POLITECNICO DI TORINO

MAPS

Advances in bioresorbable optical fibers for light delivery and sensing

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Materials for Photonics and Sensing

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Part of GLANCE group:

GLANCE
GLASSES, CERAMICS AND COMPOSITES

MAPS: Research topics

1. Optical materials
2. Multifunctional optical fibers
3. Nano/micro structures
4. Optical based sensors

Overview

- Bioresorbable optical fibres:
  - Design, fabrication and characterization
  - Past activities
- Femtosecond laser writing of structures:
  - On single mode optical fibres
  - On planar samples
- Testing of the CPG fibres as probe for pH sensing in physiological environment
- Future developments

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Why bioresorbable fibres?

CONCEPT

- Combine in a single material optical and biomedical functionalities

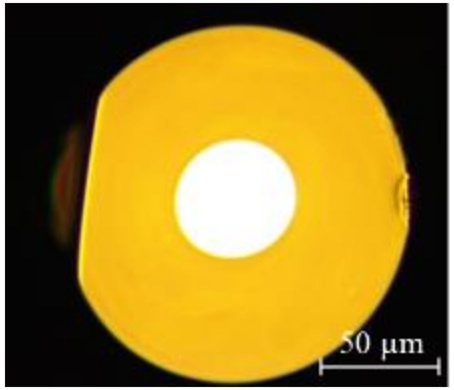
AIM

- Develop phosphate optical fibers with the following properties:
  - Optically transparent (extended to UV) and biocompatible
  - Biodegradable and soluble in biological fluids (bio-resorbable)
  - Suitable for fiber drawing

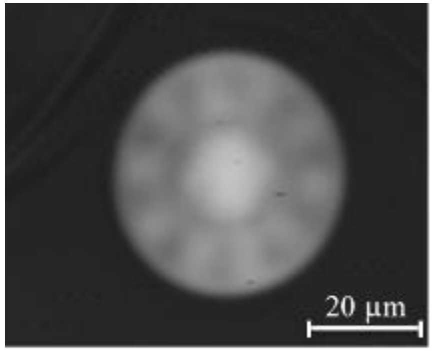
Calcium Phosphate Glass (CPG) fibers

Multi-mode fiber

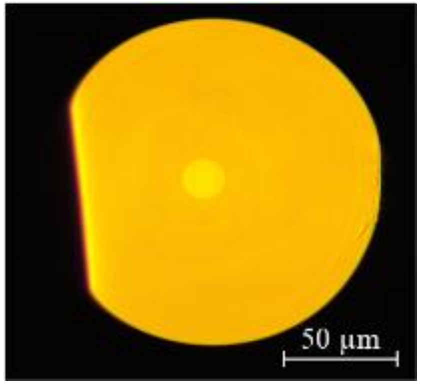
Core glass	BPh1
Cladding glass	BPh4
Core diameter	45 µm
Fiber diameter	125 µm



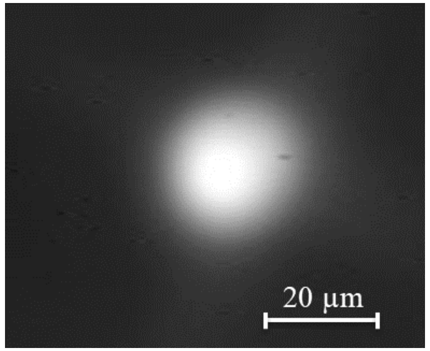
Loss at 1300 nm	6 dB/m
Loss at 633 nm	14 dB/m
Numerical Aperture	0.15



Single-mode fiber



Core glass	BPh1
Cladding glass	BPh2
Core diameter	15 µm
Fiber diameter	120 µm

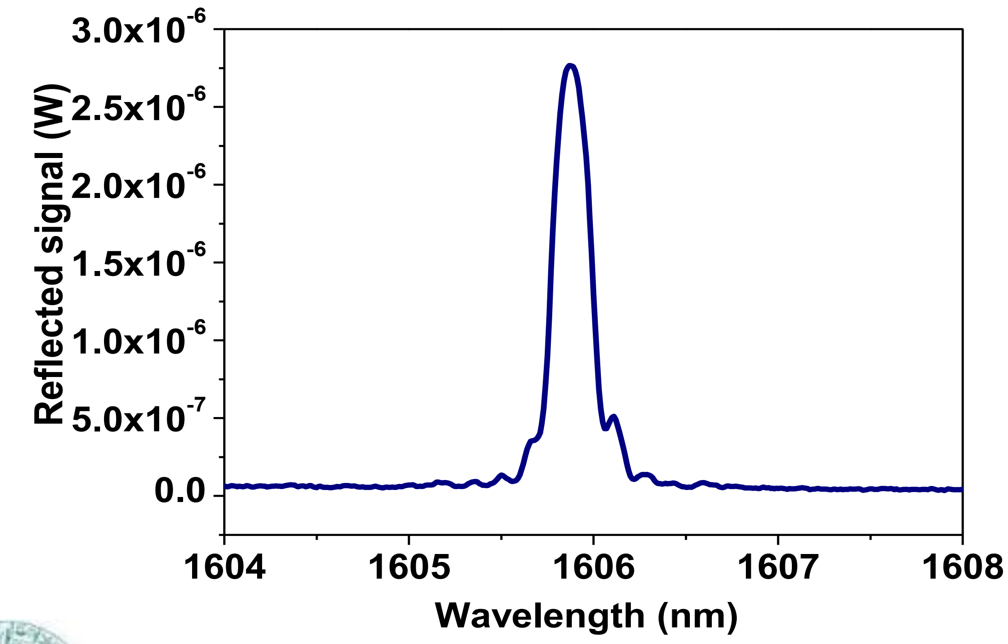


Loss at 1300 nm	2 dB/m
Loss at 633 nm	5 dB/m
Numerical Aperture	0.08

E. Ceci-Ginistrelli *et al.*, *Opt. Mater. Express* **2016**, 6, 2040

Past activities (I): UV laser written FBGs

- ArF excimer laser @193 nm, 108 mJ/cm^2 pulse energy density
- 100 min inscription, accumulated energy density ~7 kJ/cm^2
- Well defined symmetric 6 dB FBG



STSM 2016: POLITO to FORTH

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M. Konstantaki et al., Proc. ICTON 2016

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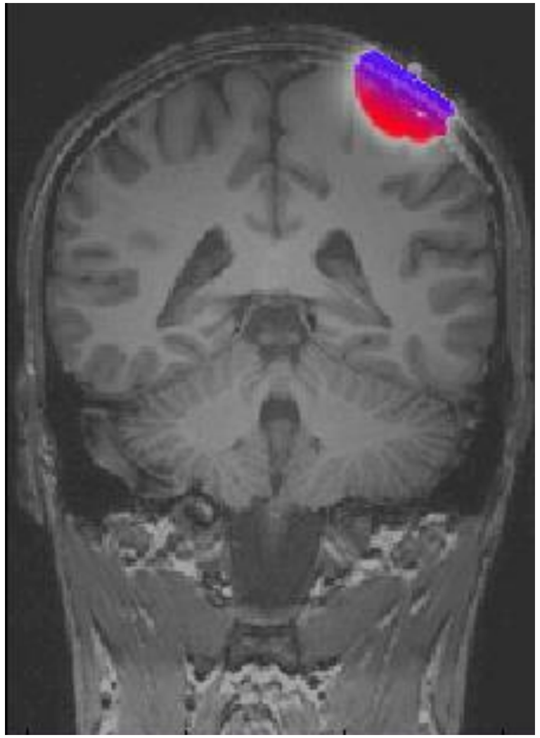
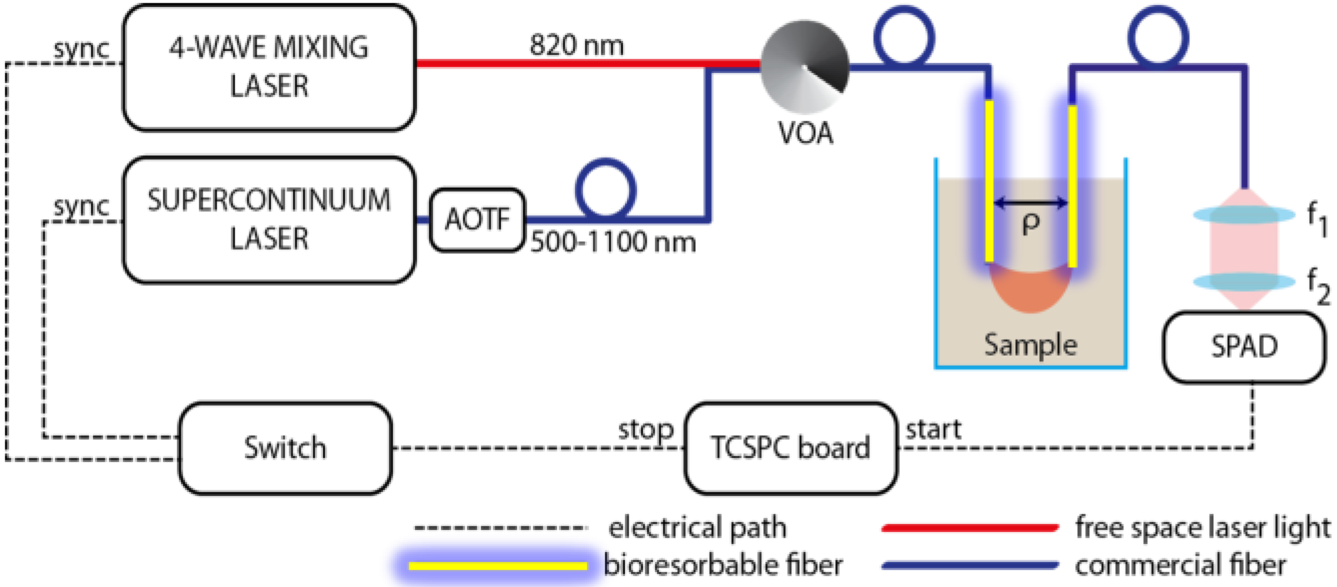
D. Pugliese et al., submitted Opt. Lett.

Collaboration with S. Pissadakis and M. Kostantaki (FORTH, Greece)

Past activities (II): application for TD-DOS

- **First time use** of bioresorbable fibres for TD-DOS: high NA fibers (50, 100 and 200 µm core diameters) were fabricated and tested





- Good dynamic range and narrow temporal response, without spurious effects
- Absorption and scattering coefficients spectra of a chicken breast: fingerprint of the main tissue constituents detected

Collaboration with A. Pifferi's group (POLIMI, Italy)

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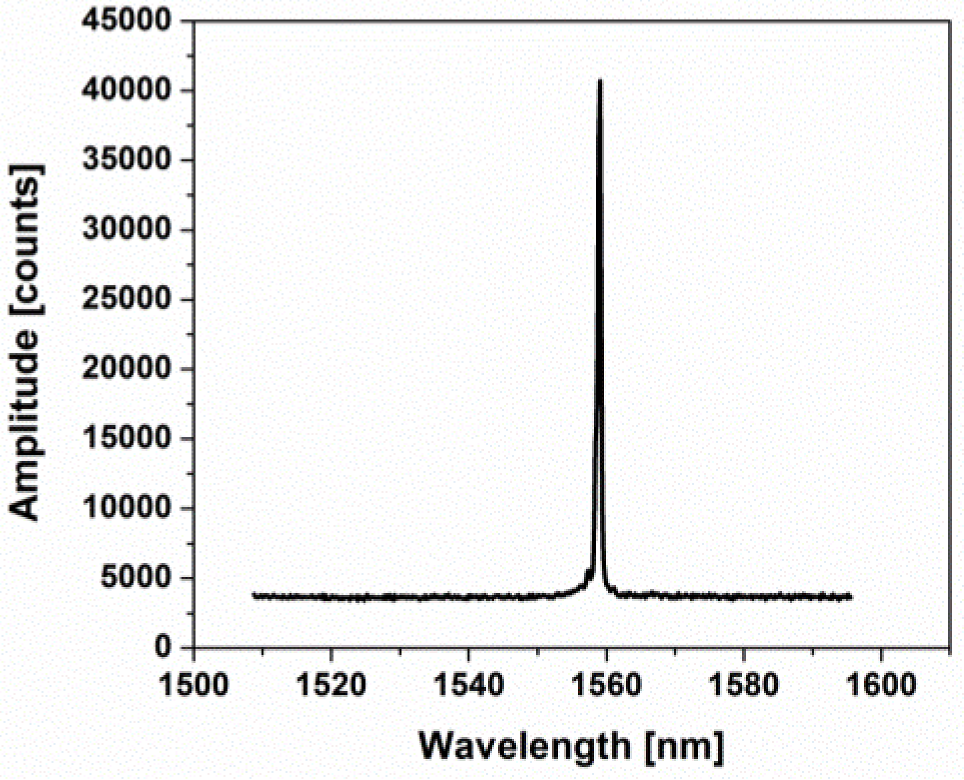
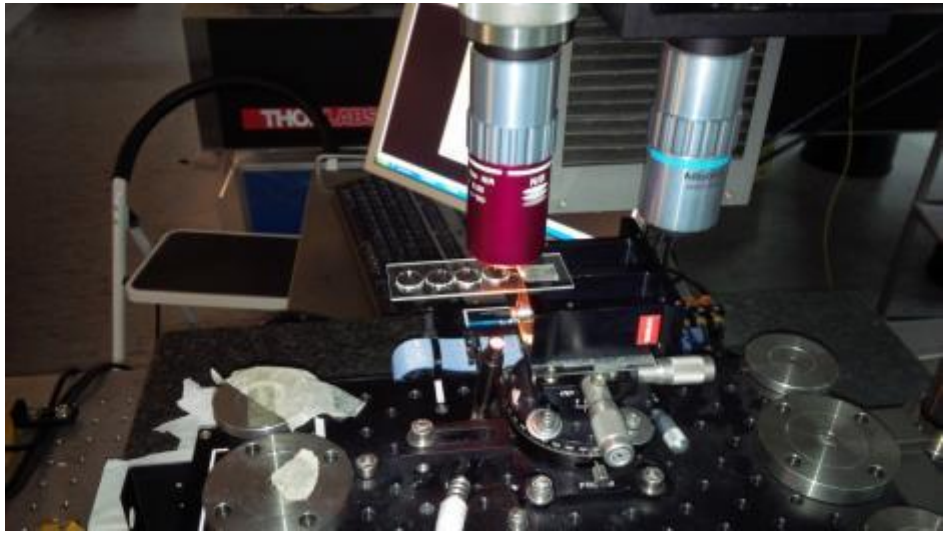
Femtosecond laser writing of structures: on single mode optical fibers

- femtosecond laser system (HighQ femtoREGEN^{TM}IC 355) @517 nm
- 220-fs pulse duration, 1-kHz repetition rate
- FBG written to operate at 1560, grating period ~ 2 µm, 1000 planes

Fiber diameter

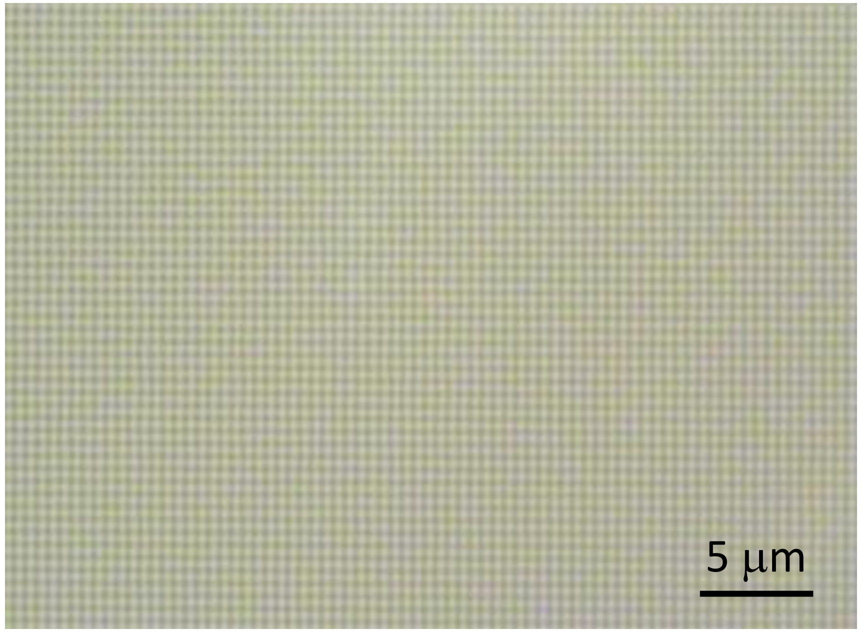


Femtosecond laser writing of structures: on planar samples



Set-up used for the inscription of periodic structures in planar glass samples

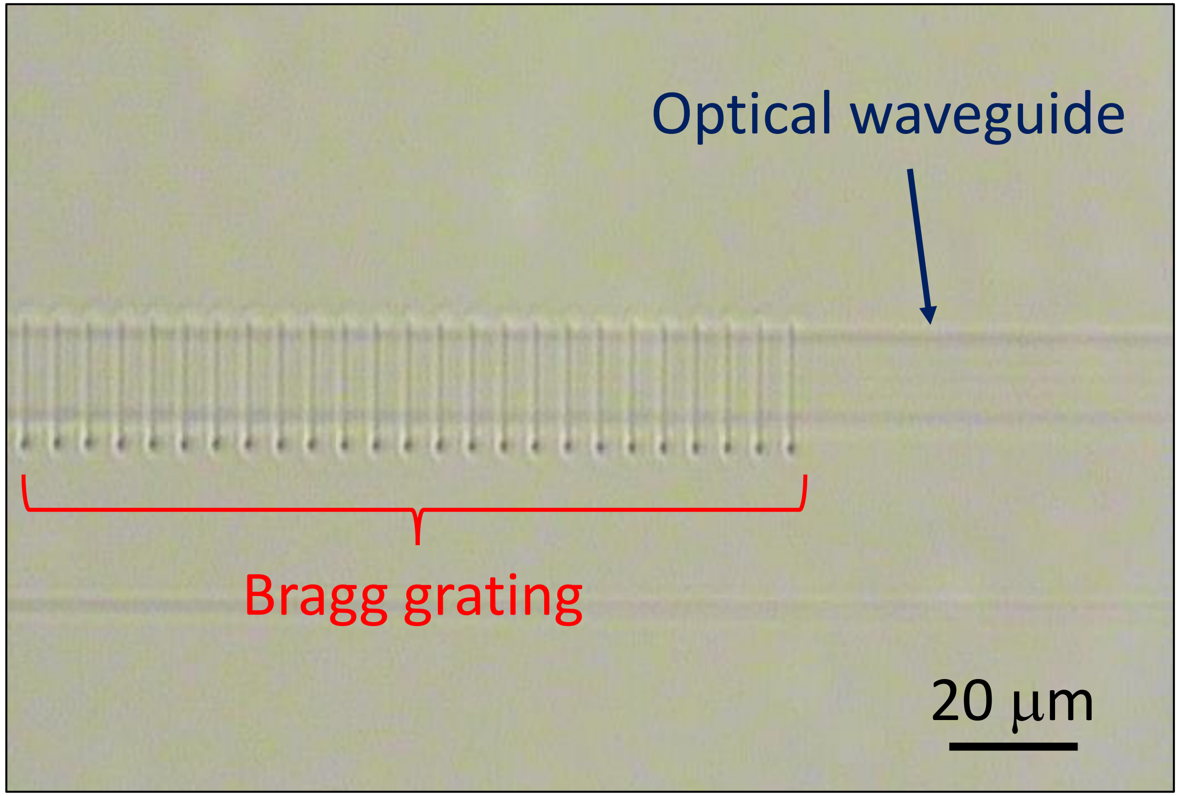
- 2D array inscribed in an un-doped core glass sample
- 5 μm below the surface, lines spaced 1 μm
- 100 nJ laser pulse energy, repetition rate of 100 kHz



Yb/Er doped waveguides and BGs

- **Optical waveguide** in Er-Yb co-doped glass:
  - 30 lines spaced 0.3 μm
  - inscribed 30 μm below the surface
  - Laser parameters:
    - writing speed = 100 μm/s
    - pulse energy = 90 nJ
    - rep. rate = 100 kHz

- **Eighth-order grating**:
  - 1000 planes
  - period 4 μm to operate at 1560 nm
  - Laser parameters:
    - pulse energy = 125 nJ
    - rep. rate = 100 kHz



- Characterizations are ongoing
- Publication under the COST: submission planned early october

Femtosecond laser writing of structures

Work carried out during STSM in 2017: POLITO to CUT

Characterization of FBGs and dissolution kinetics ongoing

Publication under COST MP1401: submission planner October 2017

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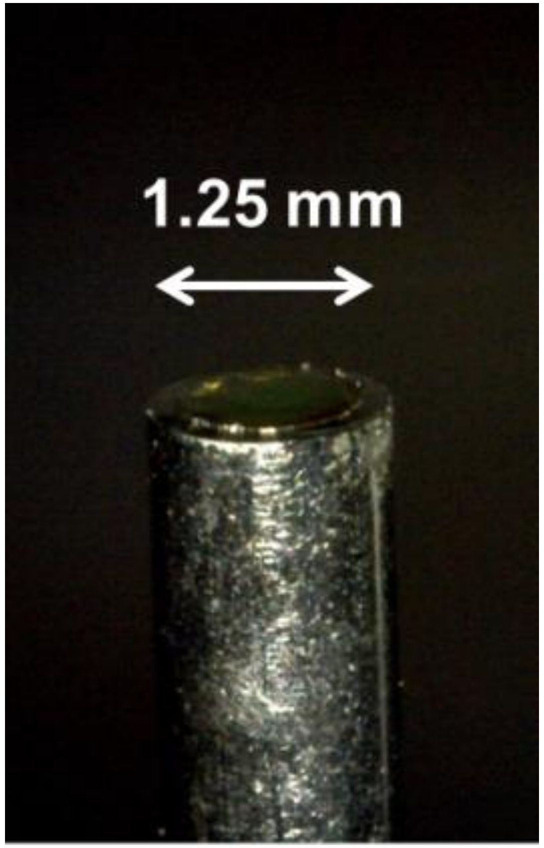
Optical pH sensing

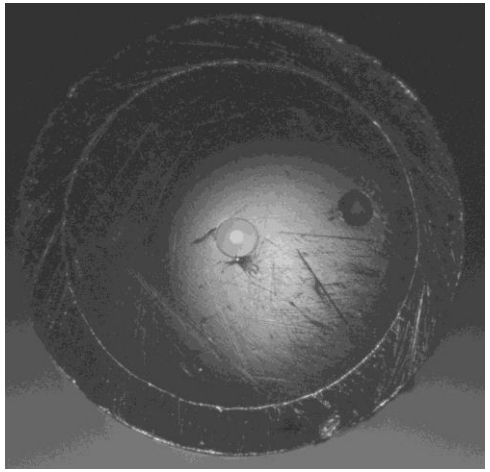
- Prototype of a fiber-optic pH-meter
- Sensing principle
  - 8-hydroxypyrene-1,3,6-trisulfonic acid trisodium salt (HPTS) + hexadecyltrimethylammonium bromide (CTAB) ionic pair immobilized in organo-silicate matrix by sol-gel method
  - Ratiometric fluorescence measurement
  - Two excitation wavelengths (405 nm and 445 nm) and one emission wavelength (515 nm)

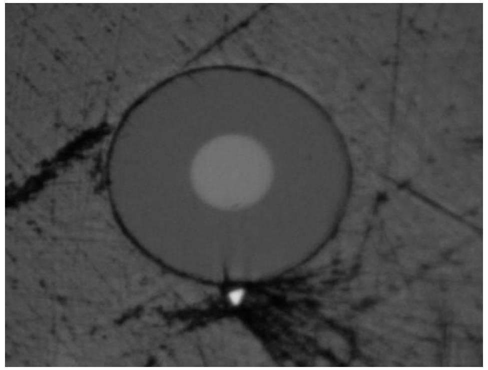
I. Kašík et al., “In vivo optical detection of pH in microscopic tissue samples of Arabidopsis thaliana,” In Materials Science and Engineering: C, 33(8), 4809-15, 2013.

Fiber optic probe pilot experiment

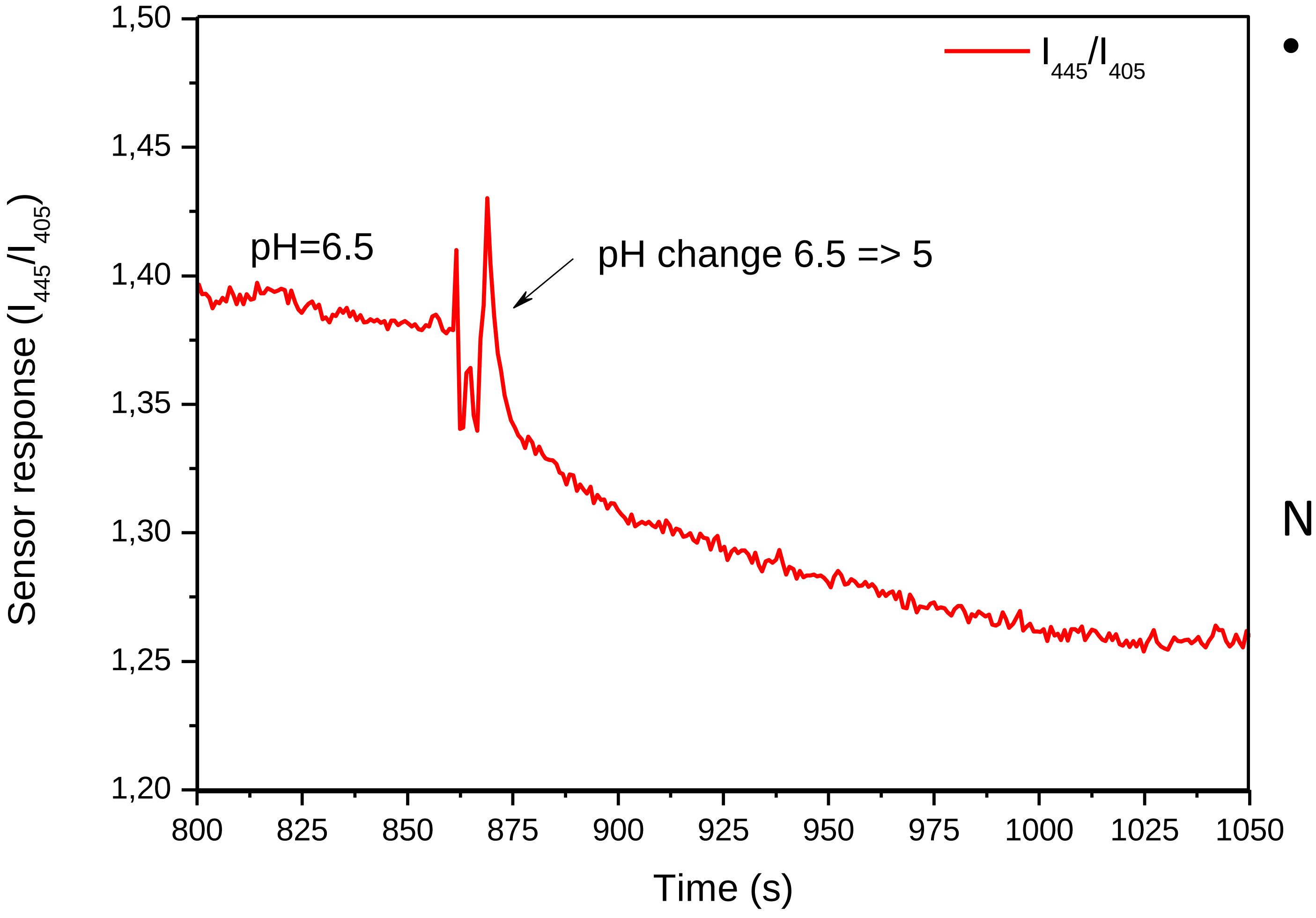
- Bioresorbable fiber connected with GI 50/125 mm fiber and sealed by epoxy resin in a steel tube
- The protective steel tube will not be necessary for polymer coated fiber
- Sensitive layer deposited at the end-face







Fiber optic probe pilot experiment



- Response time after change of pH from 6.5 to 5.0 was approx. 3 min due to the layer thickness

Note: The sensitive layer peeled off after approx. 1100 s of measurement, this should not be the case for polymer coated fiber

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Future developments

- New functionalities and new configurations for bioresorbable fibers
- Femtosecond laser writing of structures:
  - Characterization of laser written structures
  - New FBGs and structures both on fibers and planar samples
  - Test of Yb-Er waveguide lasing through BGs
- Fabrication of a CPG fiber based pH sensor for physiological environment
- In-vivo testing of CPG fibers and prospect for validation in medicine