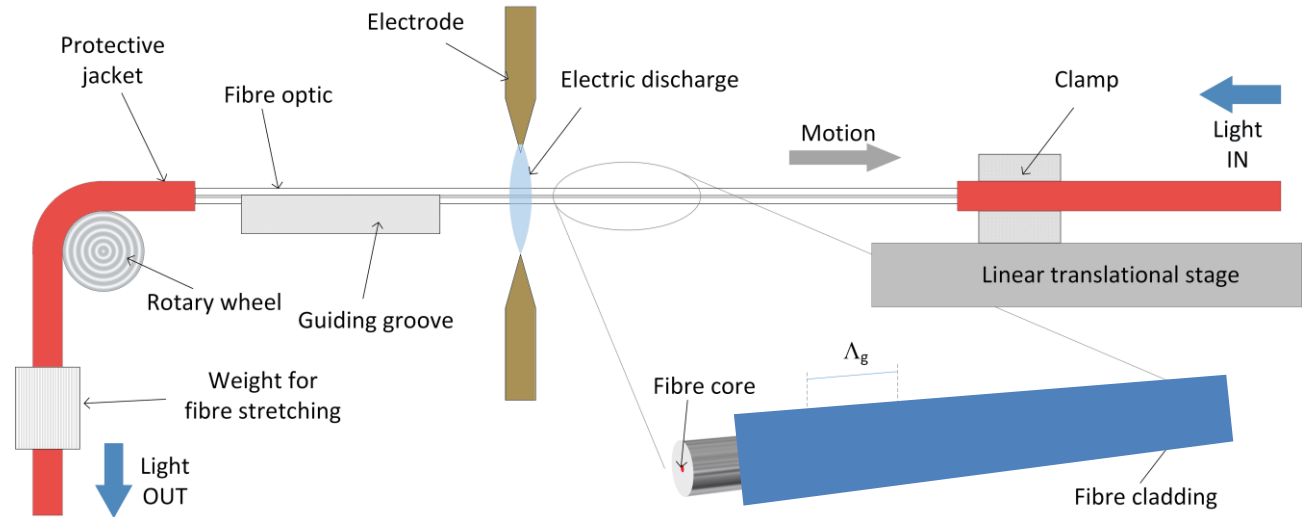
All minerals will have a particular Dynamic LIBS Fingerprint

- High energy densities achieved with **low pulse energy**
- **Plasma was easily observed in a wide range of pulse settings.**
- Preliminary results indicate possibility of **Dual pulse operation with single laser.**

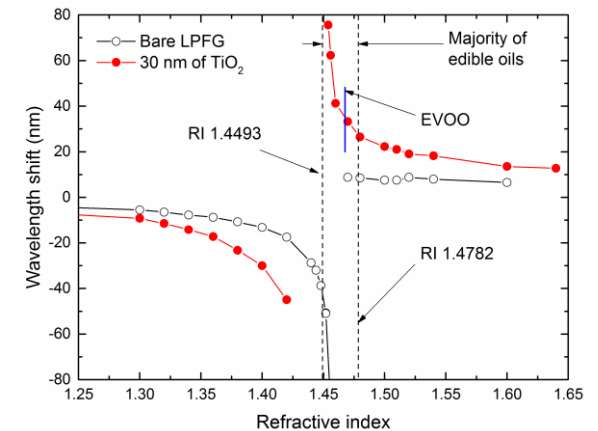
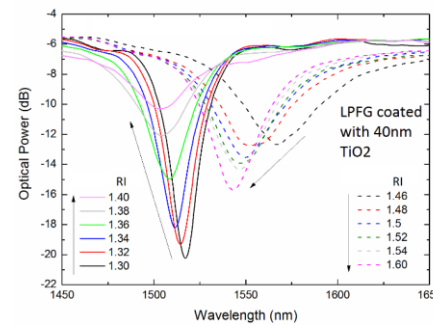
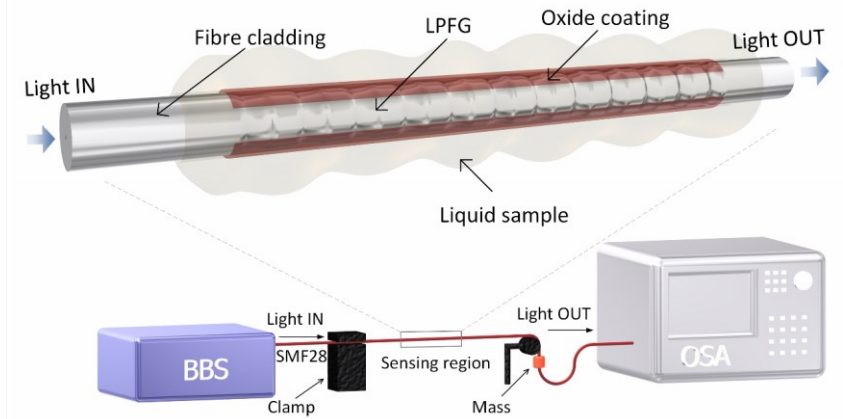
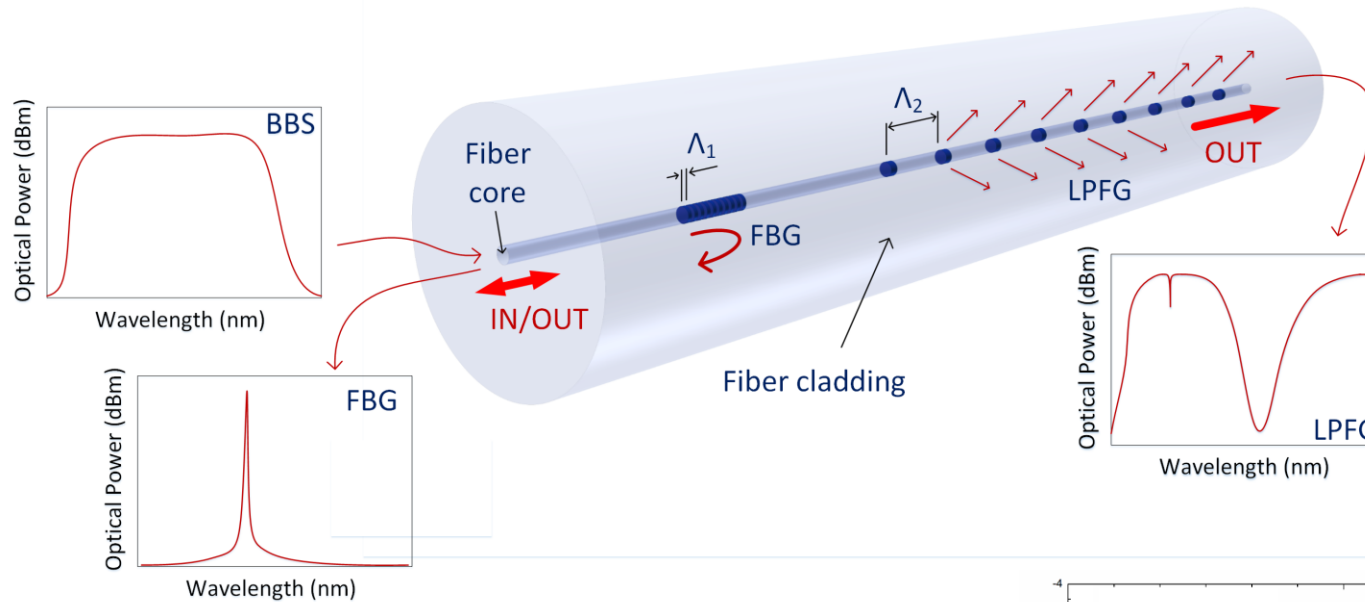


$$\lambda_{LPG} = \left[n_{eff}(\lambda) - n_{clad}^i(\lambda) \right] \Lambda$$

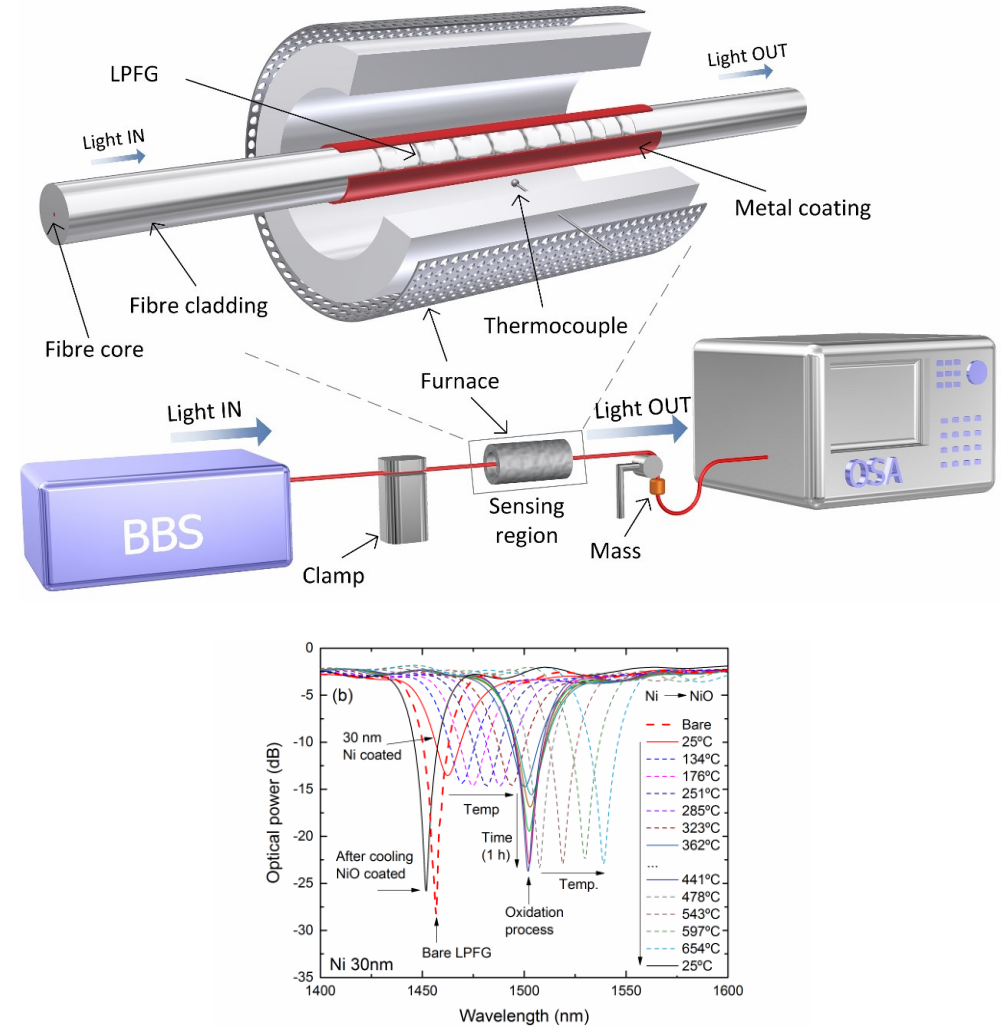
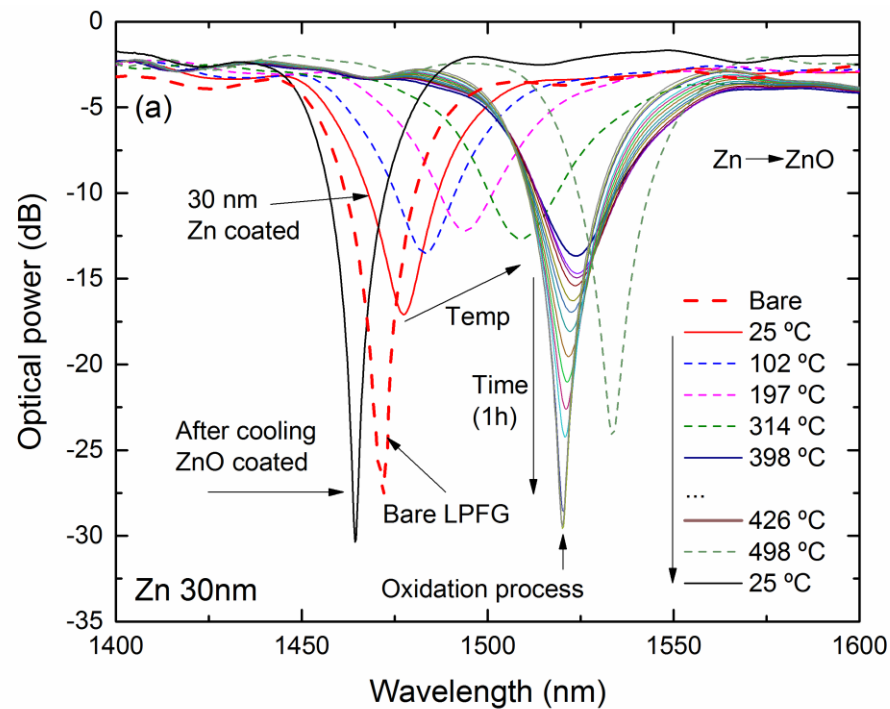
Long period fibre gratings



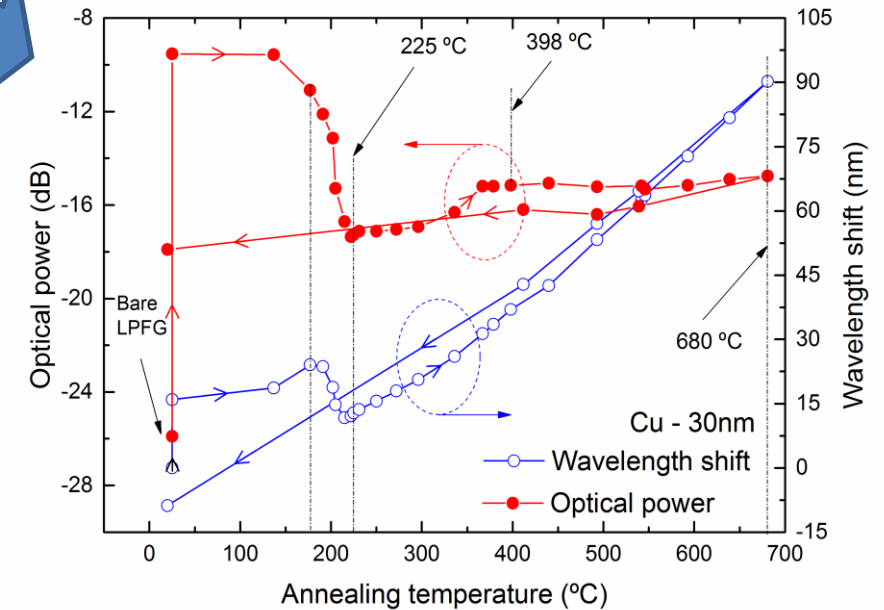
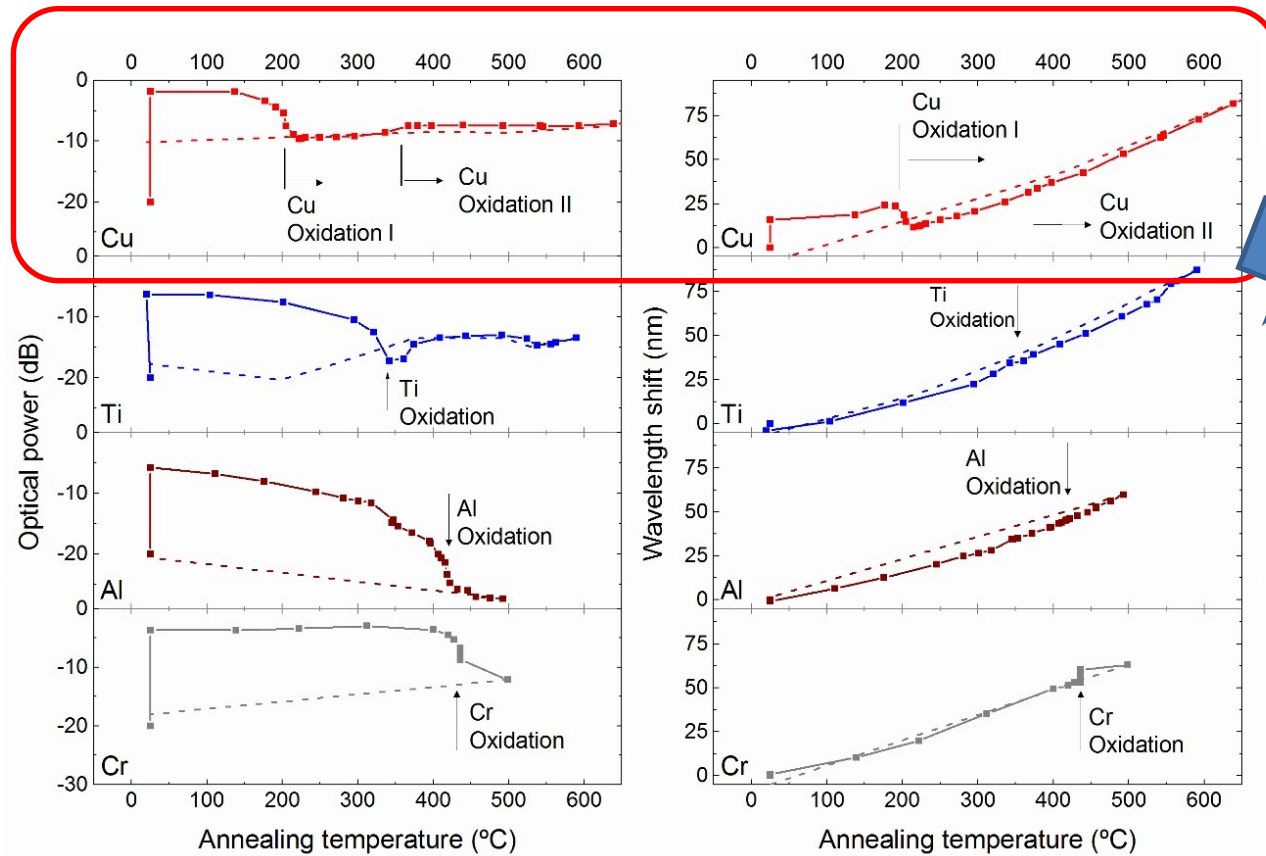
Evanescent wave fiber sensors



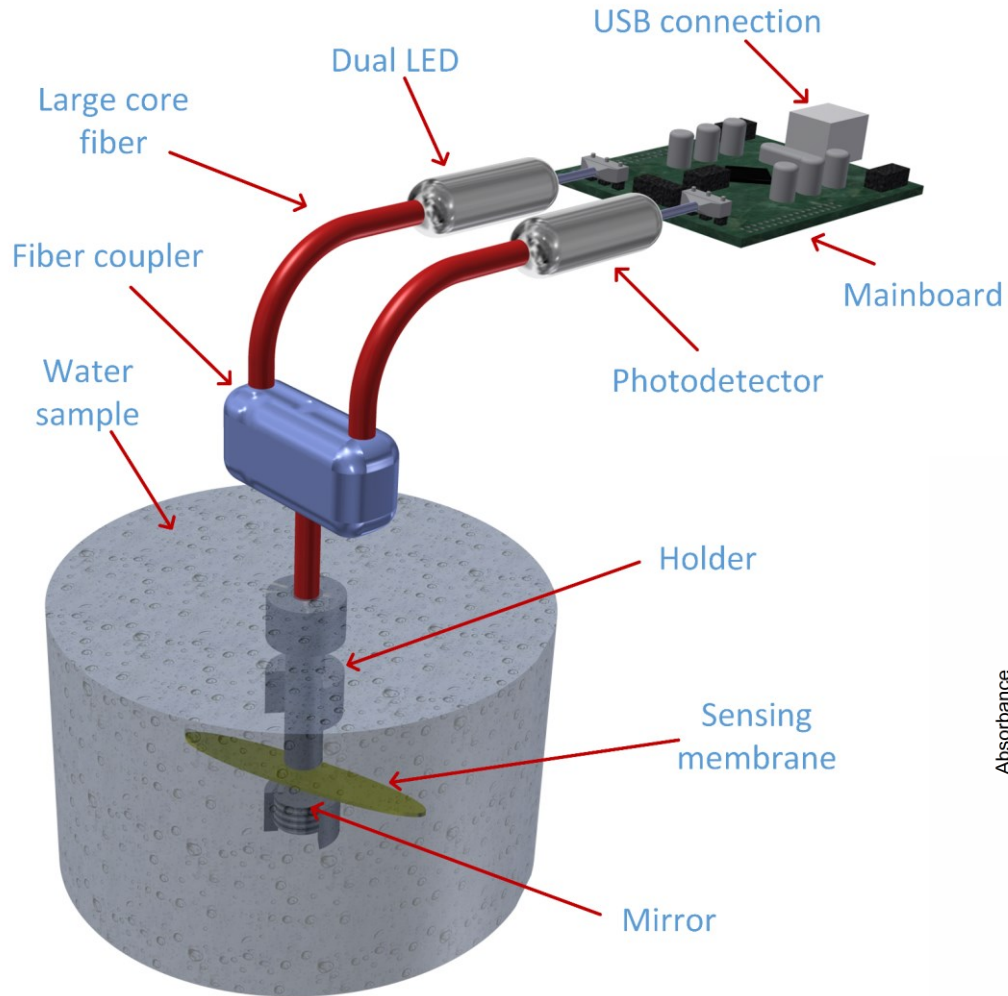
Long period fibre gratings coated with metals



Long period fibre gratings coated with metals

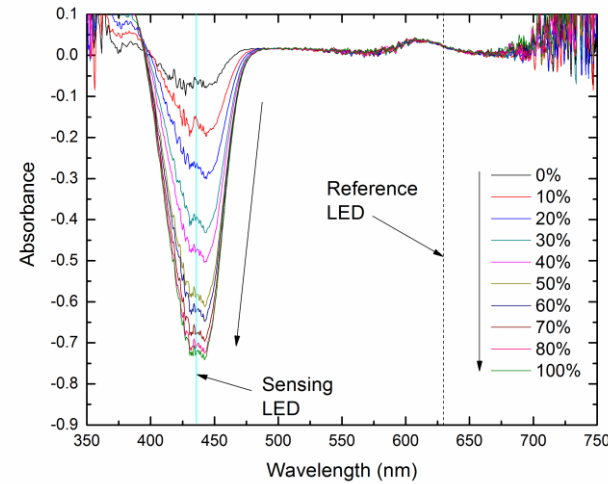


Optrodes with low cost optoelectronics: dCO2 sensor



Low Cost LED based optoelectronic platforms

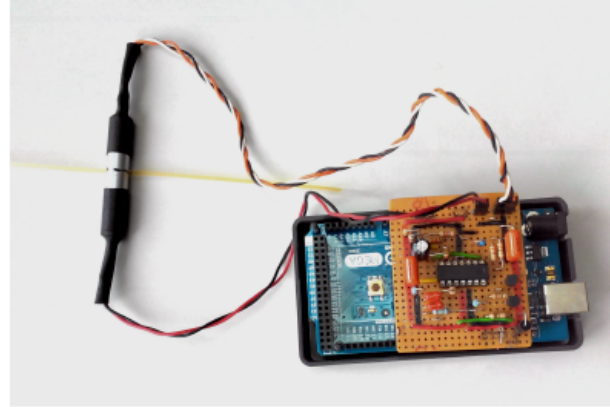
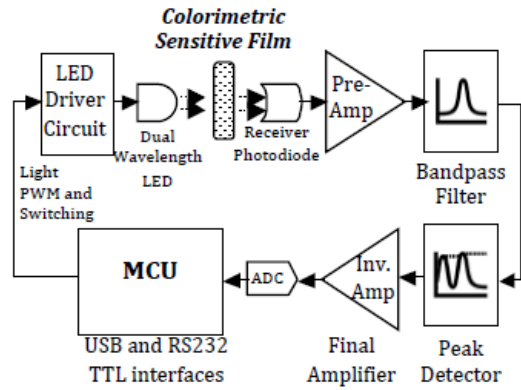
COMPACT chemical sensors
Colorimetric/Fluorescent



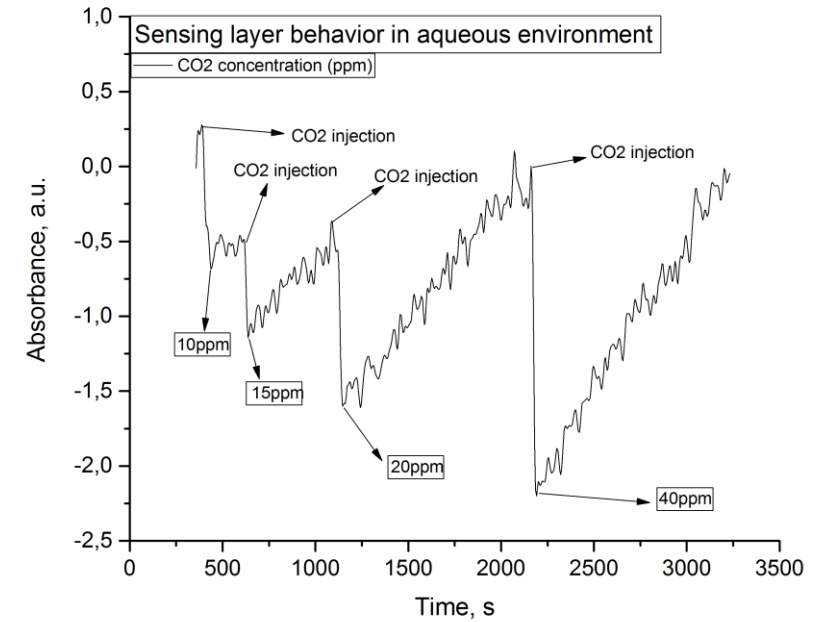
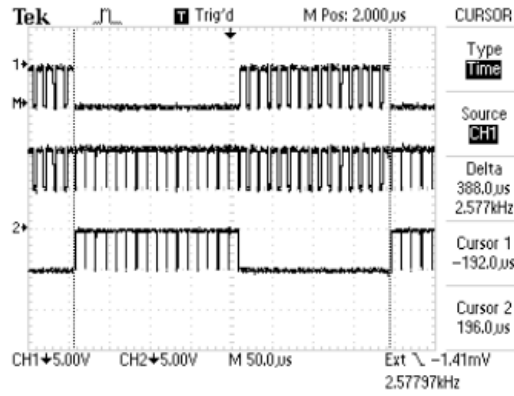
Interchangeable components

Sensing of other analytes

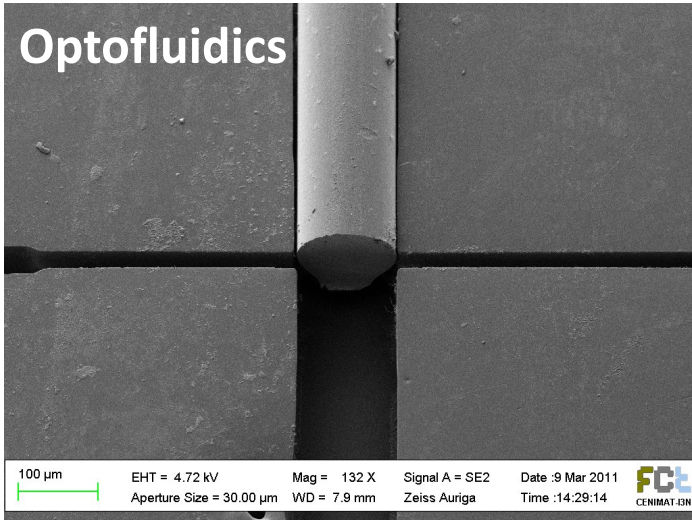
Optrodes with low cost optoelectronics: dCO2 sensor



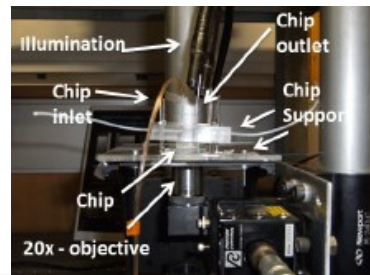
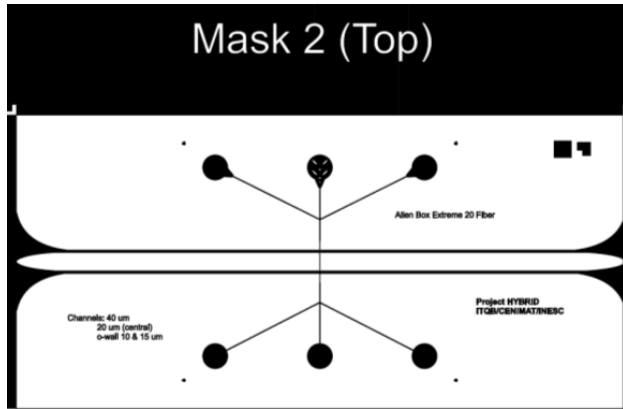
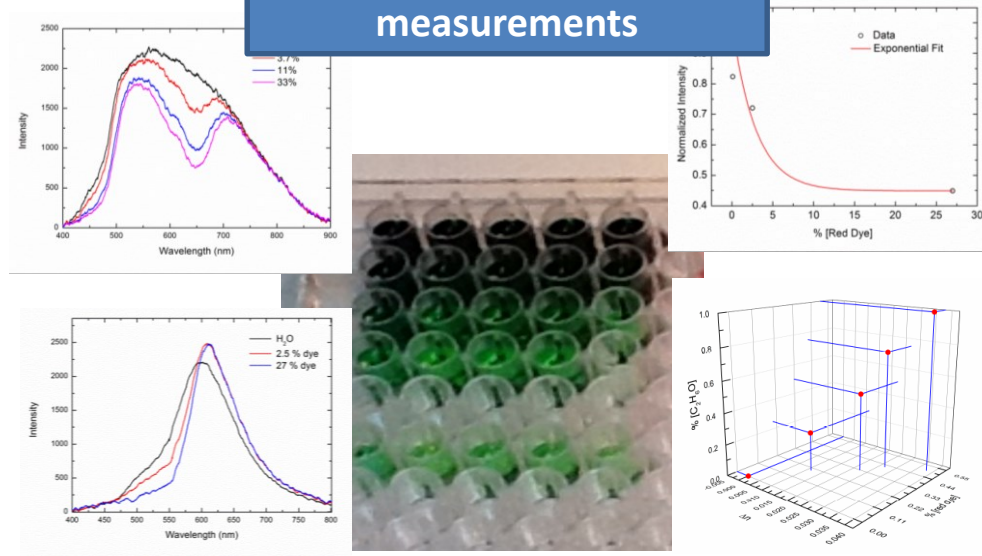
Small footprint
 Low power consumption
 High sensitivity
Suitable for standalone operation
Aquaculture
Marine applications



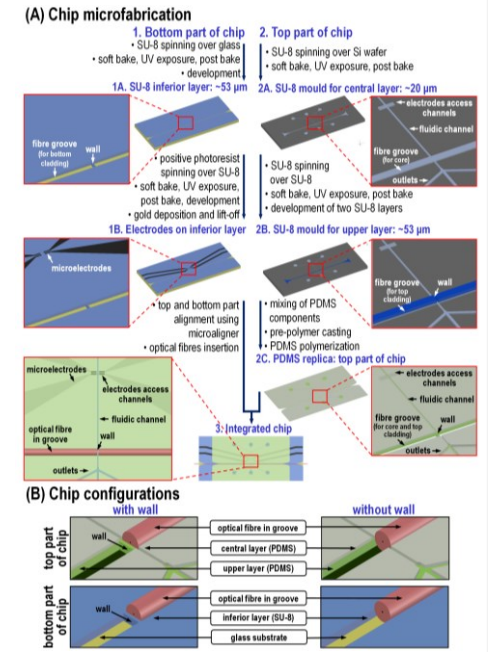
Miniaturization of optofluidic platforms



Multiparametric measurements

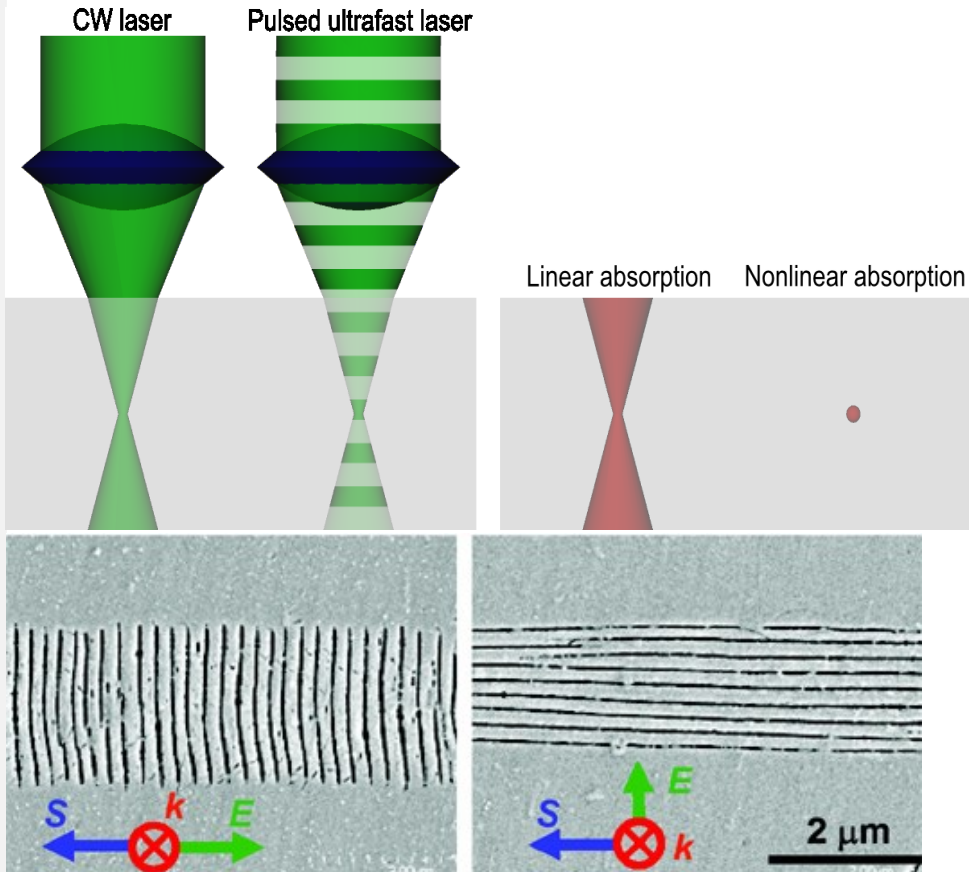


Complex photolithographic process



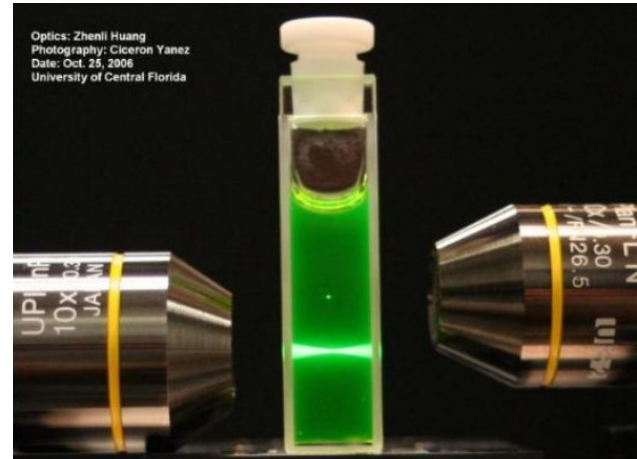
Femtosecond silica processing for integrated optics

The advantages of nonlinear absorption:

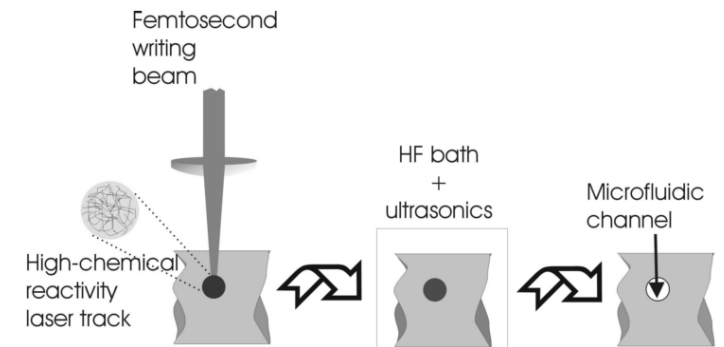
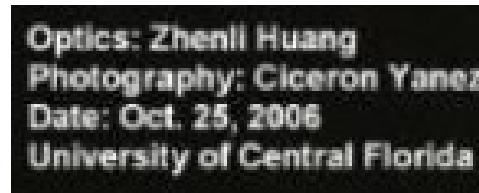


Simova et al., Ultrafast laser pulses create periodic planar nanocracks in glass, Micro/Nano Lithography, 2007

- Truly 3D microfabrication
- High spatial resolution



- Refractive index modification
- Selective etching

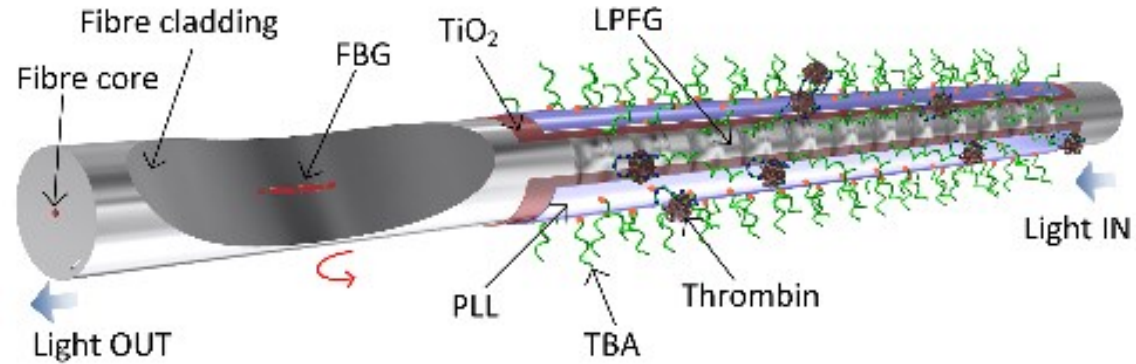


Biosensors:

- Label free biosensors
- Genomics and proteomics
- Fiber optic tweezers
- Single cell manipulation



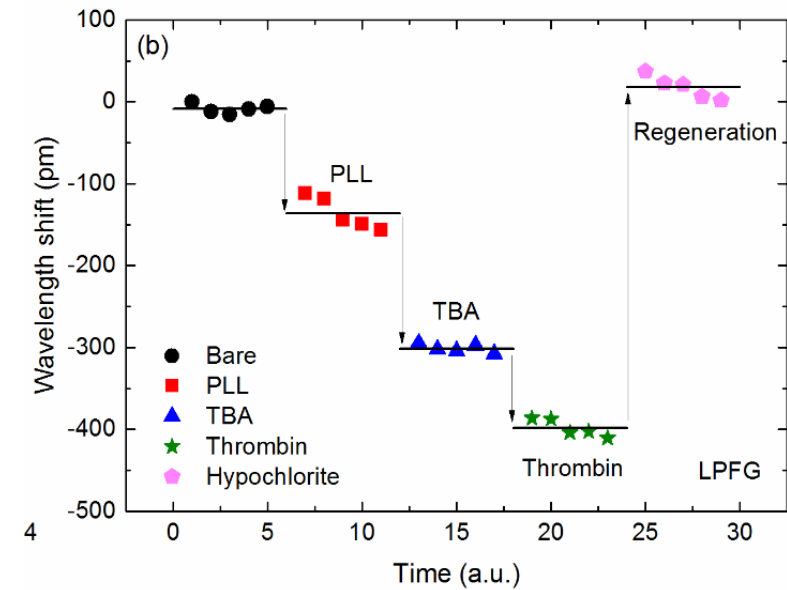
Functional coatings enable biosensing



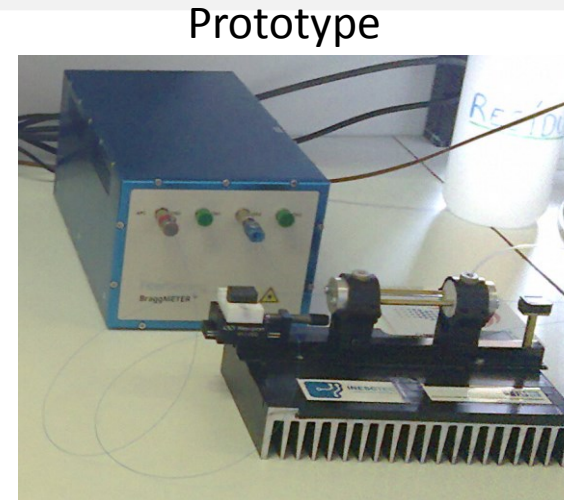
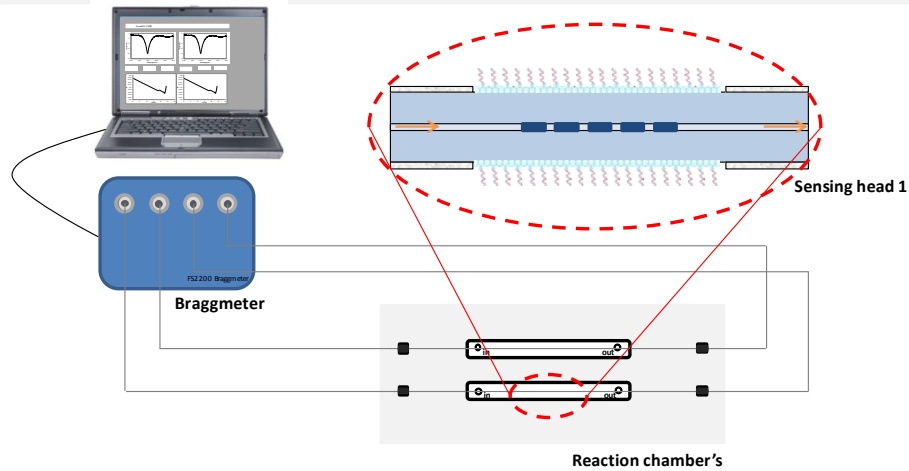
Biorecognition elements:

- DNA
- Aptamer
- Antibody
- Protein
- MIP

Detection of thrombin (10-100 mM)



Genomics and proteomics enabled in the same system



- Laser scanning interrogation Unit FS2200 (FiberSensing Sa)
- Laser scanning unit with 4 channel; Resolution 2.5 pm; 1 sample/s, Peak tracking in real time

System validated in **Genomics**:

- **DNA recognition by hybridization** (vitis vinifera), with single base mismatch selectivity. **No PCR needed.**

Regeneration and specific binding observed in more than 40 cycles

Tool for wine varietal certification

Gonçalves et al "Biosensor for Label-free DNA Quantification based on Functionalized LPGs". Biosensors & Bioelectronics (2016). In Press

- **Detection E. Coli, with aptamer based coating.**
- **Monitoring dCO2 (sensitive polymer layer)**
- **Species identification**

Queirós et al "Evanescent wave DNA-aptamer biosensor based on LPGs for the specific recognition of E. coli outer membrane proteins". Bios.& Bioelect. (2014). 62, 2014, Pages 227–233.

WINEBIOCODE genetic fingerprinting of wine

- Same platform
- Recognition element: DNA
- PCR free, highly specific
- Tool for food certification and much more....
- Optimization: multilayer system



Results

PLL – Poli-L-Lysine coating for optical fiber

Probe – single-strand DNA probe

T1 – probe fully complementary sequence, same bp size

T2 – same bp size as probe but wholly non-complementary

T3 – non complementary in just 1 base, same size, detects SNPs

T4 – non complementary in 6 bases, same bp total

T5 – bp size bigger than probe, contains fully complementary sequence

T6 – same size, just 1 base non-complementary at 5' end

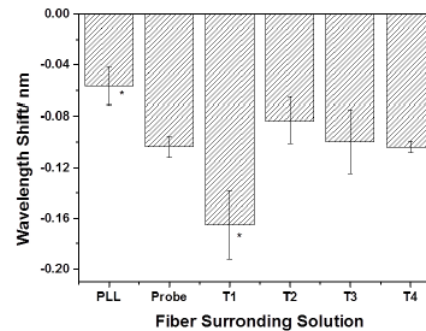
T7 – same size, just 1 base non-complementary at 3' end

T8 – same size, 2 bases non-complementary at 5' end

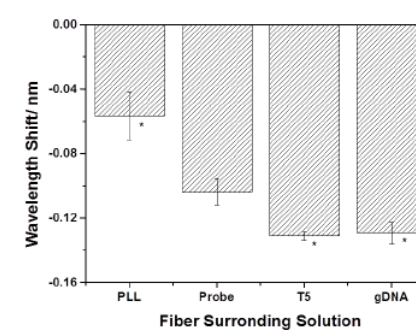
T9 – same size, 2 bases non-complementary at 3' end

gDNA – genomic DNA sample from grapevine – matching probe

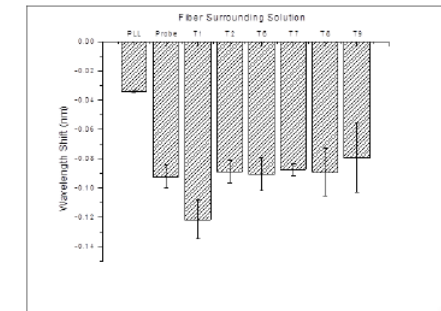
Complementarity



Genomic DNA



Specificity



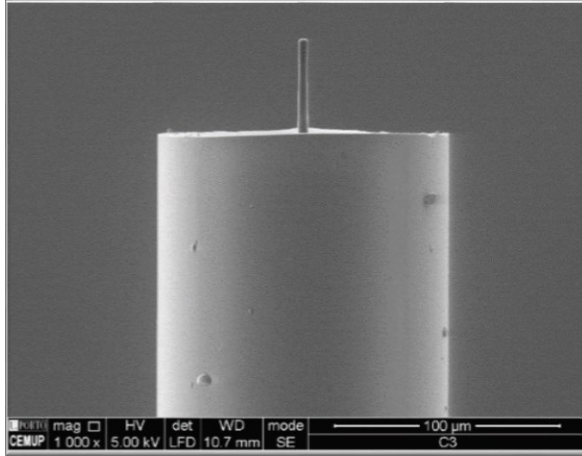
LOD: 60 ± 14 nM

LOQ: 199 ± 14 nM



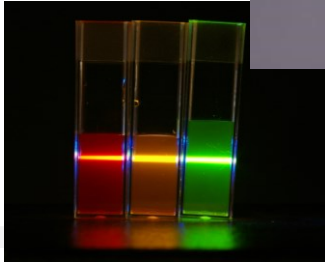
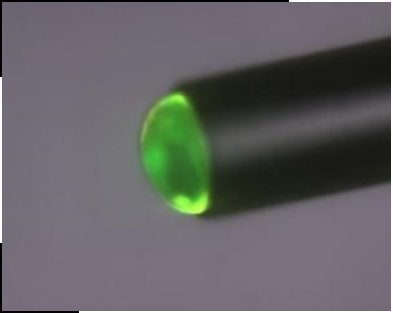
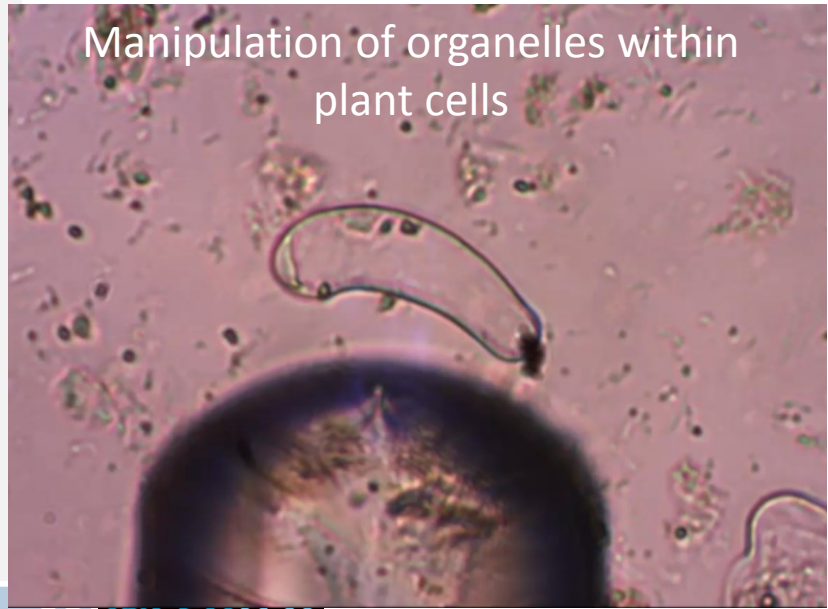
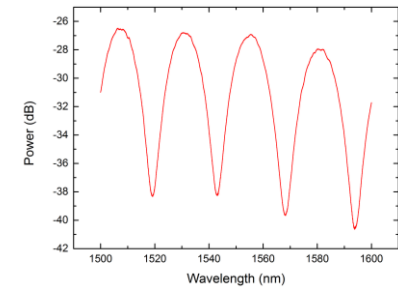
Single Cell sensing and manipulation

Self assembled Polymeric tips



Fast fabrication of microlenses
Optical trapping with fiber optic
Polymer doping with sensing agents

Towards analytical tweezers



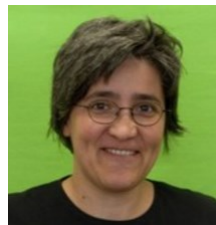
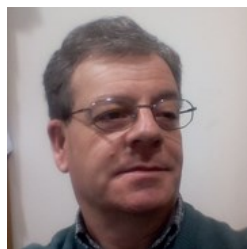
Optical technologies coupled to optical fibers are enable advanced sensing systems with suitable features for harsh oceanic environments.

Multipoint and distributed sensing ability, combined with information and energy transfer capabilities, make it a cornerstone of widespread environmental monitoring systems.

Complexity and challenges increase when going from physical to chemical and biosensor (biofouling, long term stability...)

Acknowledgments

- ❑ Paulo Marques (Micro fabrication)
- ❑ Pedro Jorge (Biosensing)
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- ❑ Carla Rosa (imaging)
- ❑ Ariel Guerreiro (modelling)
- ❑ Luis Coelho (Nano Fabrication / biosensing)
- ❑ José Manuel Almeida (Nano Fabrication / biosensing)
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- ❑ Rita Ribeiro (Optical trapping)
- ❑ Ivo Nascimento (electromagnetic sensors)
- ❑ João maia (3D microfabrication)
- ❑ Vitor Amorin (3D microfabrication)
- ❑ Duarte Viveiros (3D microfabrication)
- ❑ Many others...



COMPETE

PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE





Enjoy Portugal!

