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CHT Centre for Healthcare Technologies

Optical fibre sensing at the interface between tissue and orthosis or prosthesis

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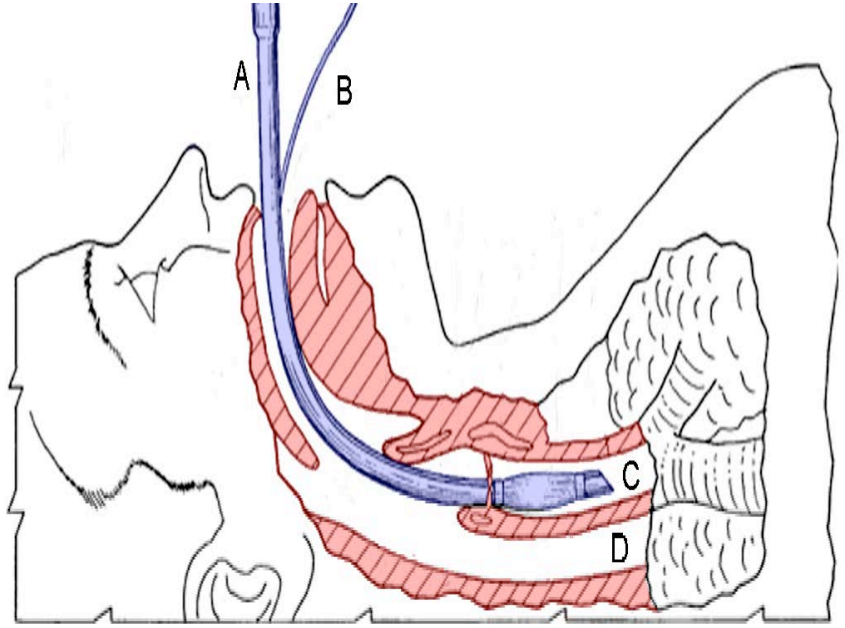
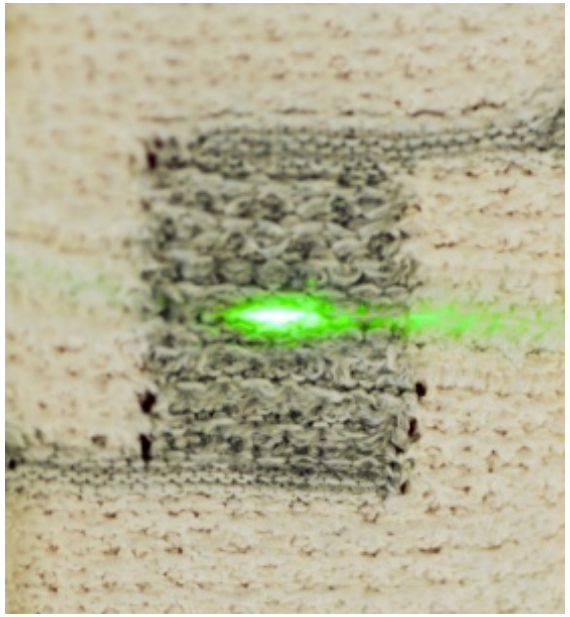
Overview

- Brief overview of optical fibre sensors
- Monitoring carbon dioxide as a biomarker of tissue breakdown
- Monitoring pressure and shear

Both a work in progress…

Why optical fibre sensors?

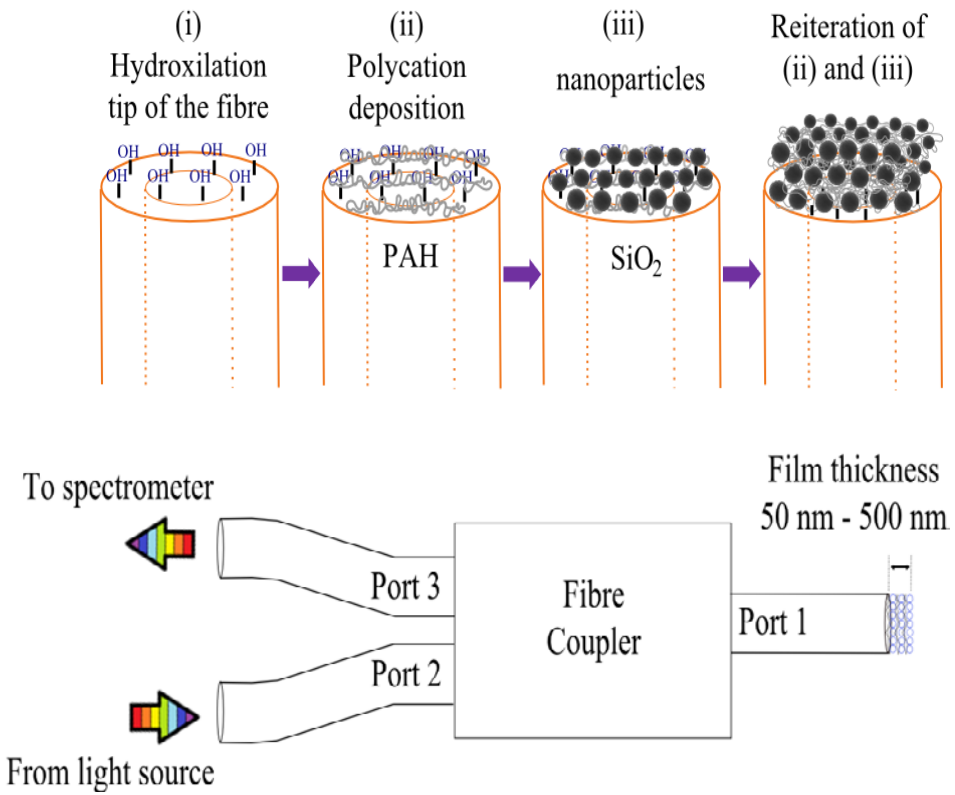


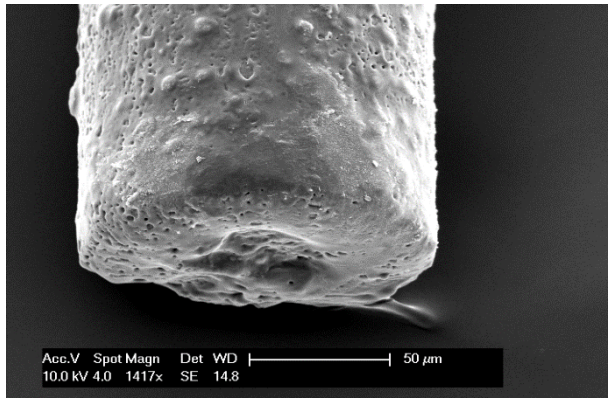


- Lightweight, thin (125μm), flexible
- Can be easily incorporated into a medical device e.g. catheter, wound dressing
- Versatile - with appropriate functionalisation, can be used to measure a range of physical and biochemical parameters

Correia *et al* 2018 J. Opt. 20 073003

Intensity based sensing (humidity)





Sensitive layer at tip that changes colour or refractive index

Correia *et al* 2018 J. Opt. 20 073003

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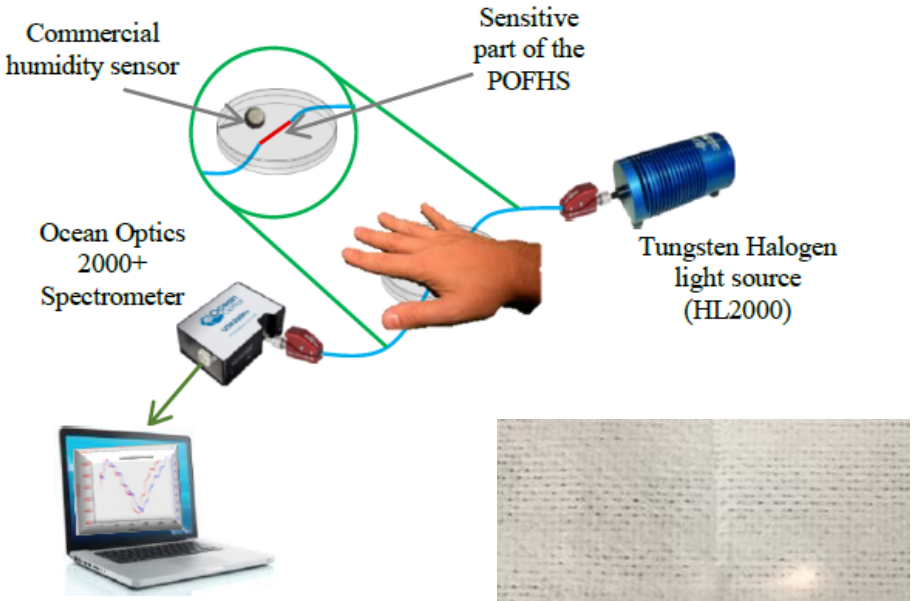

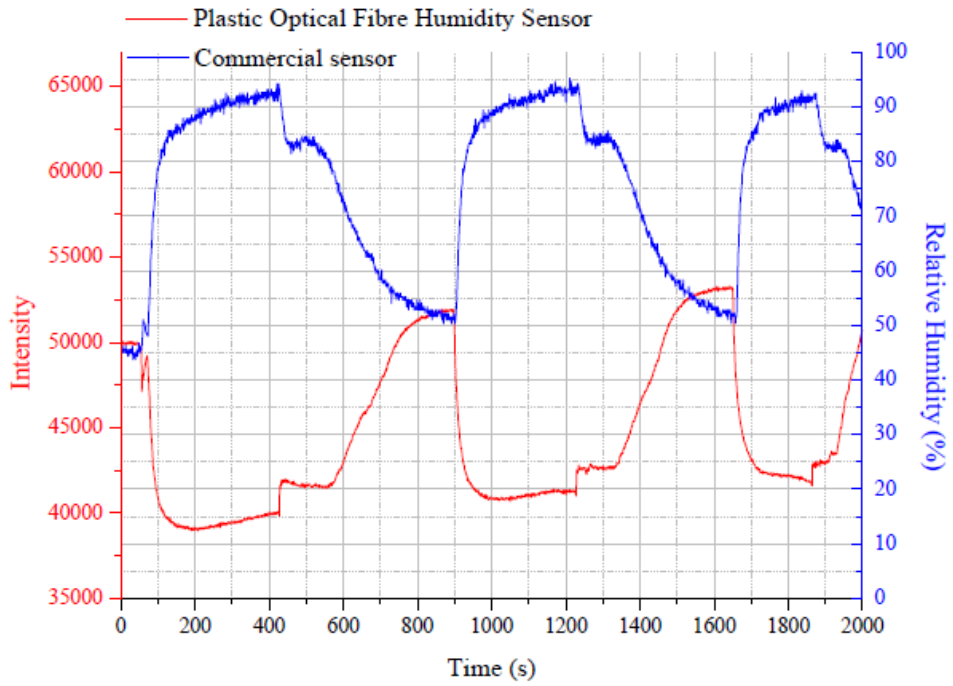

Humidity sensing, skin measurements, wound microenvironment

Gomez *et al*, Sensors and Actuators B, 254:887-895 (2018).

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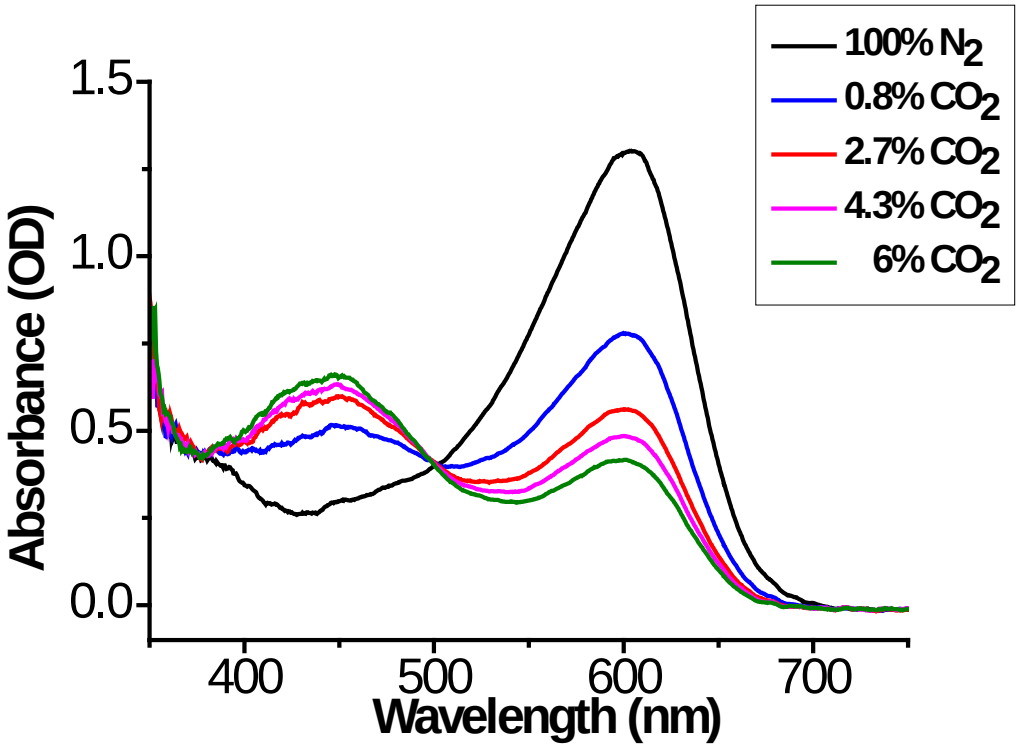
Both a work in progress…

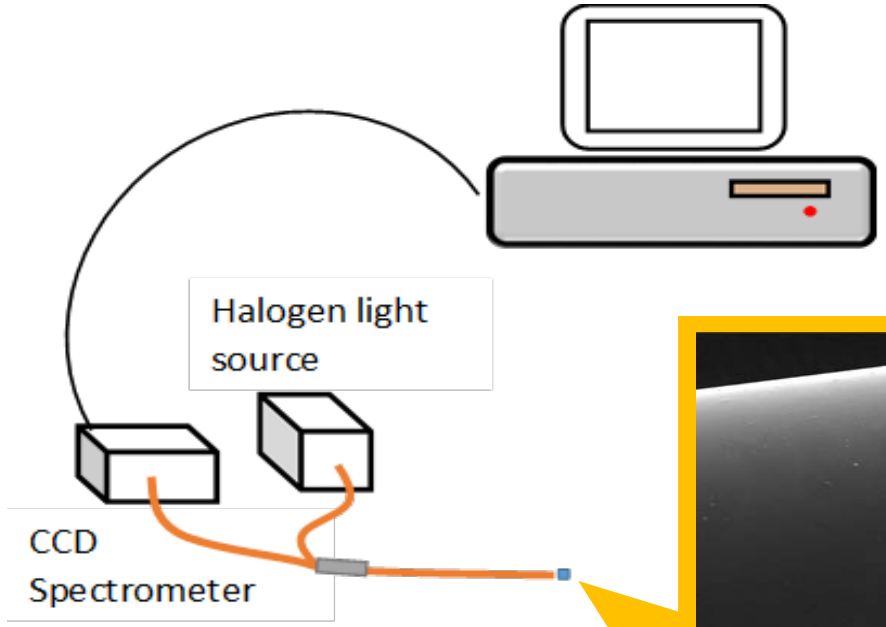
Intensity based sensing (carbon dioxide)

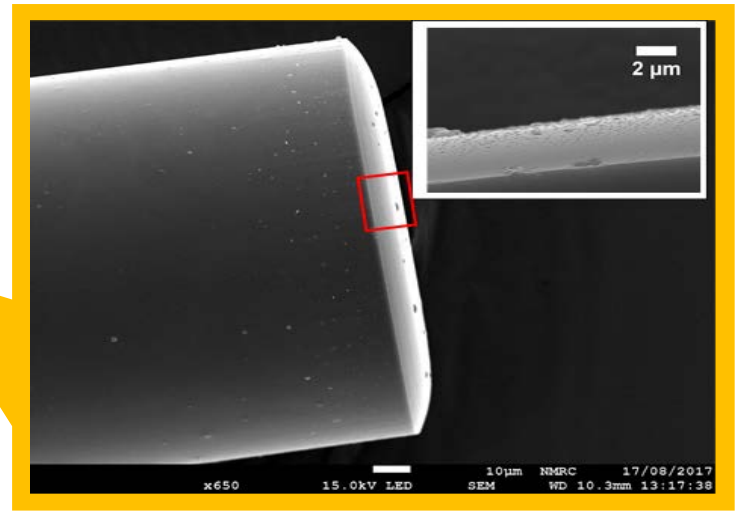
Mirtaheri, Worsley, Gjovaag, Bader. **A Review of the Role of the Partial Pressure of Carbon Dioxide in Mechanically Loaded Tissues: The Canary in the Cage Singing in Tune with the Pressure Ulcer Mantra.** Annals of Biomedical Engineering (2014)

'*Future challenges involve the development of technological solutions to measure the PCO_2 in affected tissue continuously and non-invasively without interfering the metabolism or perfusion of the tissue. Therefore, further research is needed to find "clinically friendly" methods to measure carbon dioxide in tissue.*'

Sensor set-up



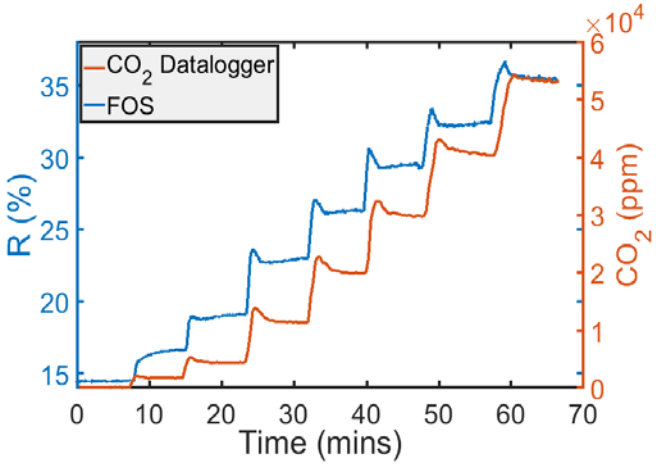


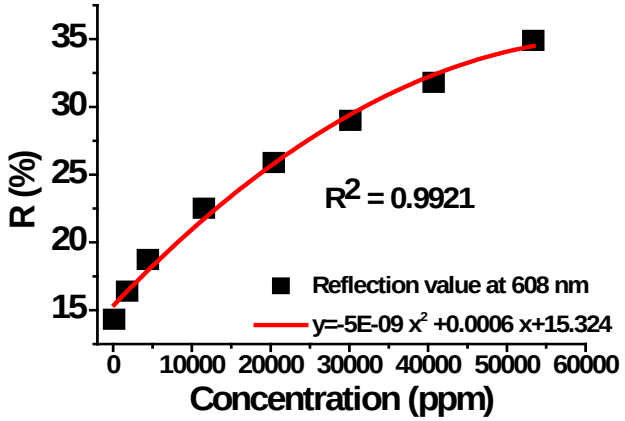


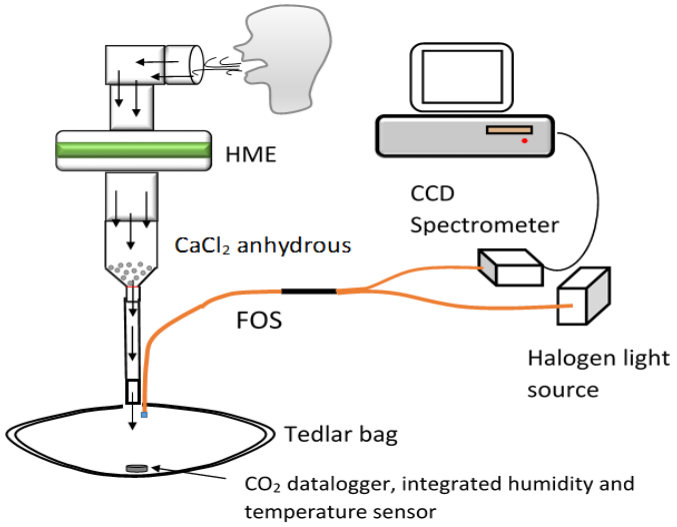
Absorption peak : 480 nm ↑
608 nm ↓

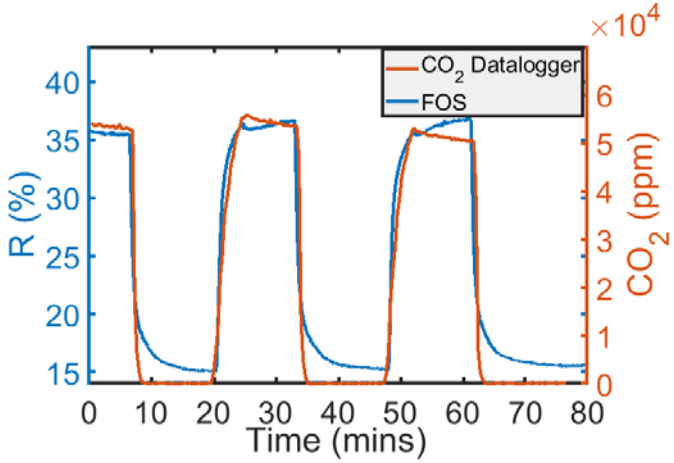
Liu *et al*, Sensing and Bio-Sensing Research, 22, 100254 (2019).

Intensity based sensing (carbon dioxide)









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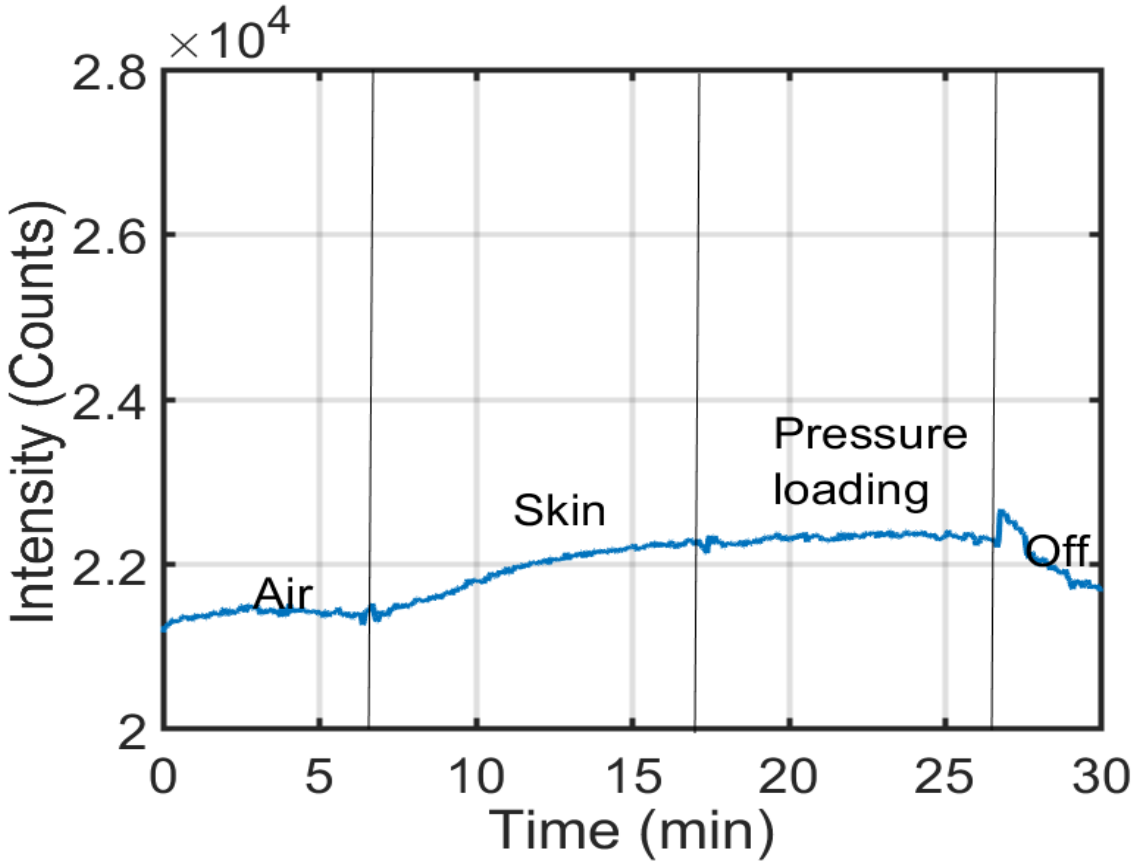
Intensity based sensing (carbon dioxide)



Pressure loading (~15 kPa), no change is observed
Keep working on….
Preliminary test, the corresponding CO_2 concentration is not converted.

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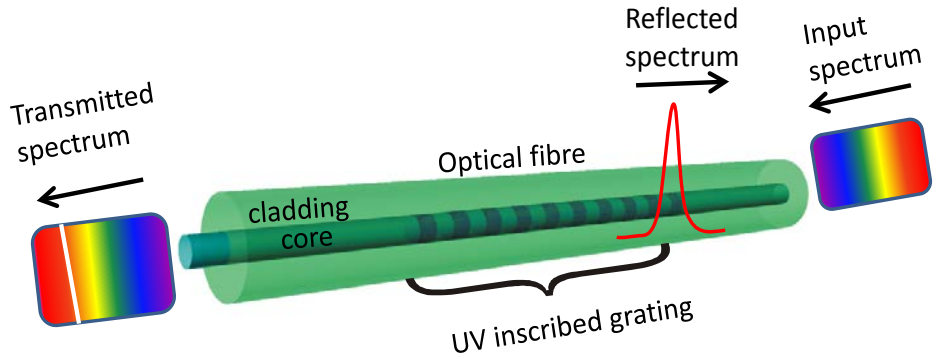
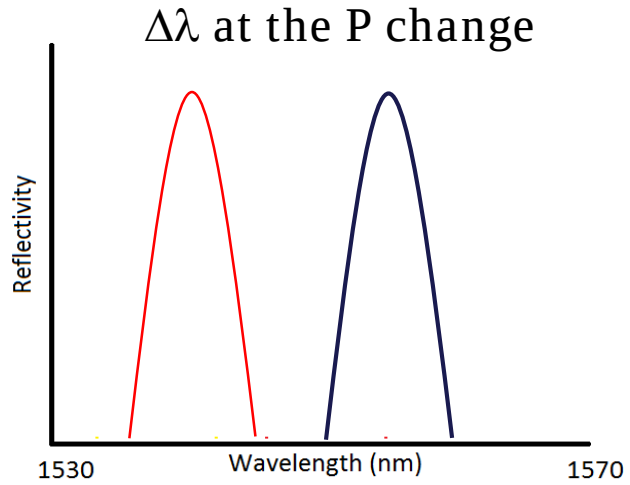
Grating based sensing (physical measurement)

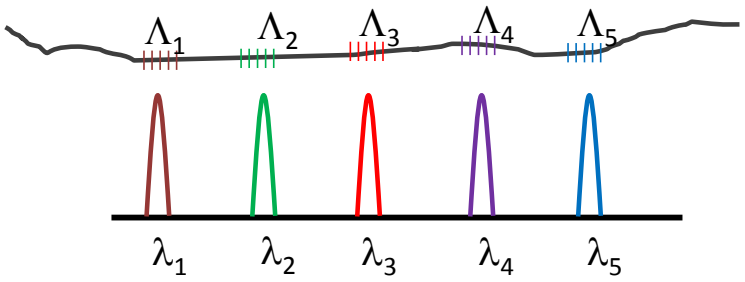




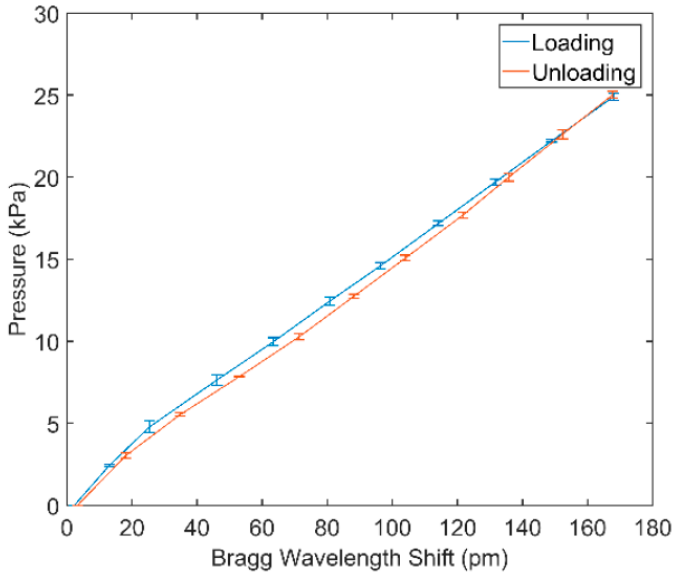
$$\lambda_{\text{Bragg}} = 2\eta_{\text{eff}}\Lambda$$

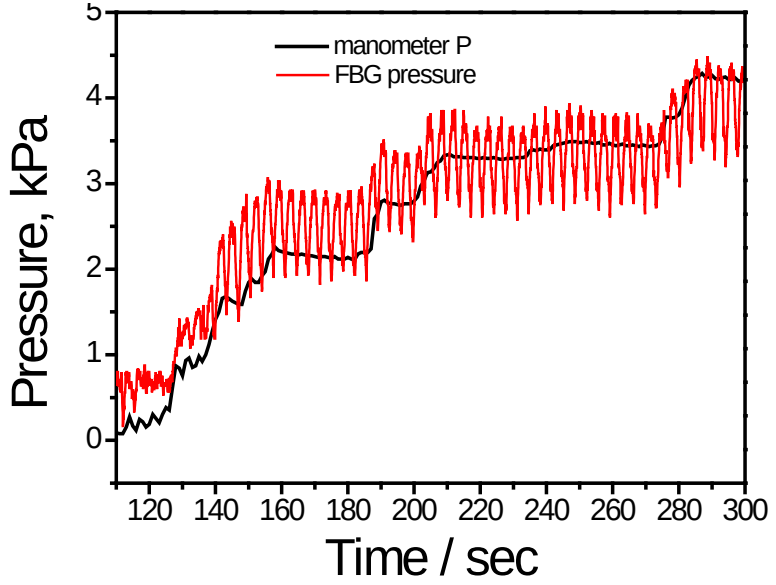
When period of grating changes wavelength shifts

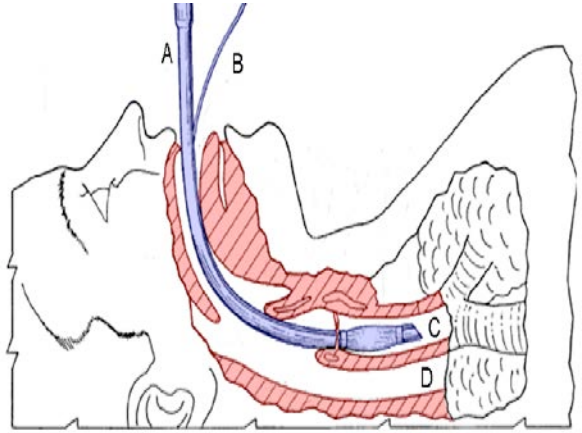
Pressure, temperature and strain measurements

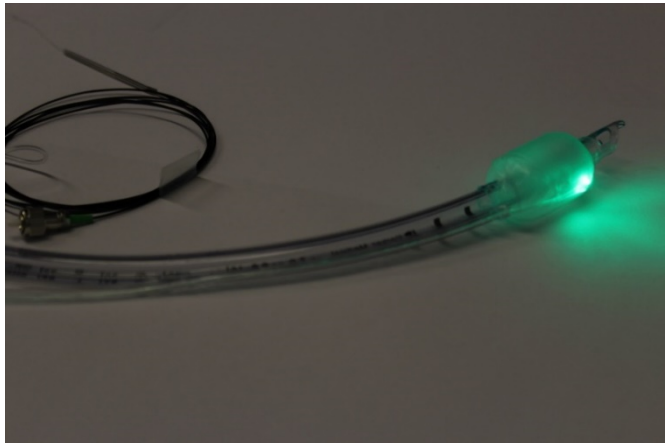


Grating based pressure measurement



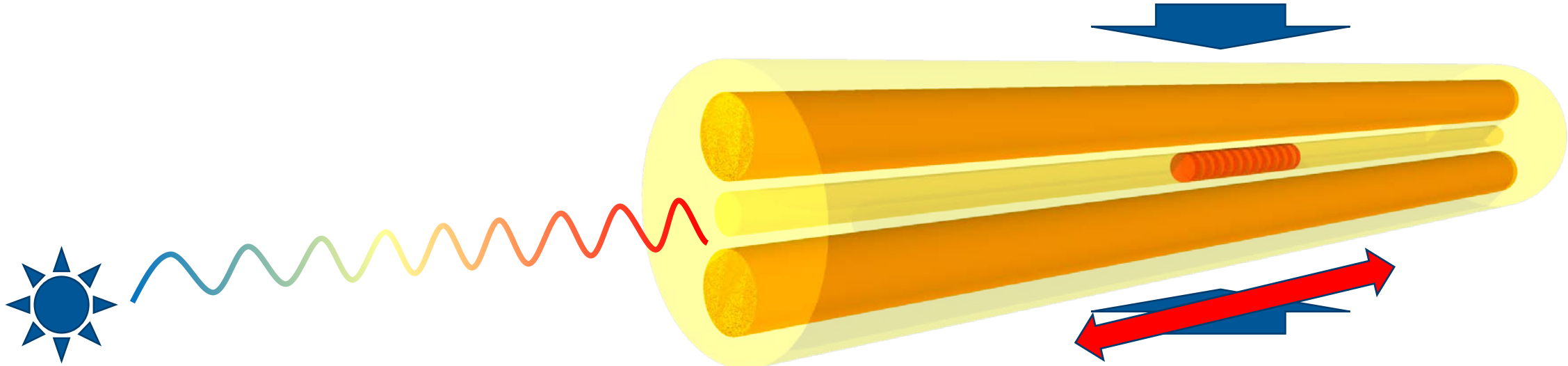


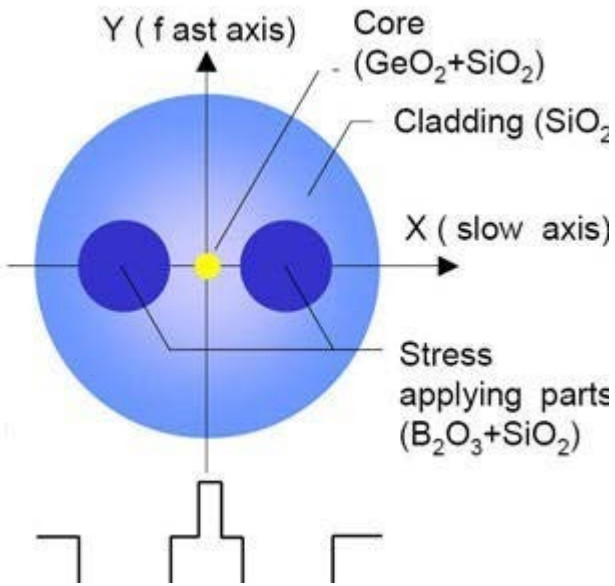




But not sensitive to shear

Grating based pressure and shear measurement



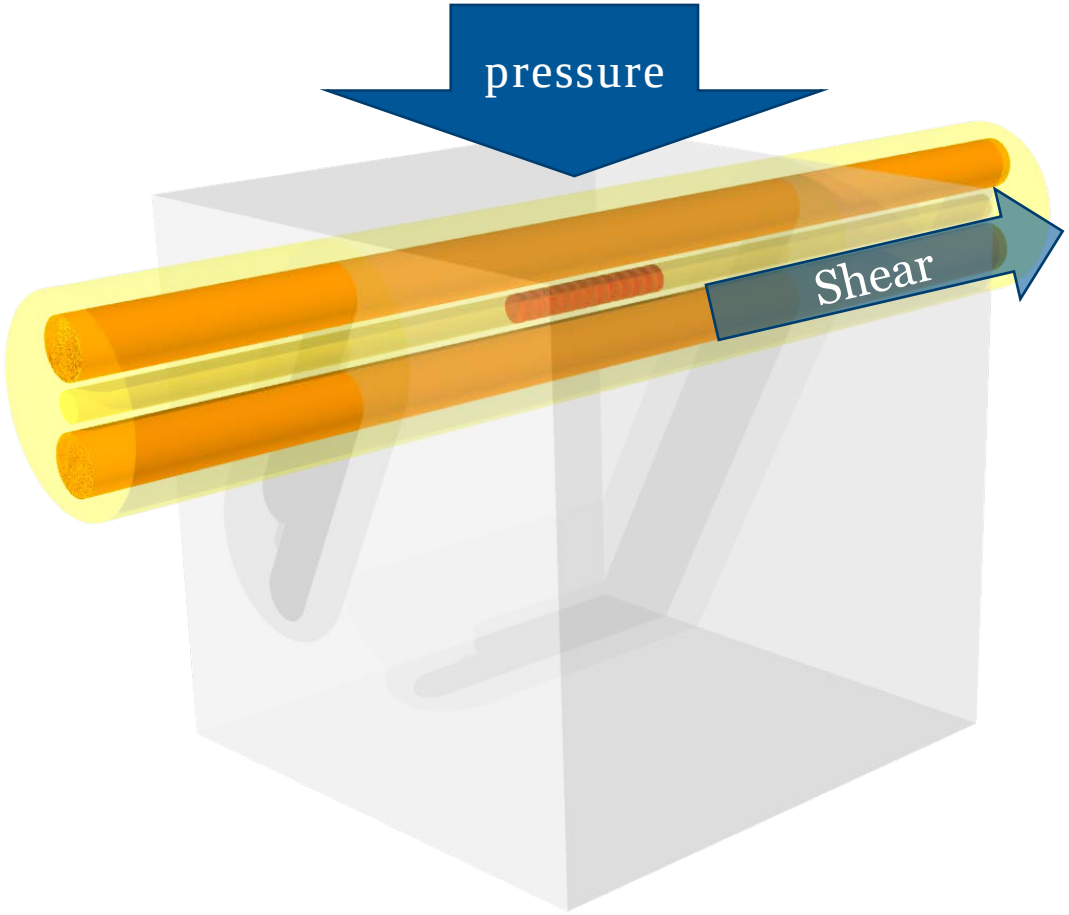


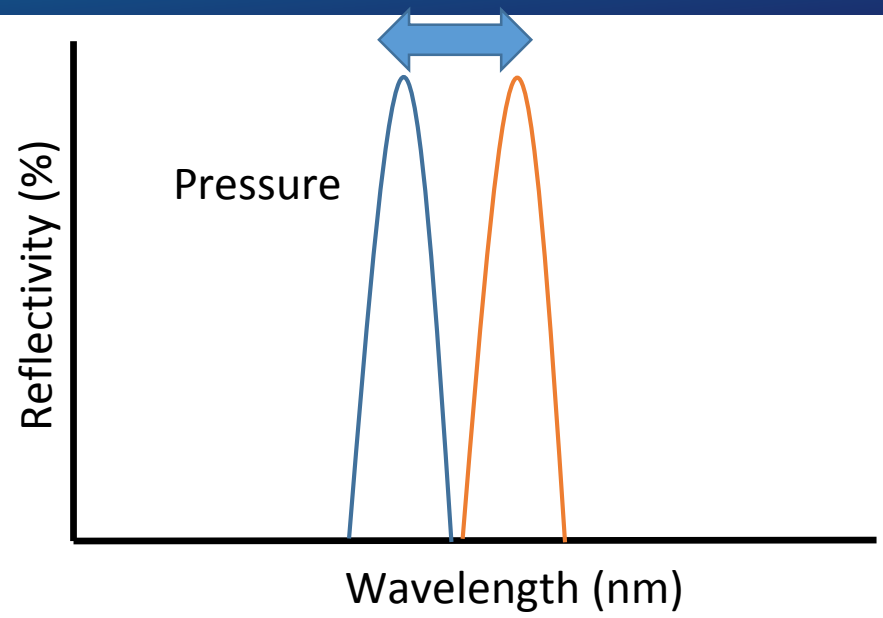
A polarization maintaining (HiBi) fibre allows 2 polarization states to propagate in 1 fibre

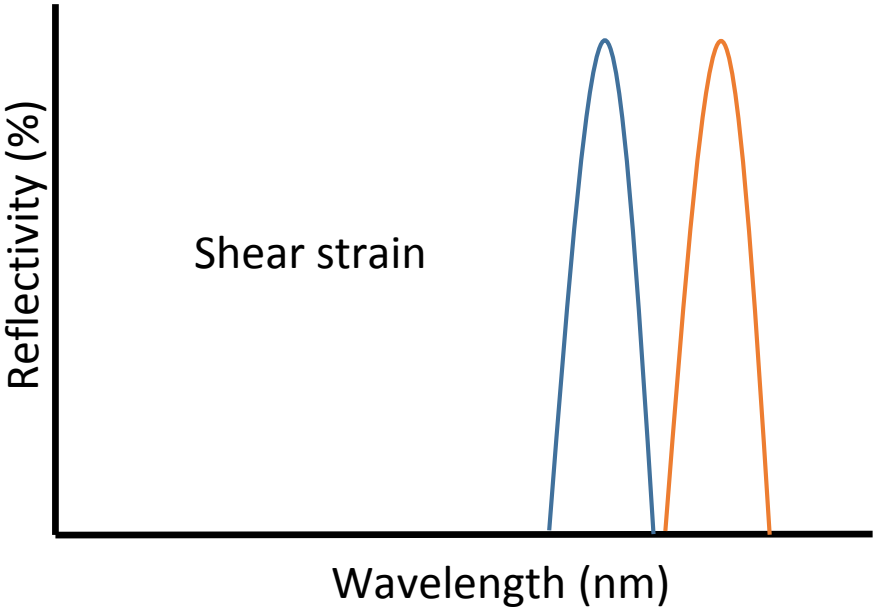
These give different reflected wavelengths from a grating (2 peaks)

Provides a response where pressure and shear can be decoupled.

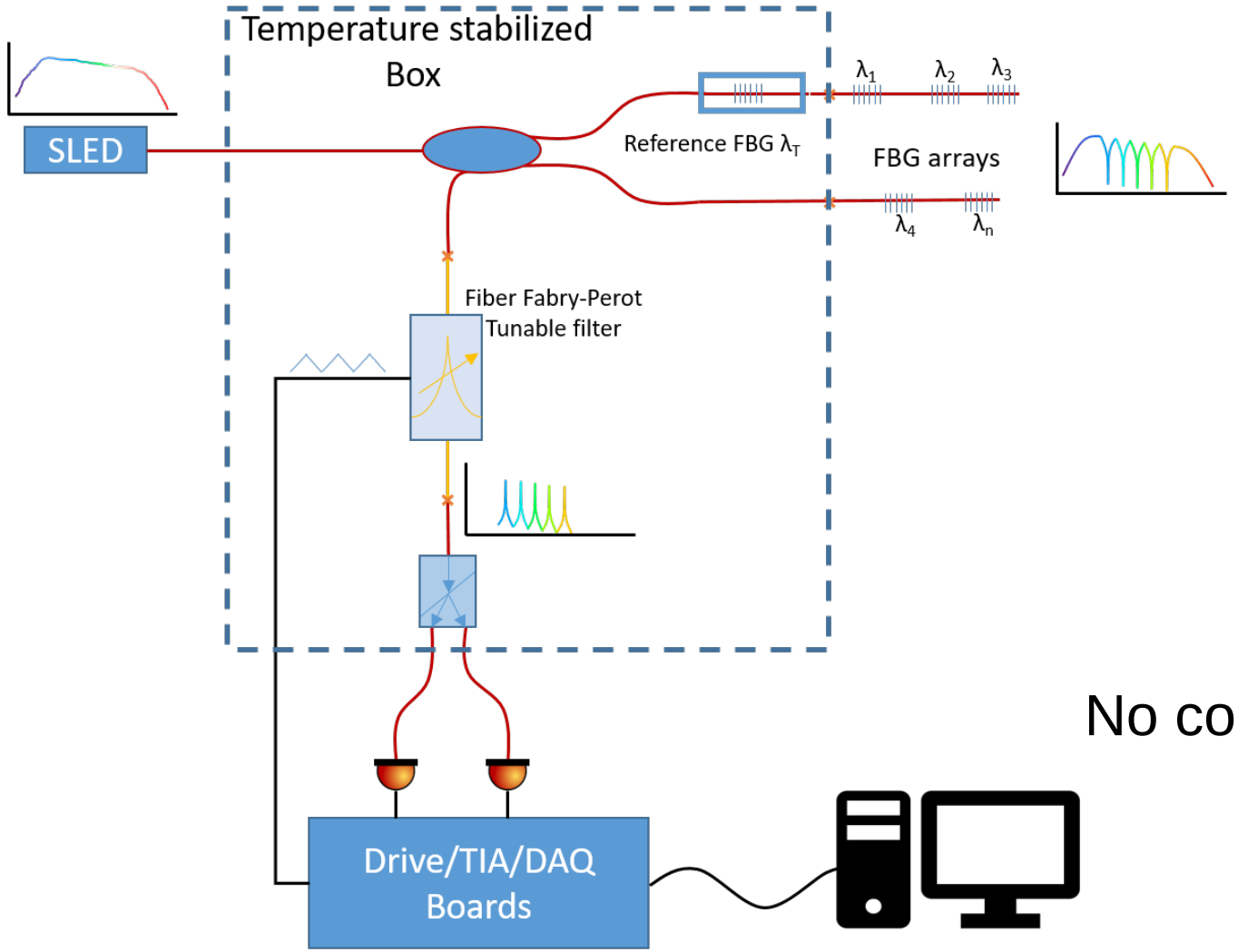
Grating based pressure and shear measurement







Grating based pressure and shear measurement



Polarisation maintaining fibre (PM)

Single mode fibre non-PM

Polarisation maintained fibre coupler

Fibre Fabry-Perot Tunable filter

Polarisation fibre splitter

Photodiode

Temperature stabilized Box

No commercially available interrogator

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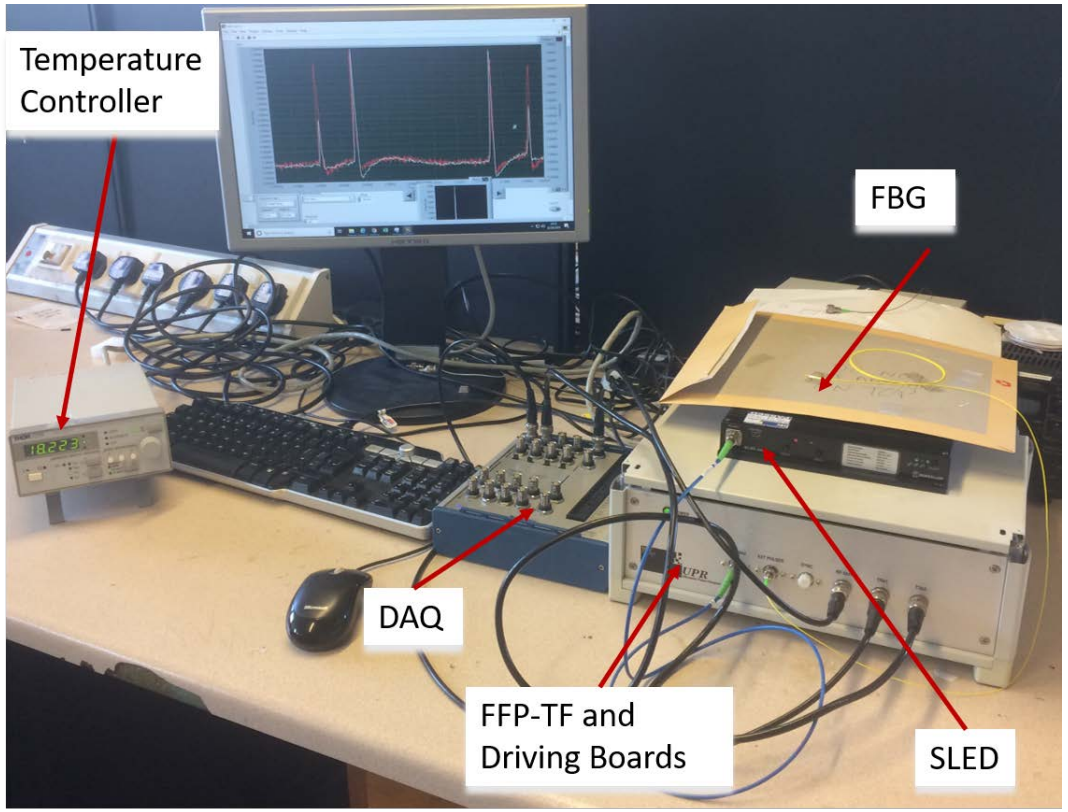
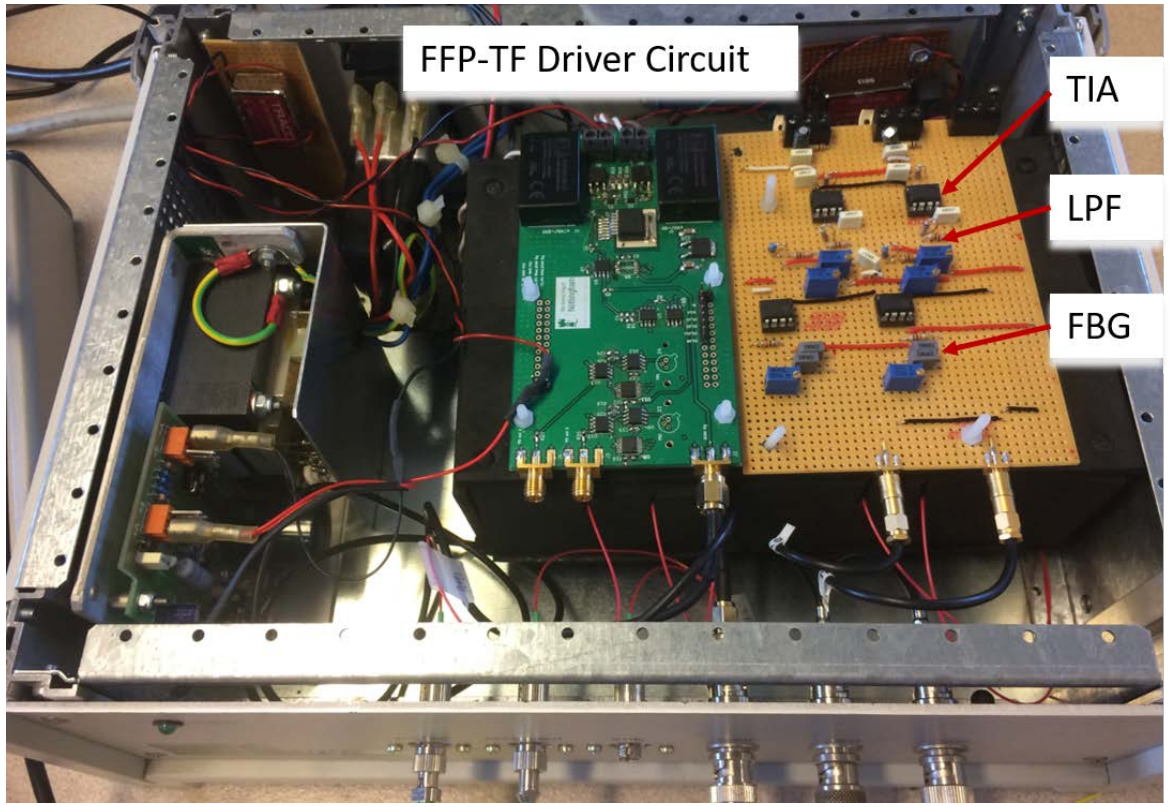
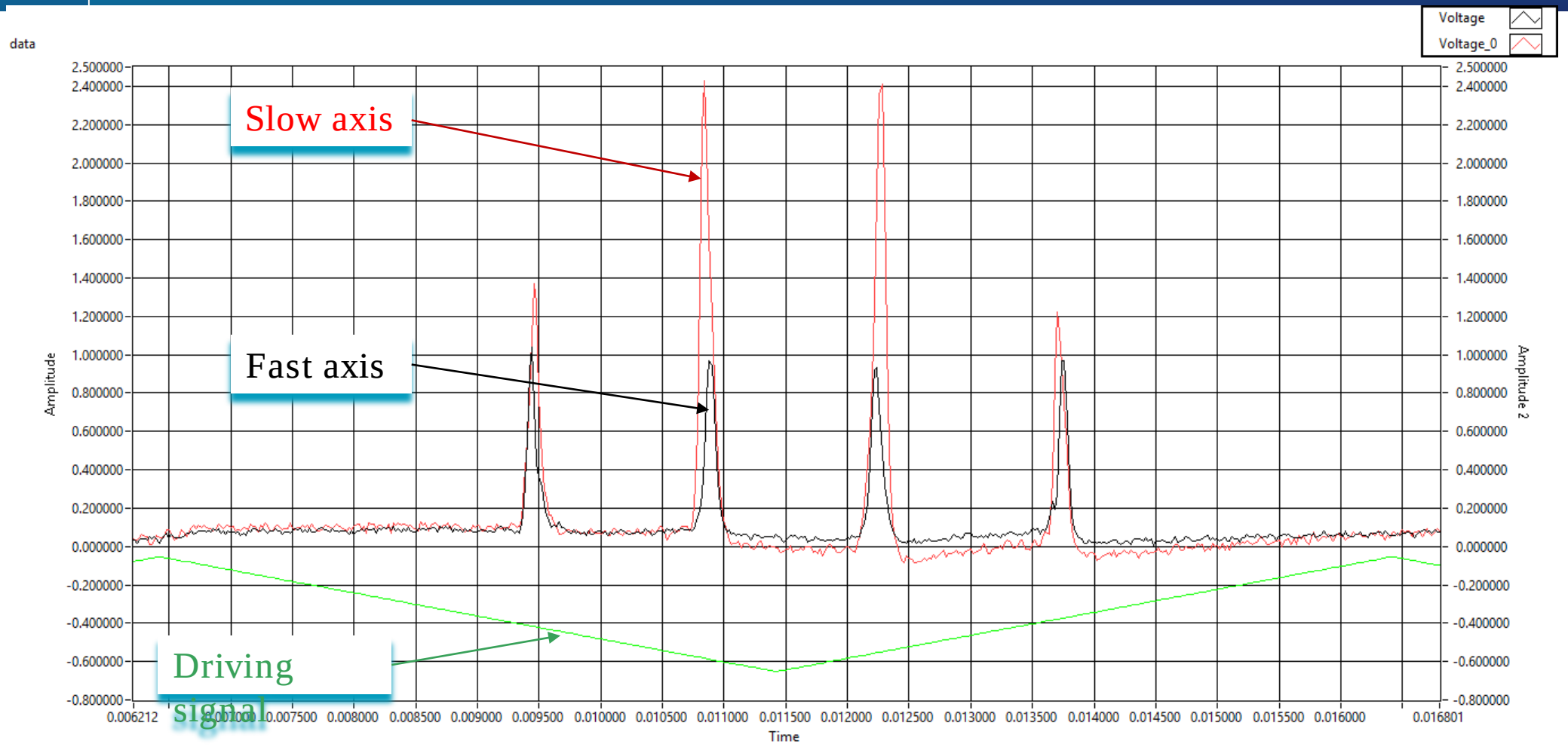
Grating based pressure and shear measurement





Grating based pressure and shear measurement



Amplitude of signals in 2 polarization states as filter is scanned
Peaks correspond to different wavelengths in 2 different channels

Summary

- Brief overview of optical fibre sensors
- Monitoring carbon dioxide as a biomarker of tissue breakdown
  - Optimise gas capture
- Monitoring pressure and shear
  - Apply controlled pressure and shear
  - Develop platform for under foot measurement

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Thankyou

EPSRC Engineering and Physical Sciences Research Council

THE ROYAL SOCIETY

MRC Medical Research Council

NHS National Institute for Health Research

European Union European Regional Development Fund

Footfalls & Heartbeats

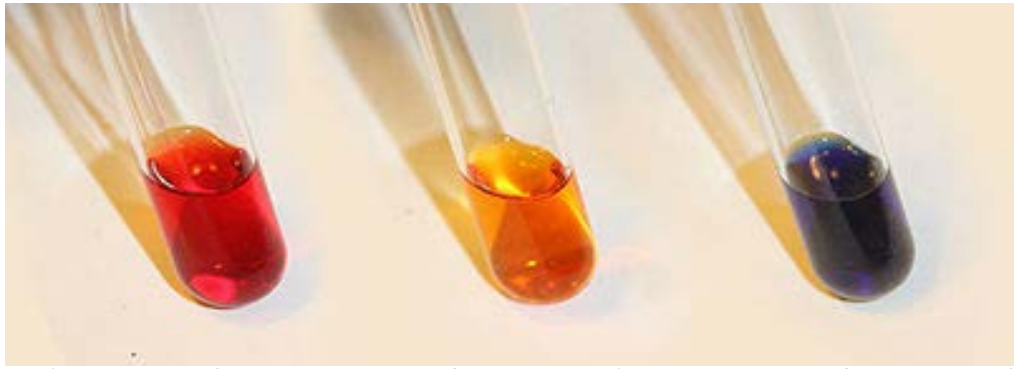
Nottingham University Hospitals NHS Trust

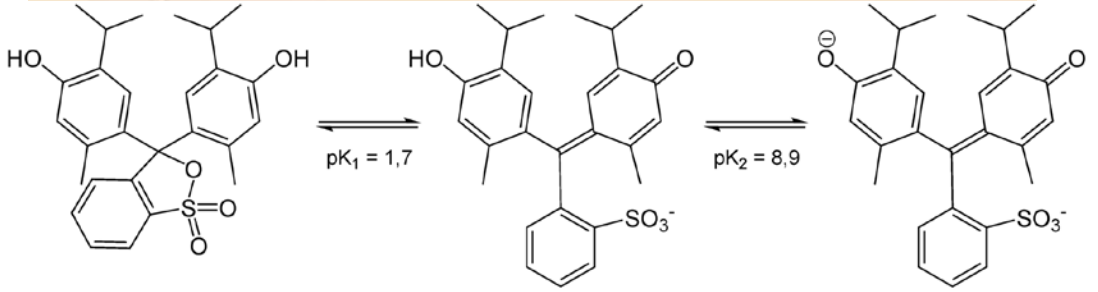
Fibre-Optic CO_2 sensor (FOS): sensing mechanism

pH sensitive dye: thymol blue

Thymol blue (pH indicator)	
below pH 1.2	*above pH 2.8*
1.2 ⇌	2.8

Thymol blue (pH indicator)	
below pH 8.0	*above pH 9.6*
8.0 ⇌	9.6





CO_2 gas phase does not have the proton.
Dissolved CO_2 produce the H^+

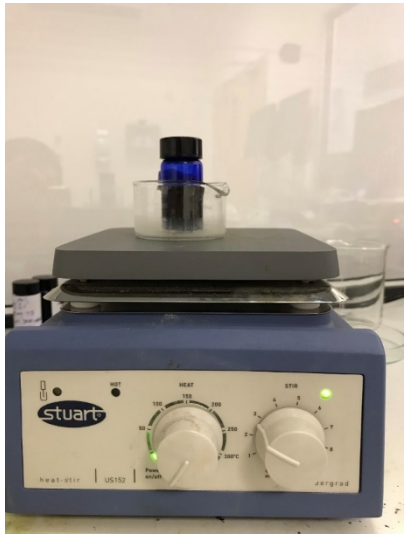
$$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-$$

A phase transfer quanternary ammonia hydroxide (QOH) is used to dissolve CO_2
And maintain the pH of sensitive layer

$$QOH + HT\ (red) \rightleftharpoons \{Q^+T^-\ \cdot xH_2o\}\ \text{(blue)}$$

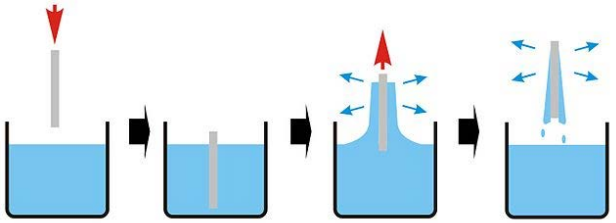
$$\{Q^+T^-\ \cdot xH_2o\}(\text{blue}) + CO_2 \rightleftharpoons Q^+HCO_3^-\ \cdot (x-1)H_2o + HT(yellow)$$

FOS fabrication



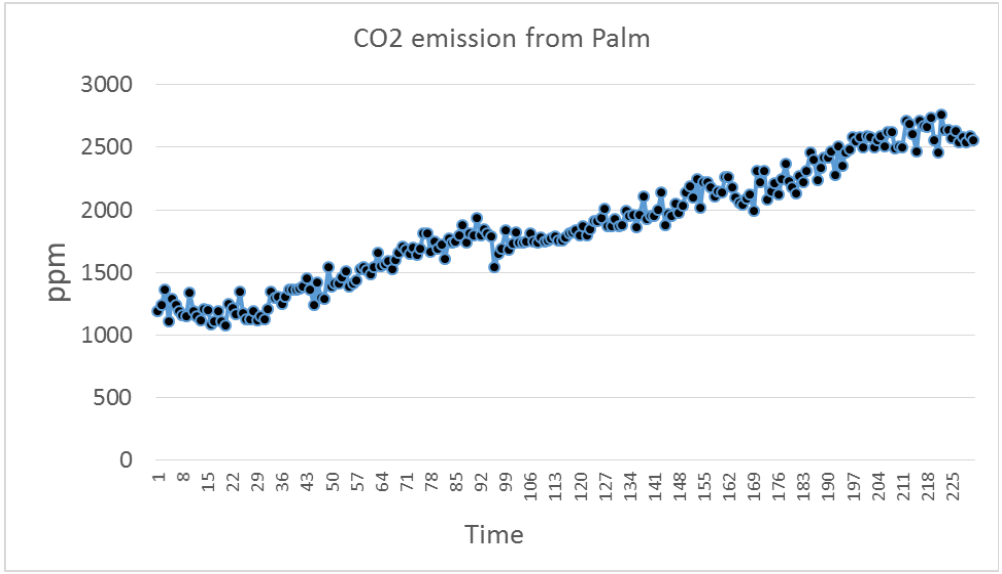
Coating solution preparation (sol-gel transition)

Optical fibre dip coating process



Drying & Annealing

Intensity based sensing (carbon dioxide)



Hand in bag