FBG & LPG Development in BRAZIL

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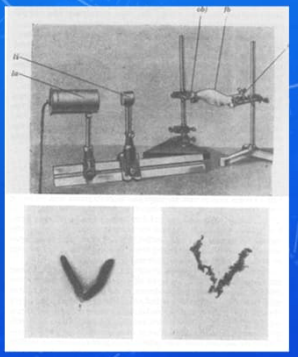
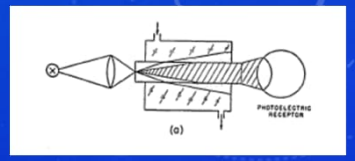
BACKGROUND

- Following modern definition of Fiber Optic Sensors (FOS), e.g., Culshaw's books:
  - 1st FOS by Heinrich Lamm (1930)
  - N.Kapany (~1957) – Rod & Fiber refractometer
  - Menadier et al. (1967) – Photonic Sensor (reflective bundle)
  - Pincher & Hepner (1967), Vali & Shorthill (1976), Lefevre (1977 ...) – Fiber Gyro



J. Hecht, City of Light



N. Kapany, *op. cit.*

H. Lamm, Zeitsch. Instrumentenkunden, 579, 1930
N. Kapany, JOSA 47, 1109 (1957)
C. Menadier et al., Instrum. Control Systems 40, 1967

EARLY HISTORY OF FOS IN BRAZIL

- FOS gained international recognition along 1977 – 1983 (1st OFS Conference)
  - Fiber Gyros attracted attention of Air Force (CTA/ITA)
    - Graduate Studies in Other countries
  - 1984 – Suzana Planas – 1st sensor paper in Brazil
  - Mid 1980's – Scattered work in a few groups
  - > 1986 – Regular working group at UFF

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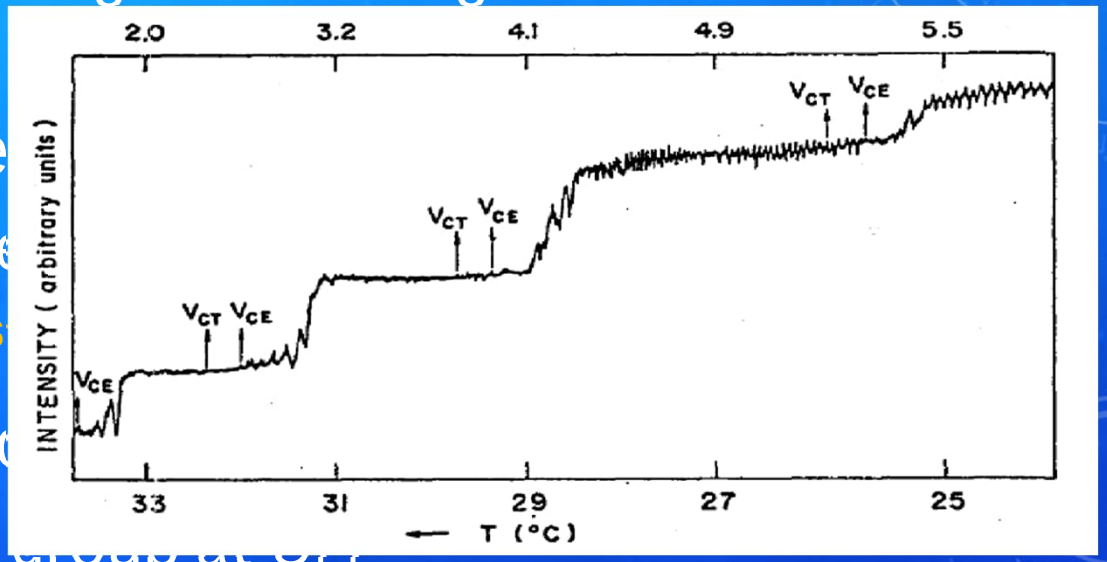

S. Planas, *op. cit.*

S.A. Planas, Sensor de Temperatura de fibra óptica de núcleo líquido, 2nd Symp Int Telecomm (1984)

STARTING YEARS

- 1978 – Discovery of FBG by Hill & coworkers
  - Spectral sensitivity with temperature & strain
- 1990-1996 UFF & CEFET/PR (now UTFPR) agreement with Universidad Nacional (& P.U. Javeriana)
  - COLCIENCIAS – CNPq funding
    - Simulation lab (SUN workstations) at UN
    - Exchange of lecturers and graduate students
    - Simulation & CAE design of optical fiber sensors
    - Publications in conference and journals
  - 1992 – II Taller Fibras y Sensores Ópticos
  - 1998 – Optilas VI & III RIAO, invited talk (FBG)
  - Pedro I. Torres > Generation 125 > Ph.D. in Brazil

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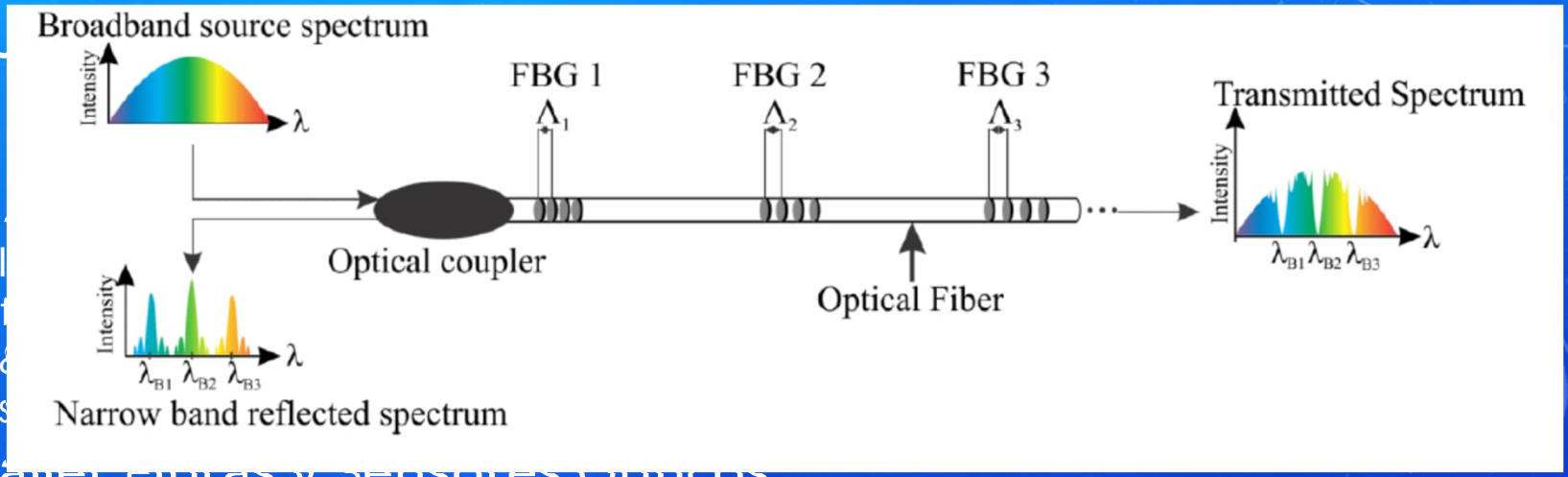

EARLY DEVELOPMENTS ON PERIODIC GRATINGS

- 1991 – 1st Brazilian work on periodic gratings, L.C. Guedes Valente
  - Bragg gratings in HiBi fiber (polarization produced and selected)
  - Thermally permanent and non-permanent gratings (~240 C)
  - Optical erasure by laser light without line selection – avoid new gratings before thermal annealing
  - Further work on rocking filters (polarization couplers)
- 1996 – Personal hands-on introduction to FBG (IROE, Anna Mignani)
  - 1997-1998 – Students travel to UNICAMP (~400 km) to realize experiments due to lack of Optical Spectrum Analyzer in the lab

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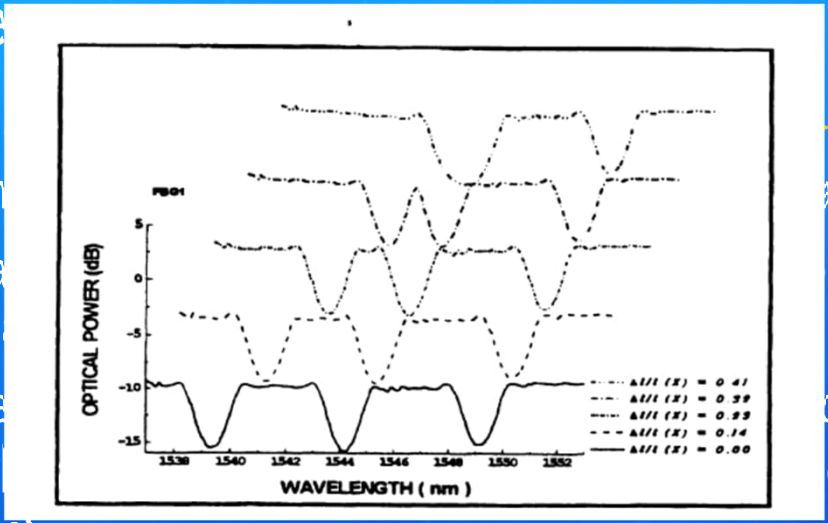


Characterization of multiplexed FBG for electrical energy application, *OPTILAS VI talk*

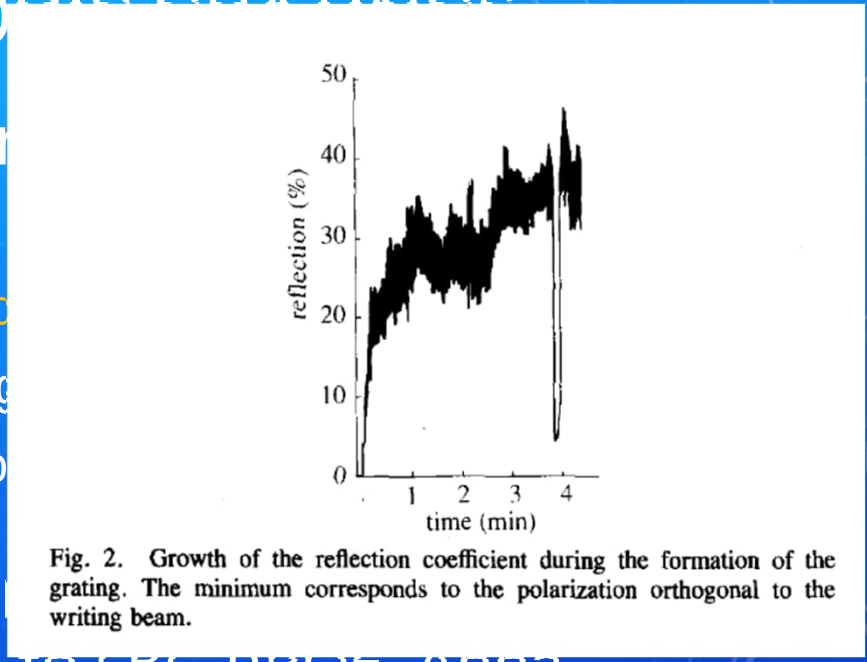
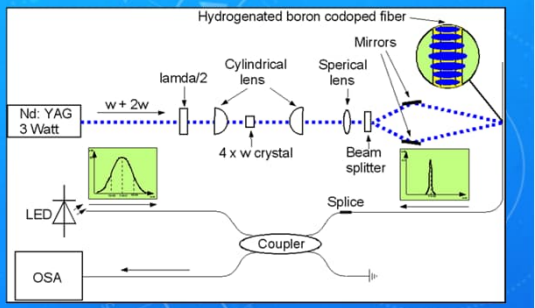


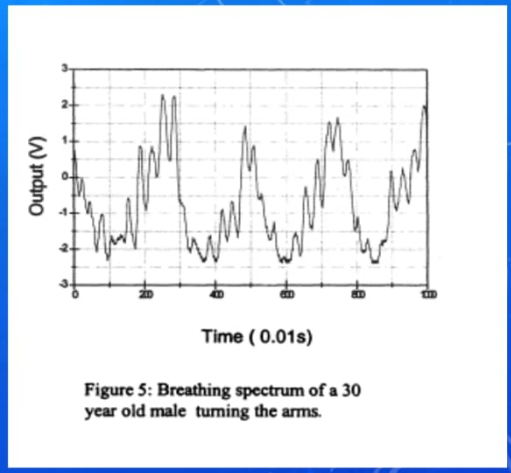
Fig. 2. Growth of the reflection coefficient during the formation of the grating. The minimum corresponds to the polarization orthogonal to the writing beam.

S. Kanellopoulos et al., *1991*

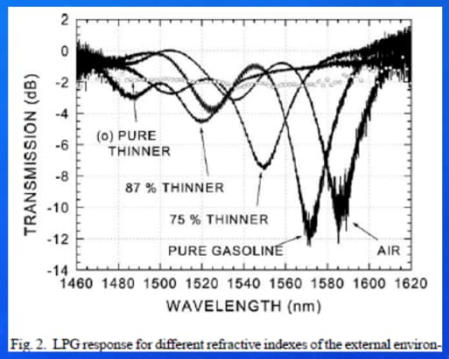
BUILDING THE GROUNDS

- FBG sensors gain space
  - First phase-mask interferometers for FBG in Brazil
    - PUC-RIO (L.C. Guedes Valente & W. Margulis)
      - L.R. Kawase (UFRJ) 1997
      - P.I. Torres (U Nacional, Colombia) 1998-2002
  - IEAv-CTA (C.L. Barbosa)
    - Cooperative policy of sharing samples
    - CEFET/PR & TFH Berlin (biomechanics)
  - Insertion in the Oil & Gas sector
    - ANP & Petrobras partnership
- LPG sensors
  - Point-to-point electrical arc discharges





G. Wehrle et al, Proc. OFS-14 2000



R. Falate et al, Sens. Act. B (2006)

CONSOLIDATING FBG RESEARCH – 2001/2005

- Cooperative work between Brazil and Portugal
  - CAPES-IICTI agreement (U. Aveiro, IT, U. Porto)
  - Ph.D., pos-doc and researchers Exchange
  - 1st *in-vivo* biomechanics application of FBG
  - Joint design of complemetary interferometers
- CEFET-PR: phase-mask interferometer for FBG production
- 2003: spin-off from OFS lab (PUC-RIO) and Petrobras
- IMOC 2003 – Invited talk (J. Canning, U. Sydney), FBG&LPG session
- 2004: position in OFS-TPC for a Brazilian researcher

gavea sensors
measurement solutions

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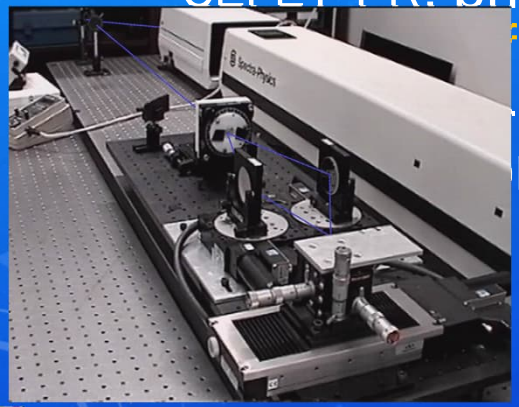

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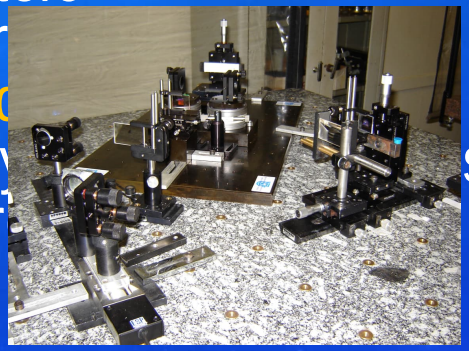


gavea sensors
measurement solutions

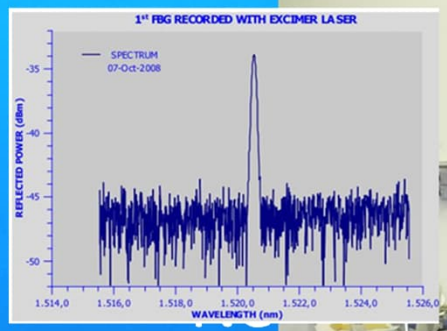
Optics & applications

UTFPR Universidade Federal Fluminense

DISSEMINATION OF FBG RESEARCH – 2006 to 2010

- Increased international cooperation
  - Number of published Papers 33% higher than 1995-2005
- New facilities for FBG & LPG installed in Brazil
  - KrF excimer laser under the phase-mask method
- Increased number of applications (ethanol, biodiesel,wines, dental resins, biomechanics, magnetic field, electrical applications, ...)

DISSEMINATION OF FBG RESEARCH – 2006 to 2010



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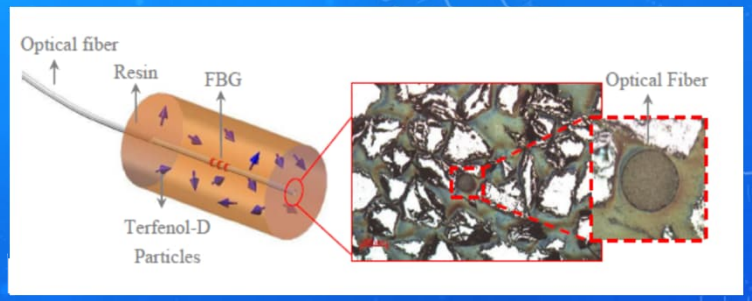
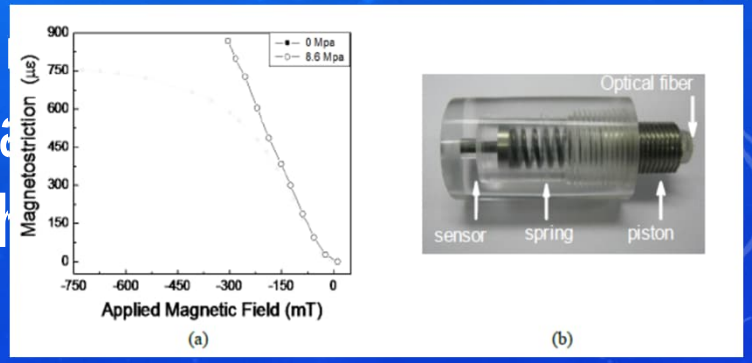




S.M.M. Quintero et al. (2006)

WIDESPREADING FBG IN BRAZIL – 2011 to 2015

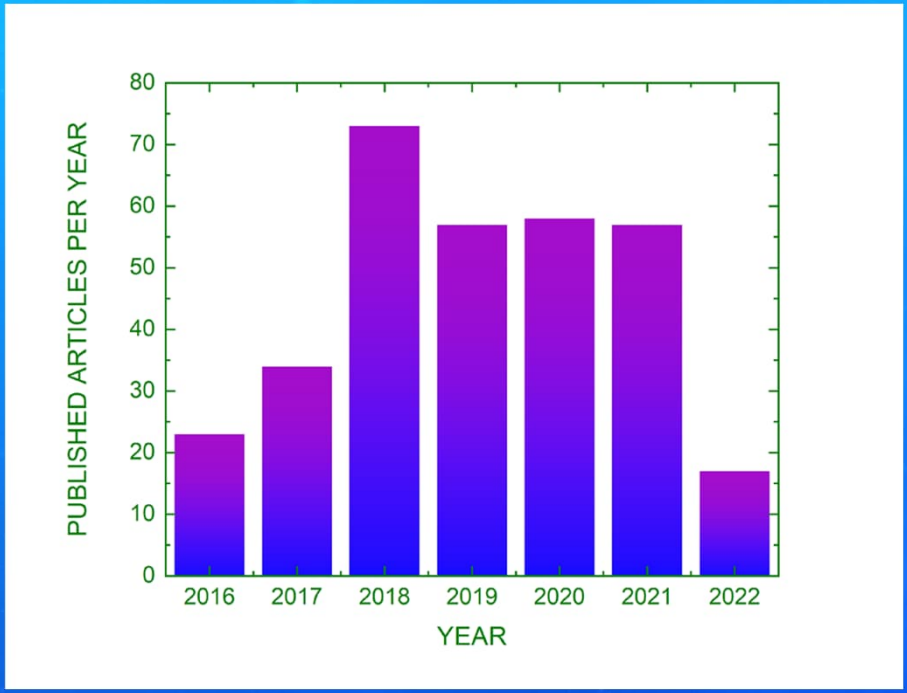
- Further FBG applications: biosensing, speciality fibers (e.g., PCF), metrological standards for FOS, tropical diseases (dengue, E. coli), plasmonic techniques, FBG applications in vivo, ...
- New facilities with shorter UV sources and femtosecond pulse lasers
  - ArF excimer laser, Ti:saphire + parametric amplifier

- Approximately 400 attendees at OFS-24
- 19 Exhibitors (18 outside Brazil)
- Excellent technical contents
  - Brazilian submission classified for best student papers final contest
- Pleasant social activities
- Impact on future meetings
  - LAWOFS (2016 and 2019, 2024)
  - Student participation at OFS-25 (Jeju)

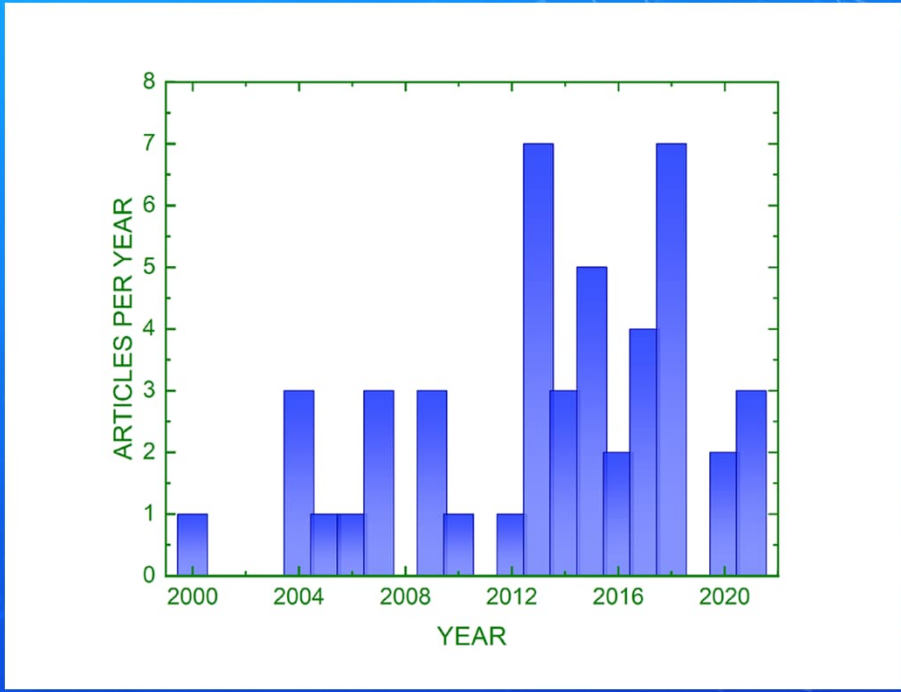
Brazilian Lifetime Achievement Award – L. C. Guedes Valente

Caipirinha ingredientes & recipe

BUBBLE GROWTH – from 2016

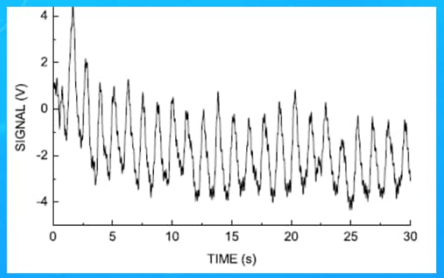


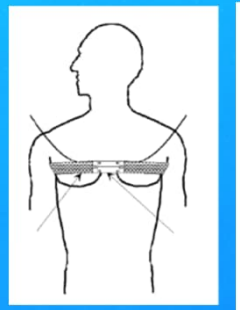
FOS Brazilian articles in WoS indexed journals

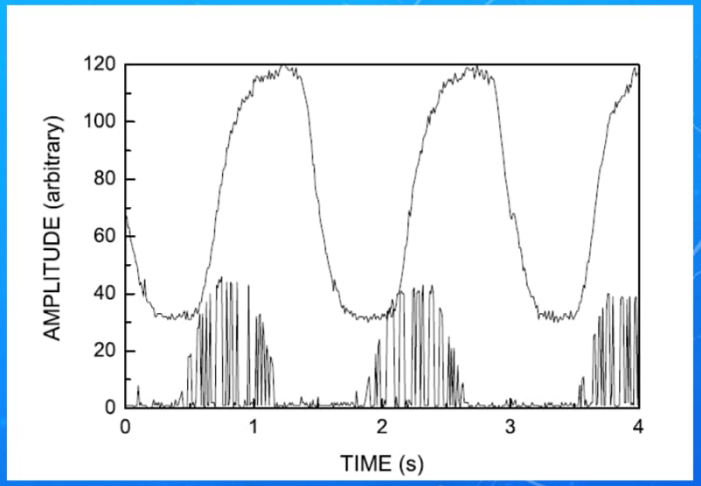


Number of FOS articles publiched in Journal of Microwaves, Optoelectronics and Applied Electromagnetics along time

BIOMECHANICS







- Very early start (1999-2001)
- Diverse approaches & materials
  - Cadaveric bone (human & animal)
  - Model bones (biomedical grade)
  - *In vitro* bone studies
  - Prosthesis & medical healing devices
  - Dental processes & materials
  - *In vivo* animal & human studies

G. Wehrle et. al, Meas. Sci. Technol. (2001)
H.J Kalinowski et al., Ch 10 Trends in Photonics, 2010

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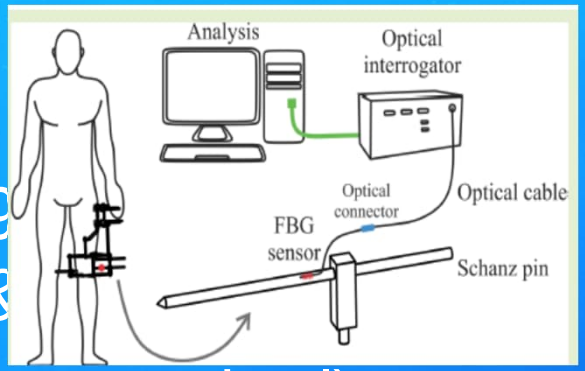


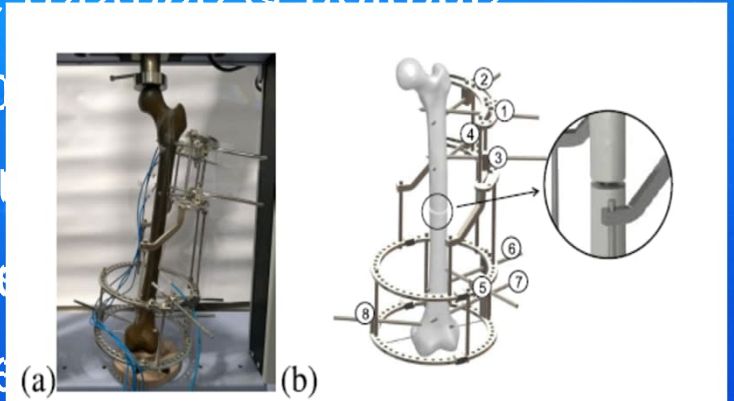
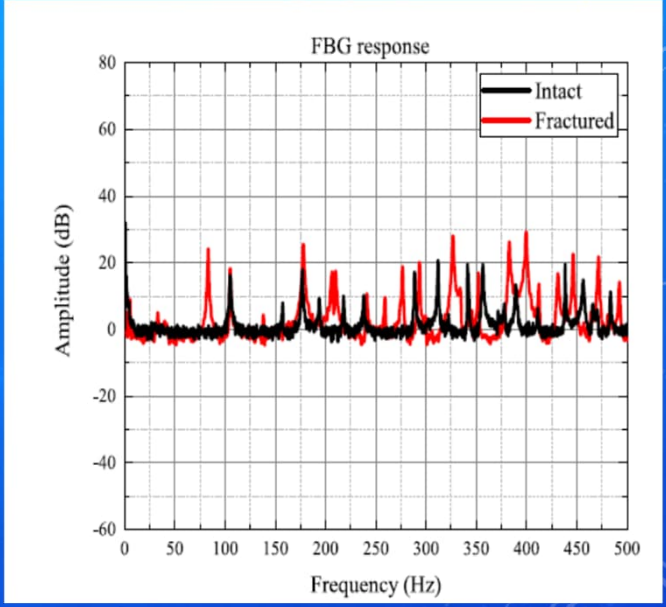


Fig. 2. (a) Experimental setup. (b) Fixator pins identification.



A.Kalinowski et al. IEEE Sensors J. (2021)

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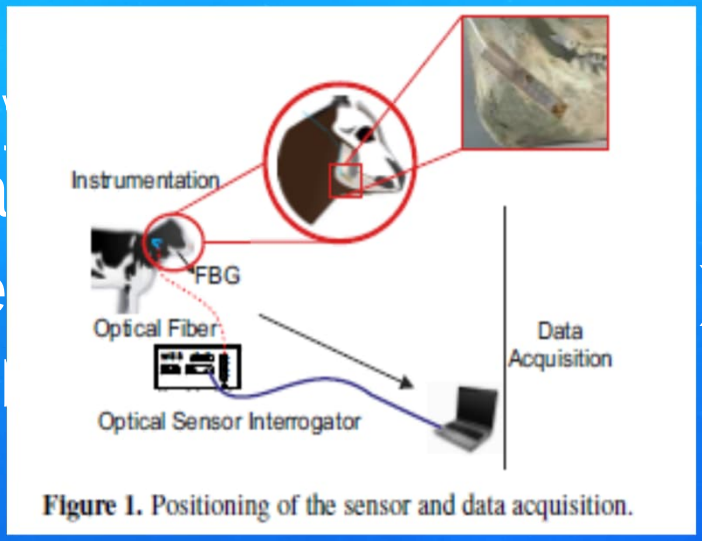

Figure 1. Positioning of the sensor and data acquisition.

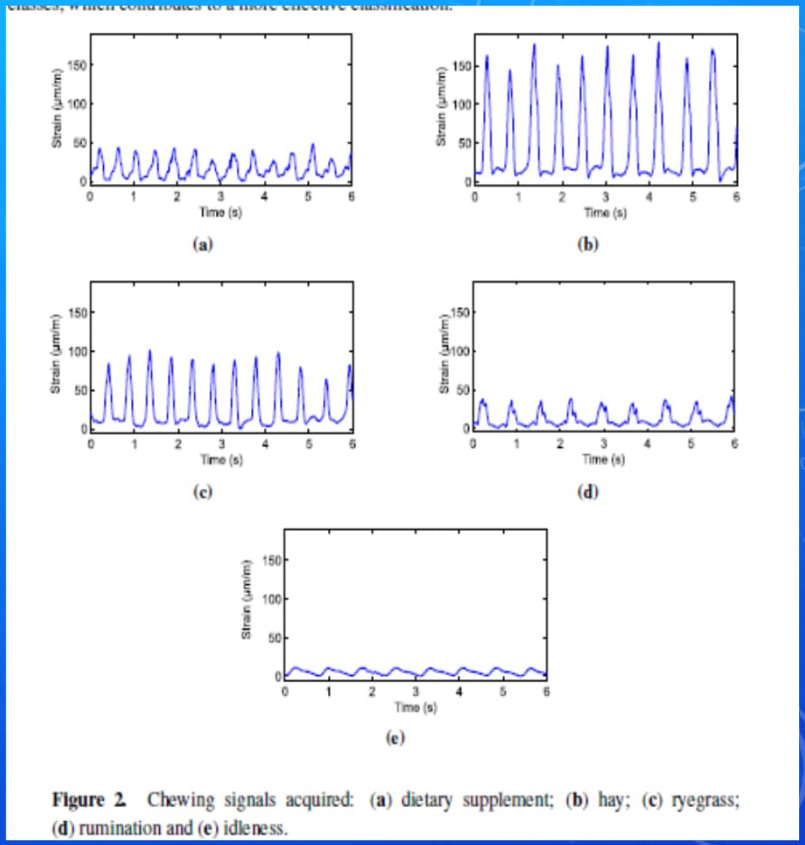

Figure 2. Chewing signals acquired: (**a**) dietary supplement; (**b**) hay; (**c**) ryegrass; (**d**) rumination and (**e**) idleness.

V. Pegorini et al., Sensors 15, 2015

BIOMECHANICS

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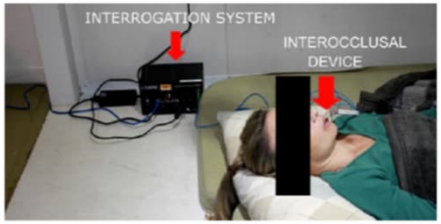

Fig. 5. Volunteer wearing the interocclusal device during the sleep hyperactivity assay.

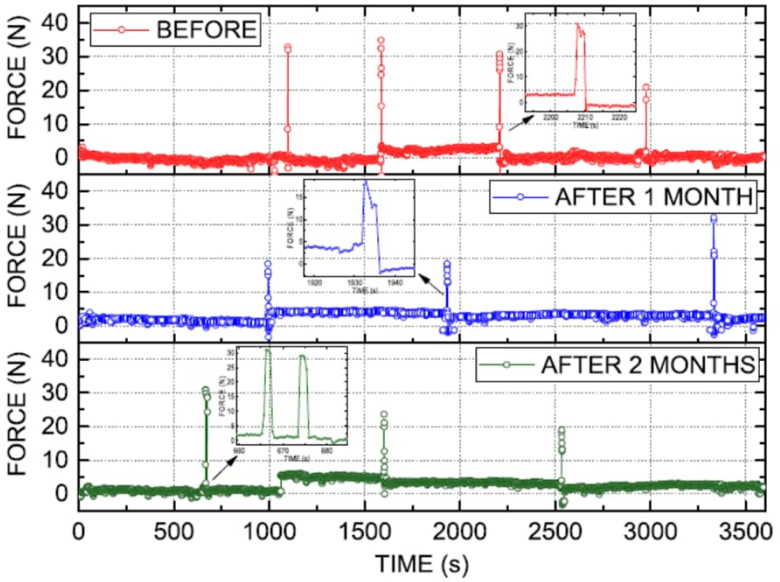

Fig. 11. Amplitude of the achieved hyperactivity forces, recorded wh the patient was sleeping, before and after the application of botulin toxin. The insets show the magnification of one of the test peaks.

D. M. Fontenele et al., IEEE Sensors J. (2021)

DENTAL BIOMECHANICS & MATERIALS

- Impact effects on dental implants
  - Cadaveric mandible
- Mandible & Maxilla models (+ FEM modelling)
- Orthodontic devices
- Dental materials (gypsum, cements, resins, ...)
- Prosthesis processes
- Calibration of numerical methods

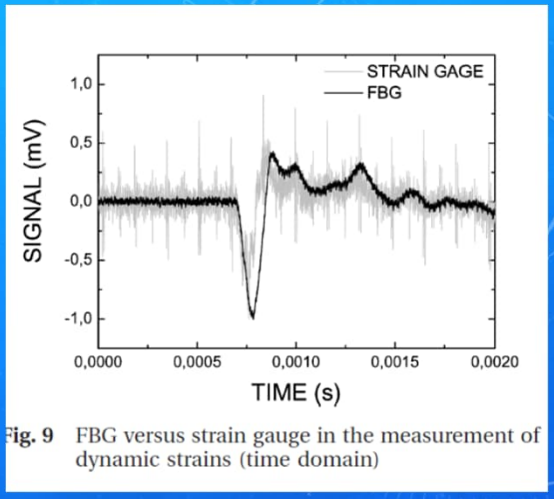

Fig. 9 FBG versus strain gauge in the measurement of dynamic strains (time domain)

L. Carvalho et al., J. Strain Analysis (2006)

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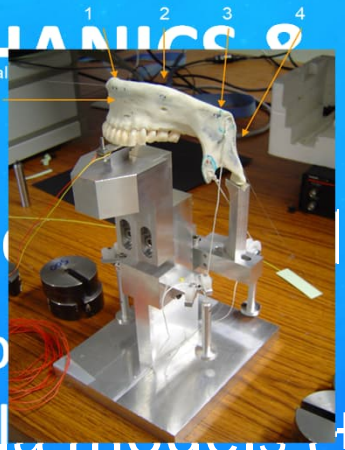

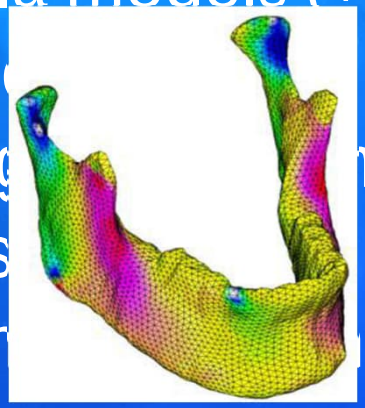

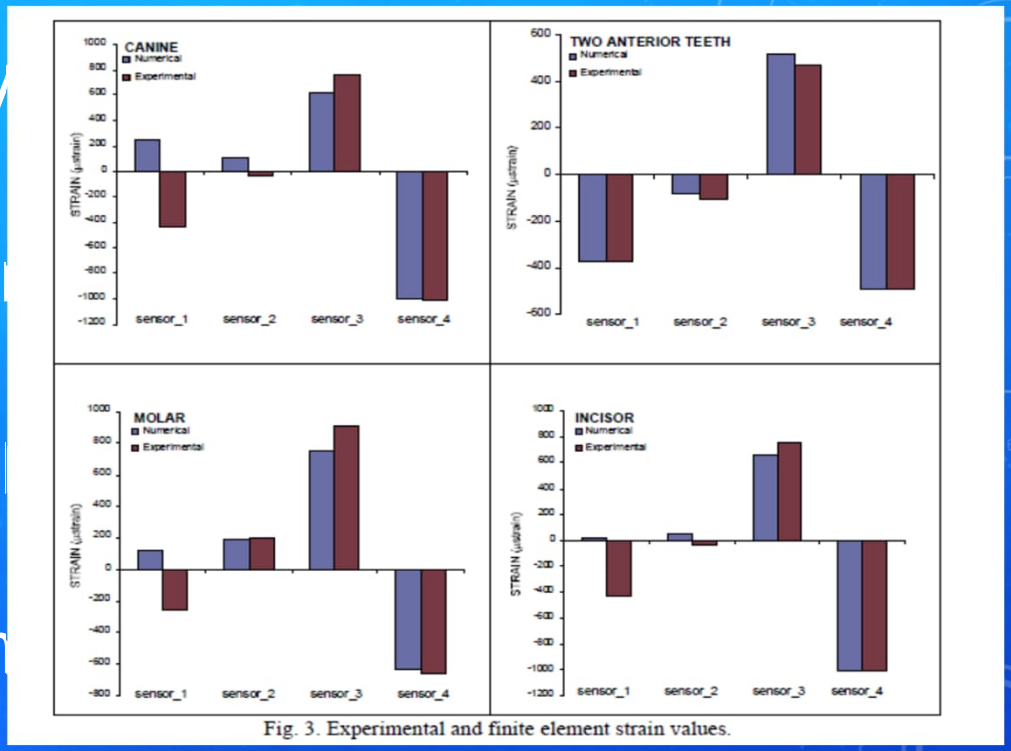

Fig. 3. Experimental and finite element strain values.

J.C.C. Silva et al., Proc. OFS-17, Brugges, (2005)

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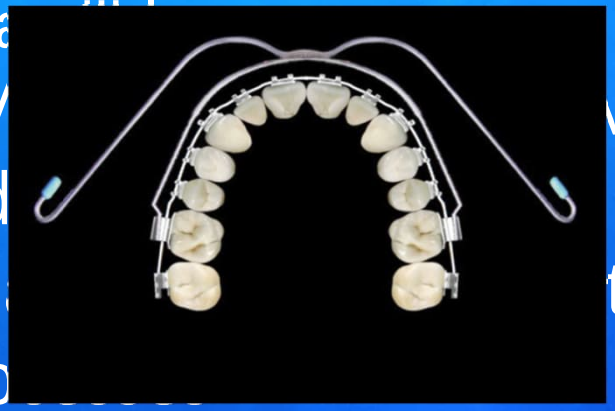

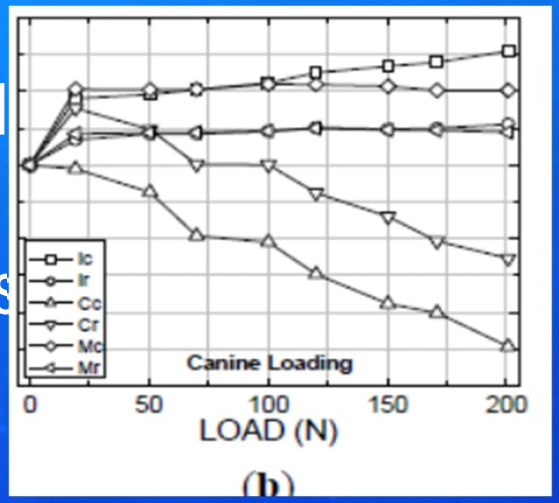

M.S. Milczewski et al. Sensors (2012)

DENTAL BIOMECHANICS & MAT

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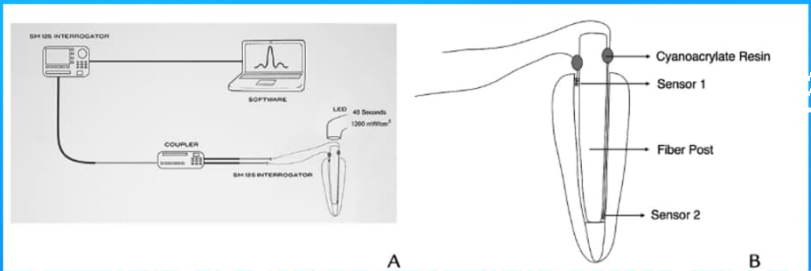
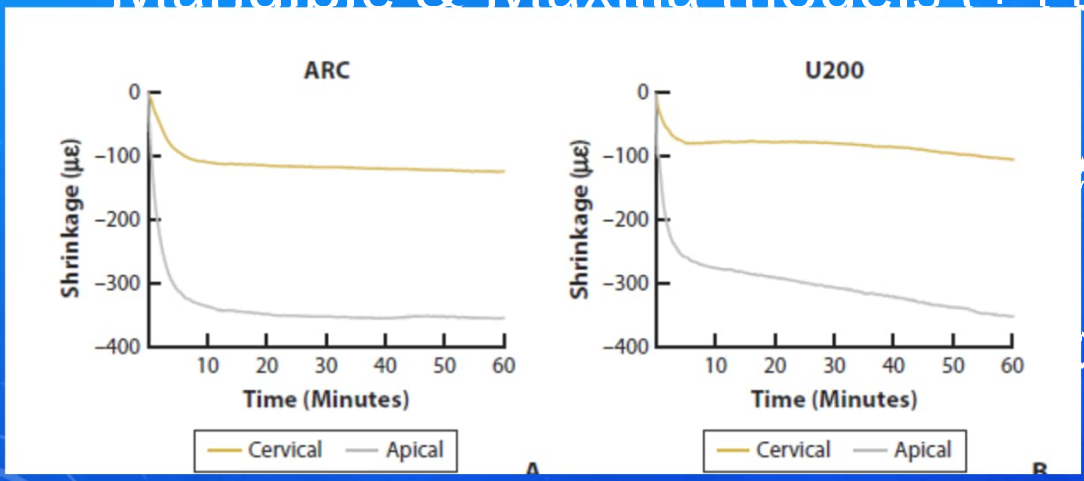
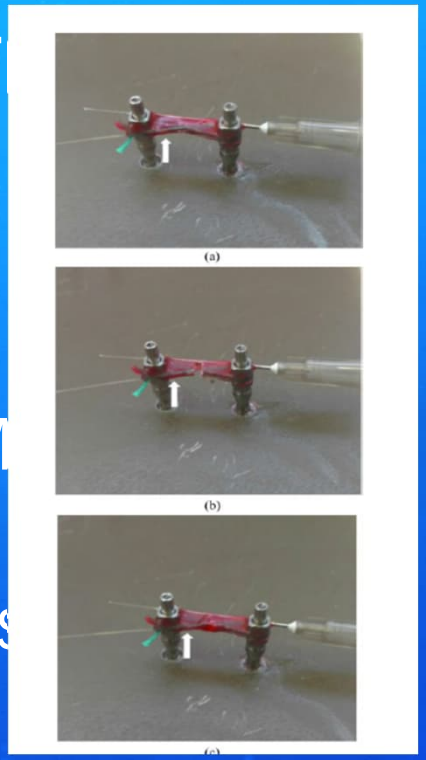
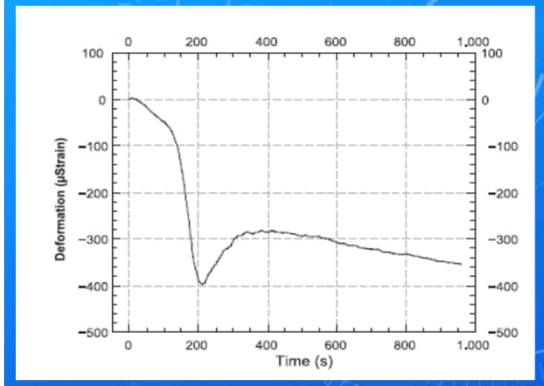
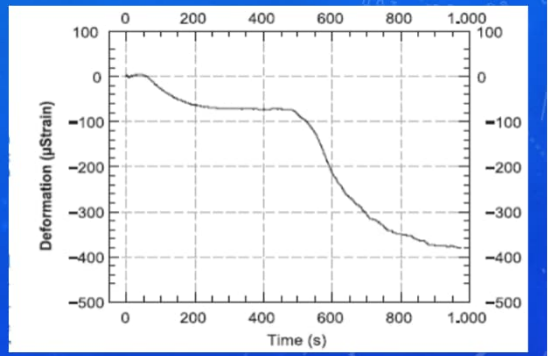




C. Pulido et. al., J. Prosthetic Dentistry, (2021)







A.P.G.O. Franco et al. J. Lightwave Techol. (2016)

Long period gratings (LPG)

- Point-to-point engraving procedures
  - Electrical arc discharges
  - UV light from Nd:YAG frequency doubled laser (@ 266nm)
  - UV light from Excimer lasers (KrF @248 nm; ArF @ 193 nm)
  - fs optical pulses from Ti:Saphire laser + parametric amplifier @ 800 nm
  - LPG response enhancement by thermal treatment & interferometers (CLPG)
  - Matching LPG response to plasmonic band of metal nanoparticles

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  - LPG response enhancement by thermal treatment & interferometers (CLPG)
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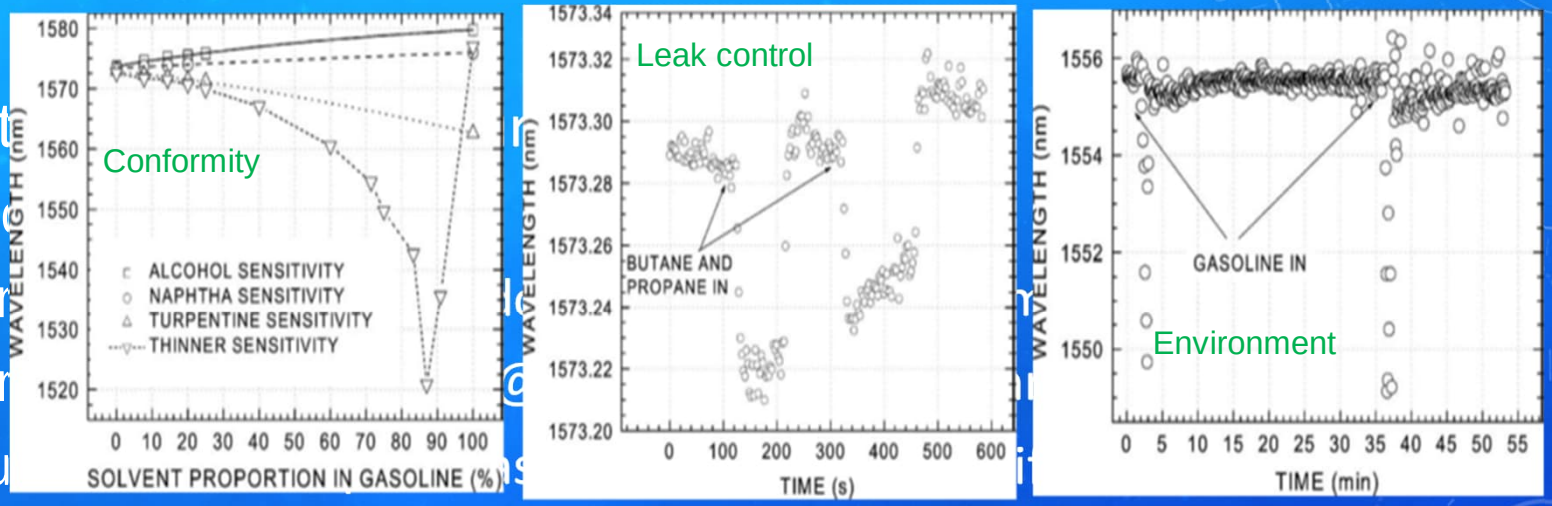
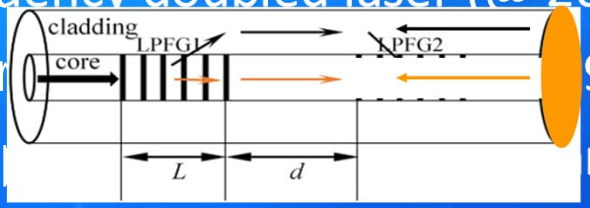
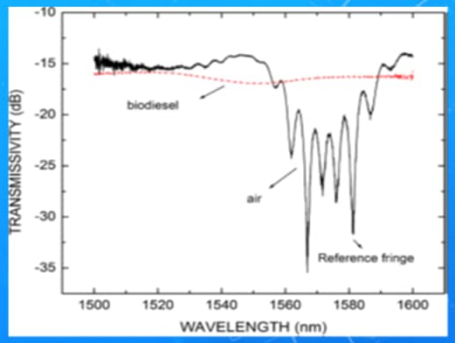


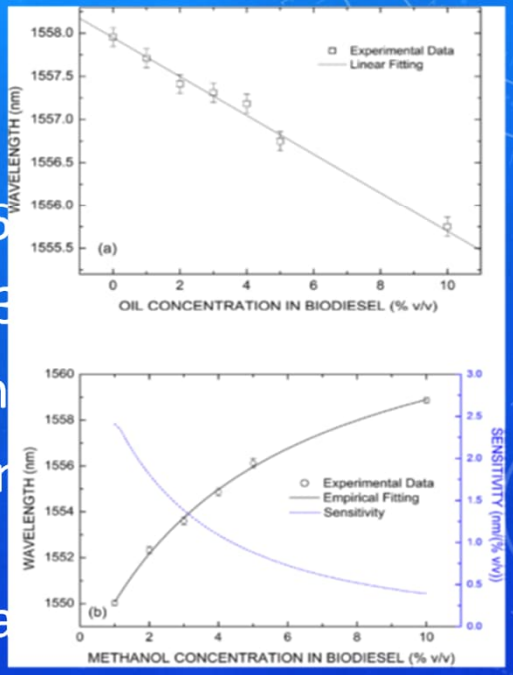
R. Falate et al, Sens. Act. B (2006)

Long period gratings (LPG)

- Point-to-point engraving procedures
  - Electrical arc discharges
  - UV light from Nd:YAG frequency doubled laser (@ 266
  - UV light from Excimer laser
  - fs optical pulses from Ti:Sa
  - LPG response enhancement by thermal treatment & ir (CLPG)
  - Matching LPG response to plasmonic band of metal na



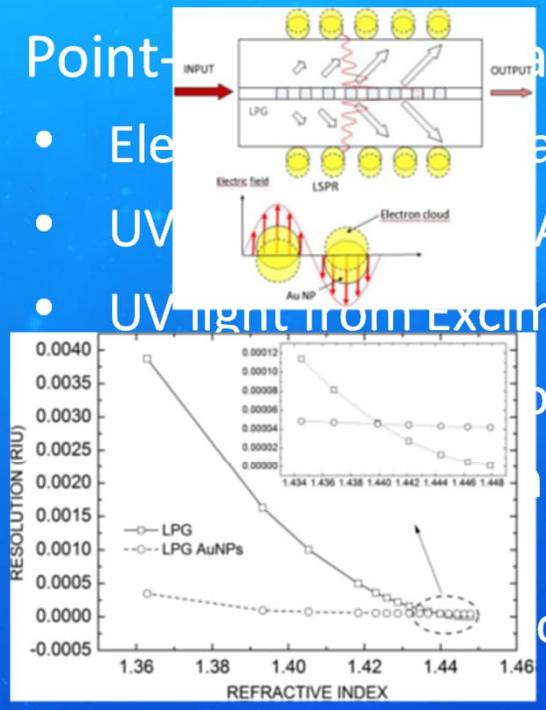




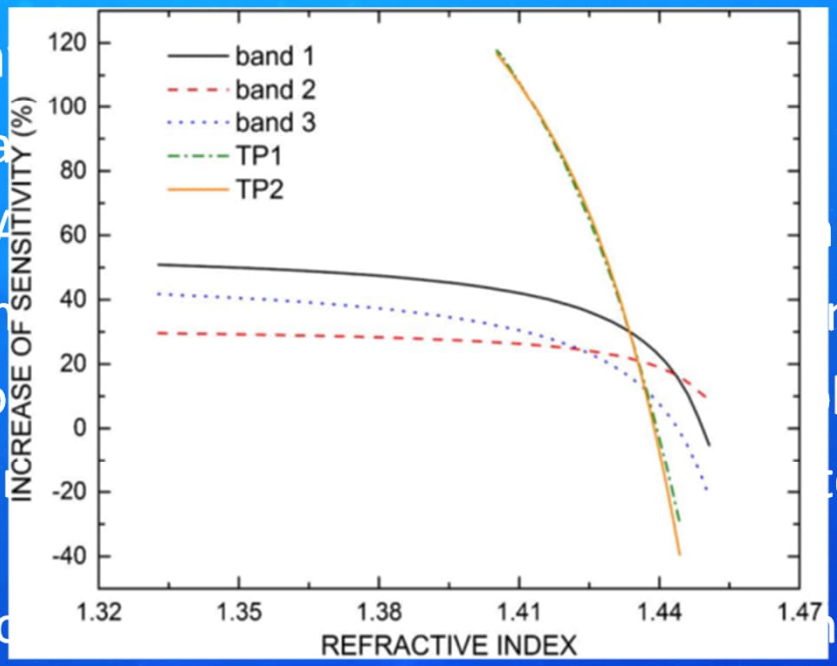
M.S. Kawano et al., Meas. Sci. Technol., (2015)

Long period gratings (LPG)

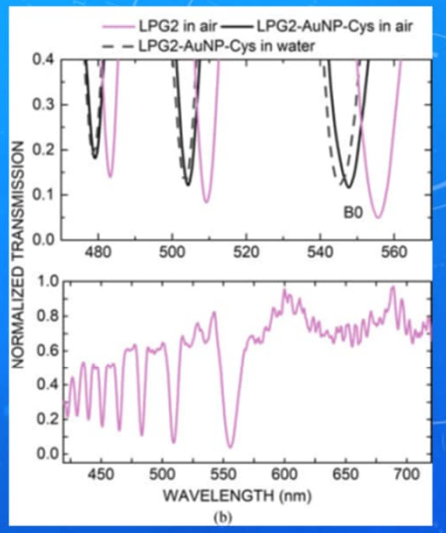
- Point-
  - Ele
  - UV
  - UV light from Excim

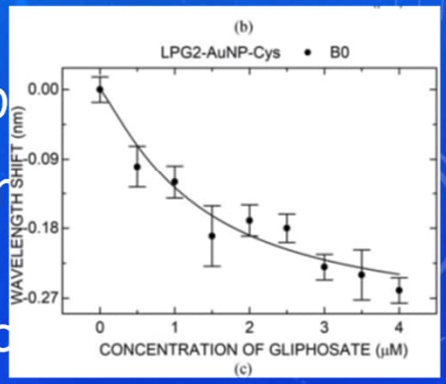


B.R. Heidemann et al., Appl. Opt. (2015)



B.R. Heidemann et al., Appl. Opt., (2016)





B.R. Heidemann et al., J. Lightwave Technol, (2018)

FBG IN THE VISIBLE SPECTRUM

- Hill – FBG with band in visible (standing wave into fiber core); Bragg wavelength = laser wavelength
- Meltz & Morley (1993) – engraving by external UV light
  - FBG in any wavelength (shift to C-band due to telecommunications applications & componentes)
- FBG in the visible region of the spectrum
  - Specific applications in visible communication systems (POF), biomedical sensing, ...
  - Less expensive semiconductors (Si technology x InGaAsP)
  - Reduced sensitivity to temperature and strain (~ 0.5 those in C-band)
  - Lack of practical interrogators (?)

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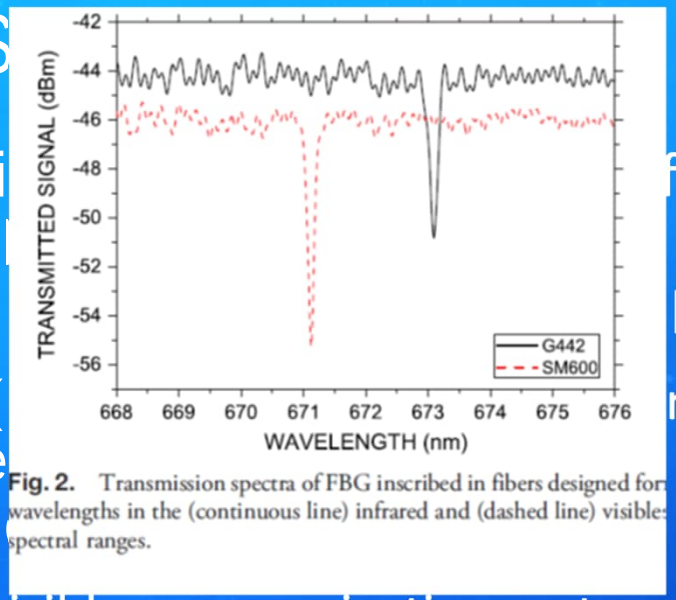
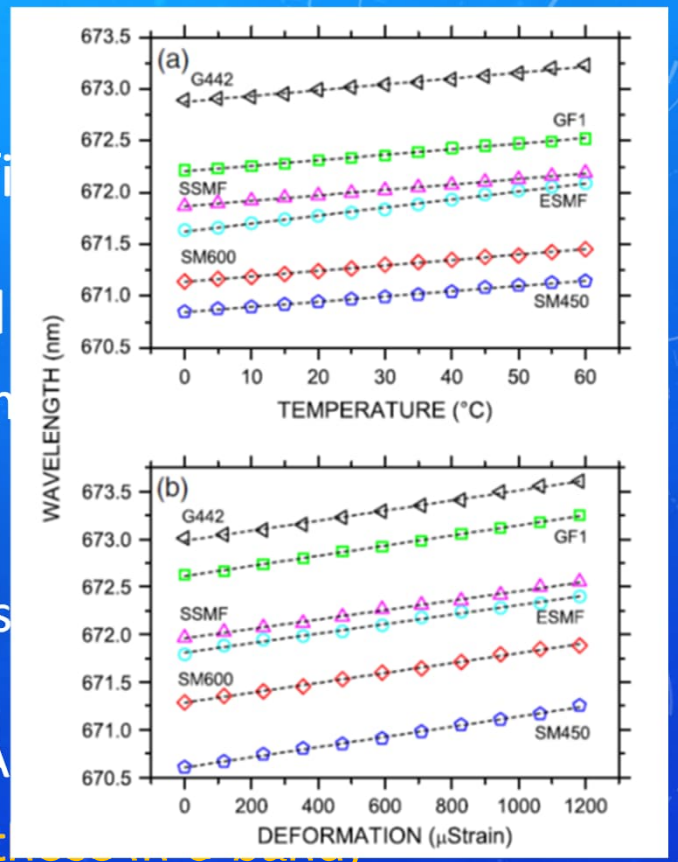
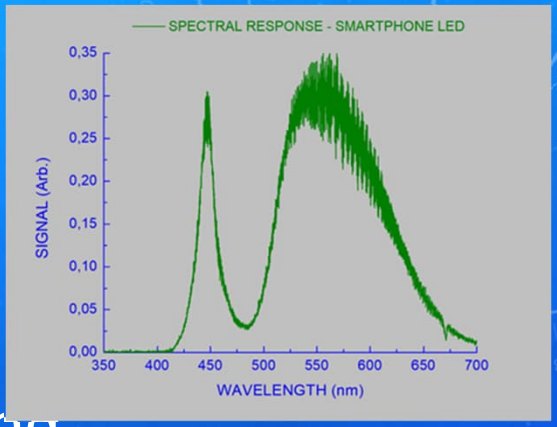


Fig. 2. Transmission spectra of FBG inscribed in fibers designed for wavelengths in the (continuous line) infrared and (dashed line) visible spectral ranges.

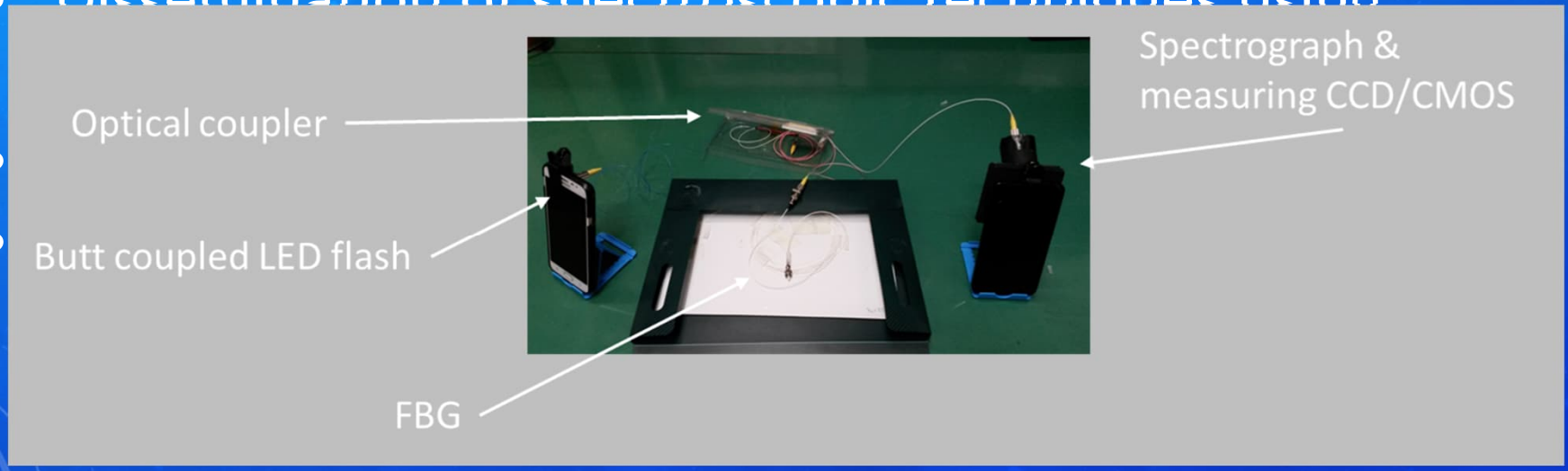
P.L. Inacio et al. Appl. Opt. (2016)



SMARTPHONE INTERROGATION OF FBG IN THE VISIBLE SPECTRUM

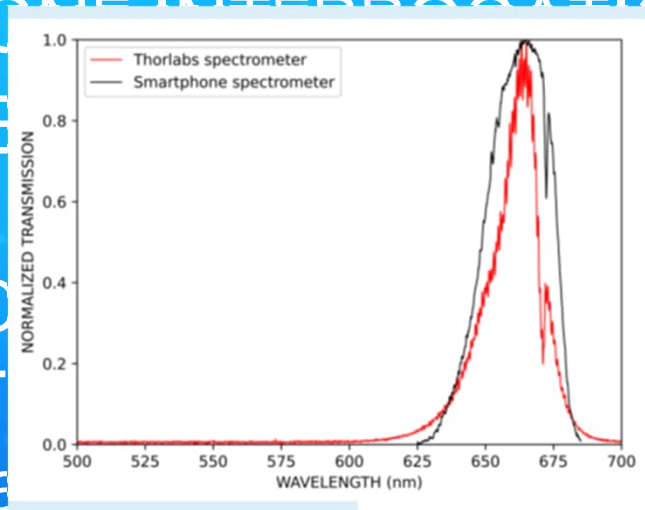


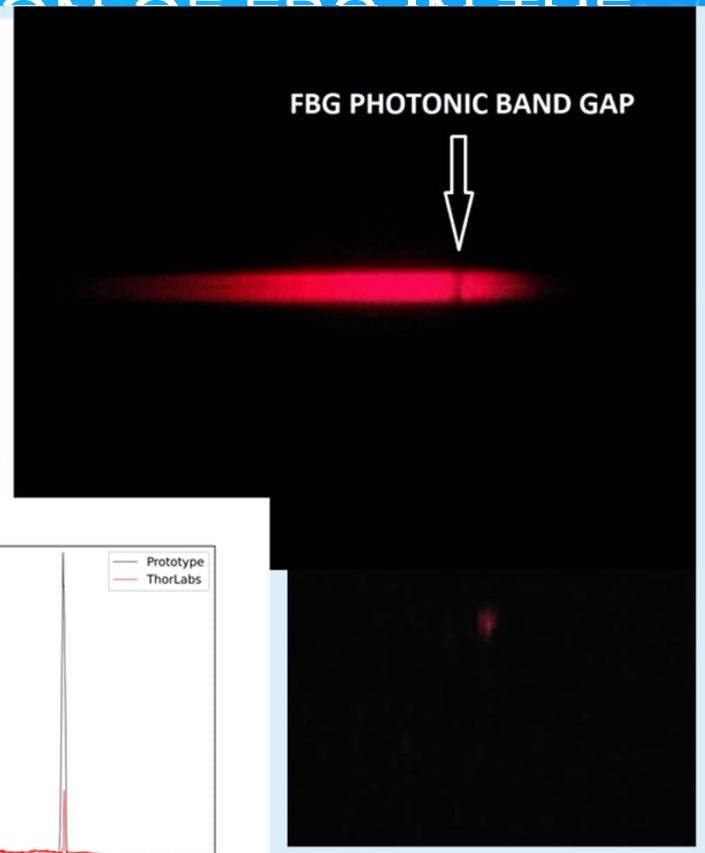
- CCD/CMOS in Si technology, increasing numbe
- Coupled ¨White¨ Flash/LED
- Dissemination of spectroscopic techniques usin

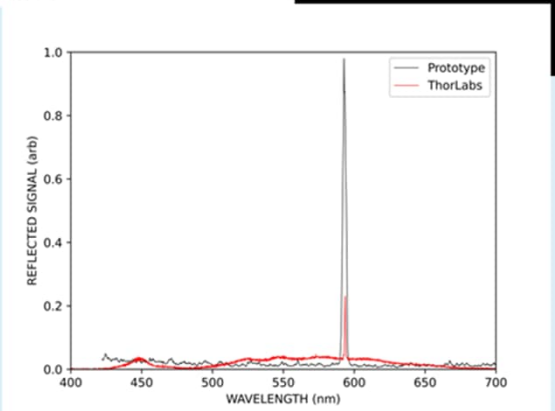


SMARTPHO… INTERROGATION OF FBG IN THE VISIBLE SPE…

- CCD/CMO… …els
- Coupled …
- Dissemina… smartpho…
- Almost 10…
- Can induc…
  - Medical…







A.A.C.O. Santos et al., Proc. FOP21 (2021)
G.C. Mastrapa et al. (2021)

PLAN IN ADVANCE – MAIN CONFERENCES

- EWOFS 2023: Mons (Belgium) 23-26 May 2023
- LAWOFS 2024 near Campinas, SP. June, 2024
- OFS-28: Hammamatsu (Japan) 20-24 November 2023
- OFS-29: Porto (Portugal) 26-30 May 2025

Partnership

- Brazilian Groups with FOS research using FBG & LPG

Ph.D. & pos-doc opportunities

There are
49 Ph.D. programs in Physics
most of them with Optics in their subjects

at least 21 Ph.D. programs in Electrical Engineering with optics related subjects

plus assorted number of Ph.D. programs in other areas with optics related research

THANK YOU FOR YOUR ATTENTION

GRACIAS

We thank funding agencies CAPES, CNPq, FINEP, FAPERJ and Fundação Araucária.

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fabris@utfpr.edu.br