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Faculty of Electronics, Telecommunication and Information Technology (ETTI)

Applications with fluorescent fibers

Assoc prof Ramona Galatus
Integrated Circuits and Systems Group (ICSG)
Optical Communications and Photonics team (OCP)
Cecilia Cristea, Bogdan Feier, University of Medicine, Cluj

ramona.galatus@bel.utcluj.ro / galatusr@yahoo.com

Content

- Hybrid sensor for ampicillin detection in water

Ramona Galatus, Bogdan Feier, Cecilia Cristea, Nunzio Cennamo, Luigi Zeni, **SPR Based Hybrid Electro-Optic Biosensor for β-Lactam Antibiotics Determination in Water,** Remote Sensing and Modeling of Ecosystems for Sustainability XIV, edited by Wei Gao,Ni-Bin Chang, Jinnian Wang, Proc. of SPIE Vol. 10405, 104050C · © 2017 SPIE CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2273318

Plasmonic Sensing in D-Shaped POFs With Fluorescent Optical Fibers as Light Sources, IEEE Transactions on Instrumentation and Measurement (Vol: PP, Issue: 99), pages 1-6, Sept 2017

Ramona Galatus, Paul Farago, Cecilia Cristea, B Feier, N. Cennamo, SPR Based Hybrid Electro-Optic Biosensor Platform, **SPR-cell with side emitting plastic optical fiber,** ***2017 IEEE*** *23rd International Symposium for Design and Technology in Electronic Packaging (**SIITME**)*

- Distributed fluorescent optical fiber proximity sensor

Ramona Gălătuș[1], Paul Faragó[1] ,Piotr Miluski[2], Juan Antonio Valles Brau[3], **Distributed fluorescent optical fiber proximity sensor**, XIVth International Conference on Molecular Spectroscopy, 3.09-7.09.2017 - Białka Tatrzańska, Poland Poland, 2017 http://www.icms.agh.edu.pl/

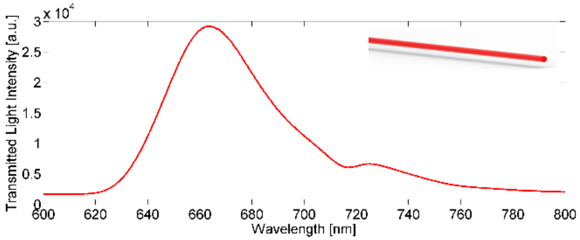
- Low-cost Quasi-distributed Position Sensing Platform based on Blue Fluorescent Optical Fiber

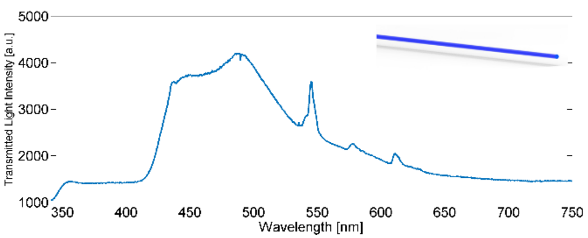
Paul Farago, Ramona Galatus, Low-cost Quasi-distributed Position Sensing Platform based on Blue Fluorescent Optical Fiber**,** ***2017 IEEE*** *23rd International Symposium for Design and Technology in Electronic Packaging (**SIITME**)*

Acknowledgement: This work was financially supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS/CCCDI-UEFISCDI, project number PN-III-P2-2.1-PED-2016-0172, within PNCDI III; also scientific supported from *MPNS COST Action MP1401*- Advanced fibre laser and coherent source as tools for society, manufacturing and lifescience.

Hybrid sensor for ampicillin detection in water

- Red and blue fluorescent plastic optical fiber – Industrial fiber optics, USA
- Side emitting fiber – FiberFin, USA

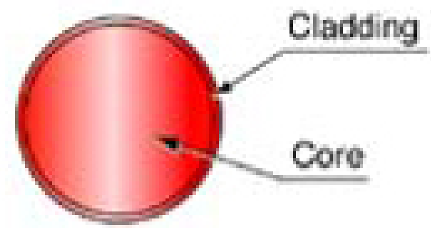




Fluorescent fibre

code 81 0087/Industrial Fiber Optics

1 mm Fluorescent Red Polystyrene



Side view and cross-section of the used fluorescent optical fiber

Main parameters of the 81 0087 fibre

Structure	
Core Material	Polystyrene
Cladding Material	Acrylic
Core Refractive Index	1.60
Refractive Index Profile	Step-index
Numerical Aperture	.58

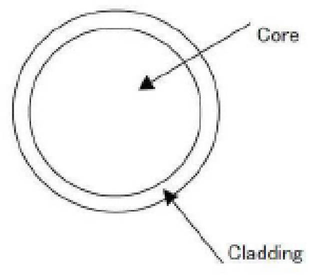
	Unit	Value
Core Diameter	µm	797 - 857
Cladding Diameter	µm	970 - 1030
Approximate Weight	g/m	.785

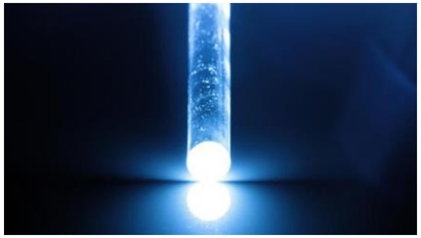
http://i-fiberoptics.com/fluorescent-fiber-detail.php?id=1020

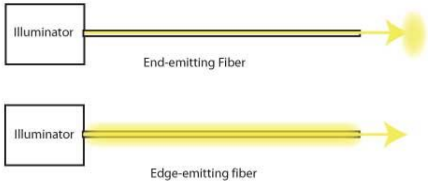
Side emiting fiber - fiberfin

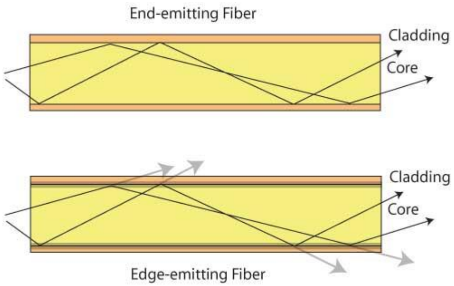
Product Data:

1. Fiber core material MMA Polymer
2. Cladding material PTFE
3. Minimum bending radius 6 x diameter
4. Wavelength range 400-700nm
5. Interior Refractive Index 1.475
6. Exterior Refractive Index 1.375









Specifications:

Item		Unit	Index	Testing method
Structural Parameters	Core diameter	mm	2	JIS C 6863
	Cladding diameter	mm	2	
	Cladding non-circularity	%	≤6	
	Length	m/roll	100	
Optical Properties	Attenuation	dB/km	≤700	650nm JIS C 6863
	Numerical Apertures	/	0.65	
	Attenuation (95% RH)	dB/km	300-350	
Mechanical Properties	Repeated bending (200times)	dB	Loss added ≤2	JIS C 6861
	Tensile strength	N	70	
	Twisting (5times)	dB	Loss added ≤2	
	Impacting (0.4N/meter)	dB	Loss added ≤2	

Operating temperature: - 40℃ to 70℃

Recommended Storage temperature: -10℃ to 35℃

http://www.fiberfin.com/product/side-emitting-1mm-diameter-bare-fiber/

Simplified fluorescent fiber model

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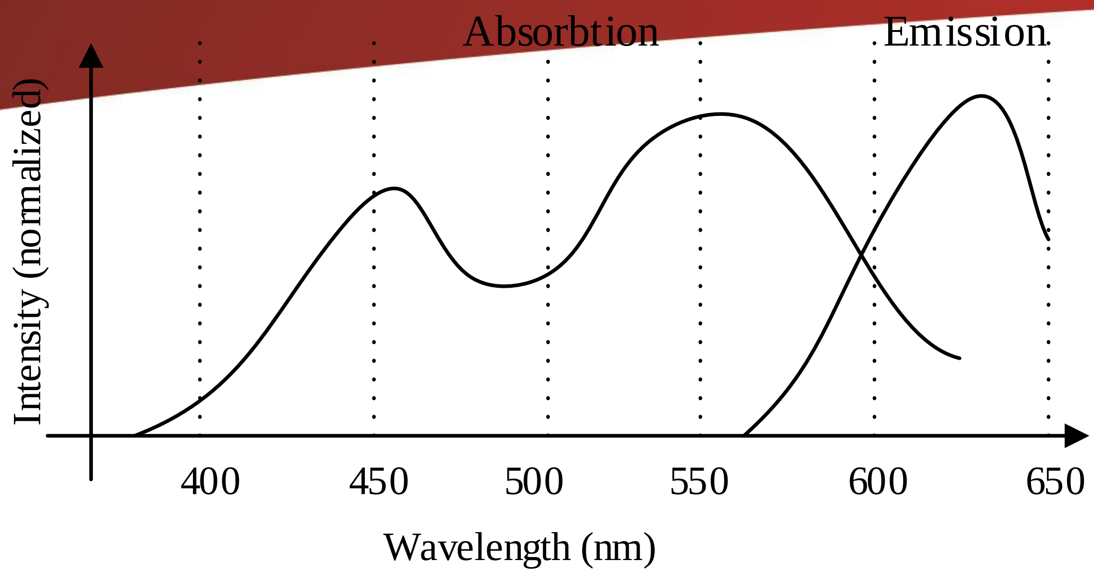

Qualitative plot of the red fluorescent fiber absorption and emission spectra

Total fluorescent power per unit thickness of fiber:

$$P_T = 4\pi \cdot \pi a^2 \cdot \rho \cdot pI$$

Where:

a is the fiber core radius,

ρ is the volume density of the fluorescent material,

I is the source intensity

p accounts for the fluorescent emission probability per unit solid angle

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Simplified fluorescent fiber model

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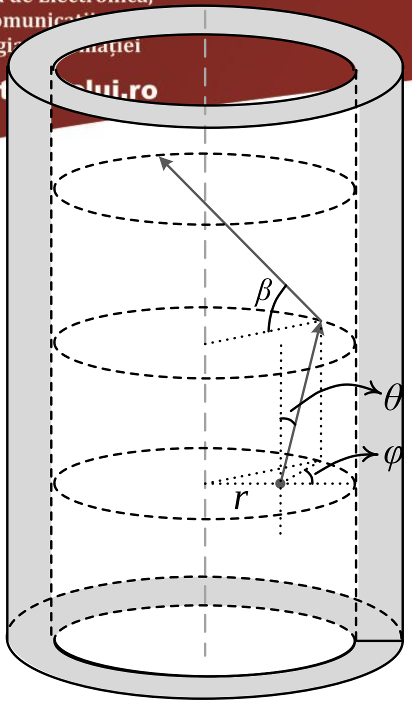

3-dimensional view of the fluorescent optical fiber illustrating a skew ray

The condition for total internal refection (TIR) is

$$\cos\theta > \frac{n_{cl}}{n_{co}}$$

azimuth φ
elevation $(\pi/2 - \theta)$
incidence angle β,
then guided fluorescence signal:

$$P_N = P_T \cdot (1 - \cos\theta_0)$$

Lateral emission power:

$$P_W = P_T \cdot (1 - \cos\theta_0) \cdot \cos\theta_0$$

Fluorescent fiber trapping efficiency:

$$TE = \frac{P_N + P_W}{4\pi^2 a^2 \rho p I} = 1 - \left(\frac{n_{cl}}{n_{co}}\right)^2$$

J. D. Weiss, "Trapping efficiency of fluorescent optical fibers", Optical Engineering, vol. 54, no. 2, 2015.

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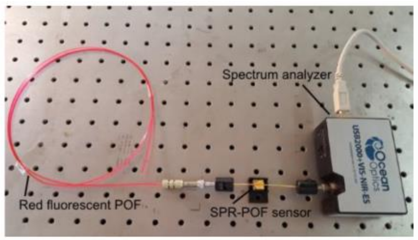
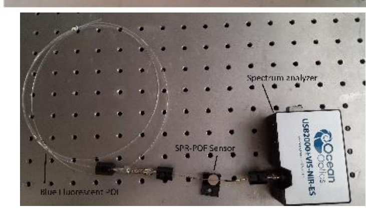
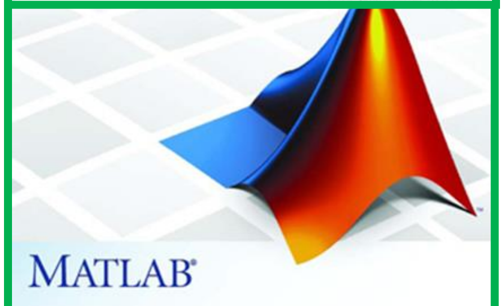
Experimental setup for optical sensor

White Light Source

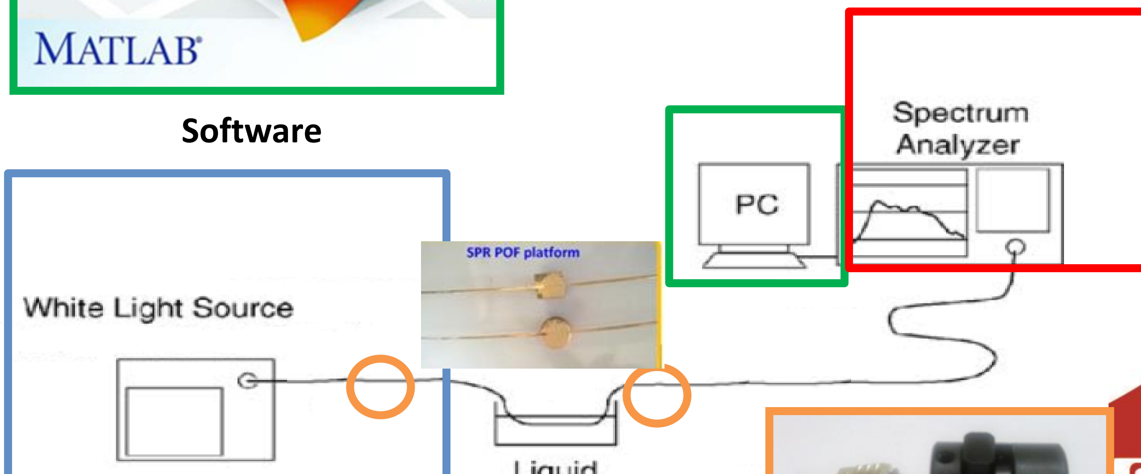






Software

Spectrum analyzer
(200 ÷ 1100 nm)



SMA connectors

Galatus Ramona, Voiculescu E, Cennamo N, Luongo L, Zeni L, "Augmented workplace for SPR sensor application", 2016 IEEE Sensors Applications Symposium (SAS), Pages: 1 – 4 (2016

Comparison simple SPR-POF and F-POF

Table 1. Performance comparison for the two sensors configurations: 250 µm and 1,000 µm diameter POF, respectively.

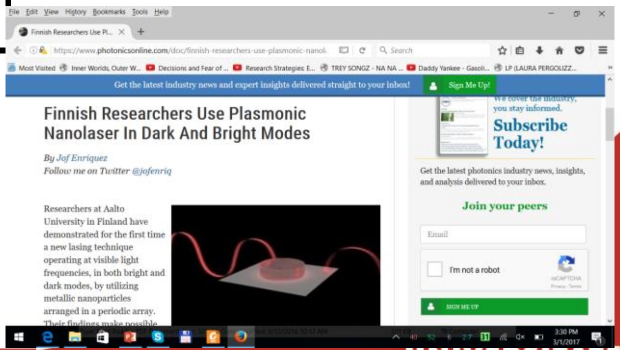
POF Diameter [µm]	Resolution (Δn) [RIU]	Signal-to-noise ratio (SNR)	Sensitivity (S_n) [nm/RIU]	FWHM/Δn [nm/RIU]
250	0.0027	1.7548	0.549×10^3	0.298×10^3
1,000	0.0010	0.8569	1.325×10^3	1.495×10^3

TABLE I. SENSOR PERFORMANCES ANALISYS

External Refractive index	Performance parameters of the SPR-POF sensor			
	Sensitivity (S) [nm/RIU]	*Resolution (Δn) [RIU]*	*FWHM [nm]*	*SNR*
1.344	1044	$1.2 \cdot 10^{-3}$	82	0.9

SNR-The narrower the SPR curve the higher the detection accurac

Atop the nanoparticles were added organic fluorescent dye molecules, which were used to pump the input energy that is needed for lasing.



https://www.photonicsonline.com/doc/finnish-researchers-use-plasmonic-nanolaser-in-dark-and-

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SPR bio-sensor setup

side emitting plastic optical fiber FiberFin (*FF-DSOF-2*) with 2 mm fiber solid core diameter – sensitivity increases in comparison with simple POF-PMMA 1.3x10^3 to S=1.6279x10^3

The scattering effect

-multiple micro bending of the fiber axis or

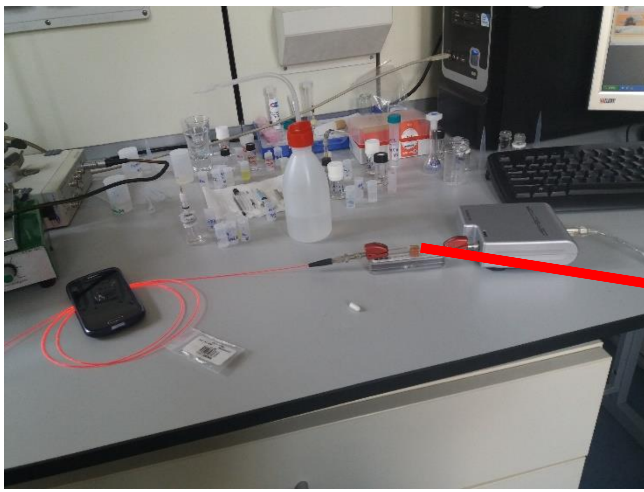
-adding specific scatterers,

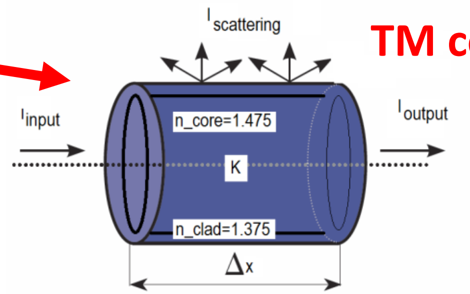
-inserting the fluorescent additives into the fiber core or cladding material, --

-creating asymmetries in the fiber core/cladding geometry,

-increasing the refractive index of the fiber cladding material over that of the core material,

-leaving air bubbles as diffusive cavities inside the fiber core or cladding etc.





TM component

SPR Based Hybrid Electro-Optic Biosensor Platform

SPR-cell with side emitting plastic optical fiber

***2017 IEEE** 23rd International Symposium for Design and Technology in Electronic Packaging (**SIITME**) – publish*

Janis Spigulis, “Application prospects of silica core side-glowing optical fibers”, Optical Fibers: Applications, edited by Leszek R. Jaroszewicz, Brian Culshaw, Anna Grazia Mignani, Proc. of SPIE Vol. 5952, 595203, (2005) · 0277-786X/05/$15 · doi: 10.1117/12.622112

J. Spigulis, “Side-emitting fibers brighten our world,” Opt. Photonics News 16(10), 2005, pp36–39.

M. Krehel et al., “Development of a luminous textile for reflective pulse oximetry measurements,” Biomed. Opt. Express 5(8), 2014, pp2537–2547.

R. George and L. J.Walsh, “Performance assessment of novel side firing flexible optical fibers for dental applications,” Lasers Surg. Med. 41(3), 214–221 (2009).

Plasmonic Sensing in D-Shaped POFs With Fluorescent Optical Fibers as Light Sources, IEEE Transactions on Instrumentation and Measurement (Volume: PP, Issue: 99), pages 1-6, Sept 2017

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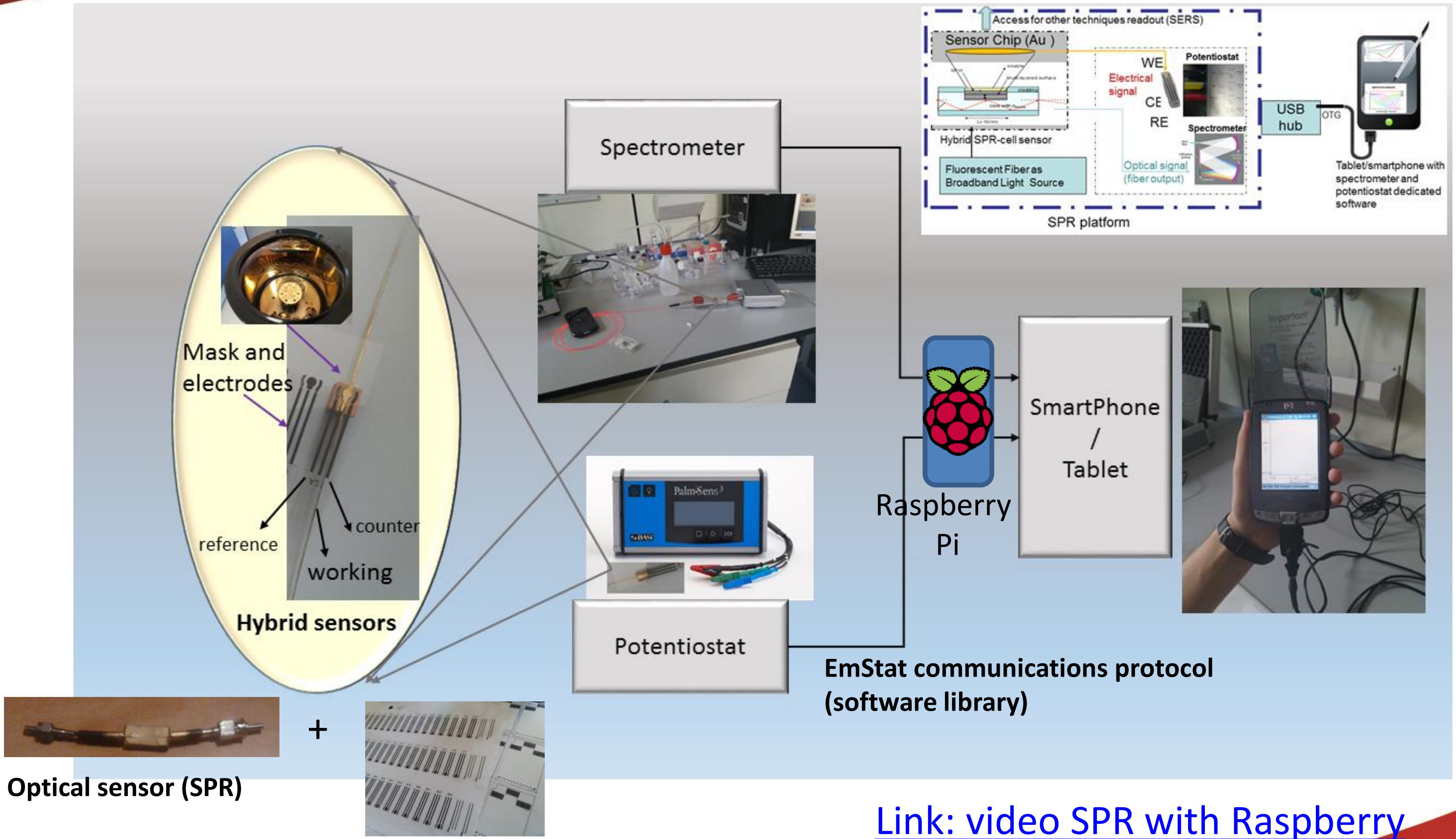
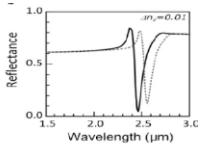
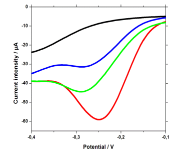
Hybrid sensor- portable platform







Link: video SPR with Raspberry

Ramona Galatus, Bogdan Feier, Cecilia Cristea, Nunzio Cennamo, Luigi Zeni, **SPR Based Hybrid Electro-Optic Biosensor for β-Lactam Antibiotics Determination in Water,** Remote Sensing and Modeling of Ecosystems for Sustainability XIV, edited by Wei Gao,Ni-Bin Chang, Jinnian Wang, Proc. of SPIE Vol. 10405, 104050C · © 2017 SPIE CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2273318

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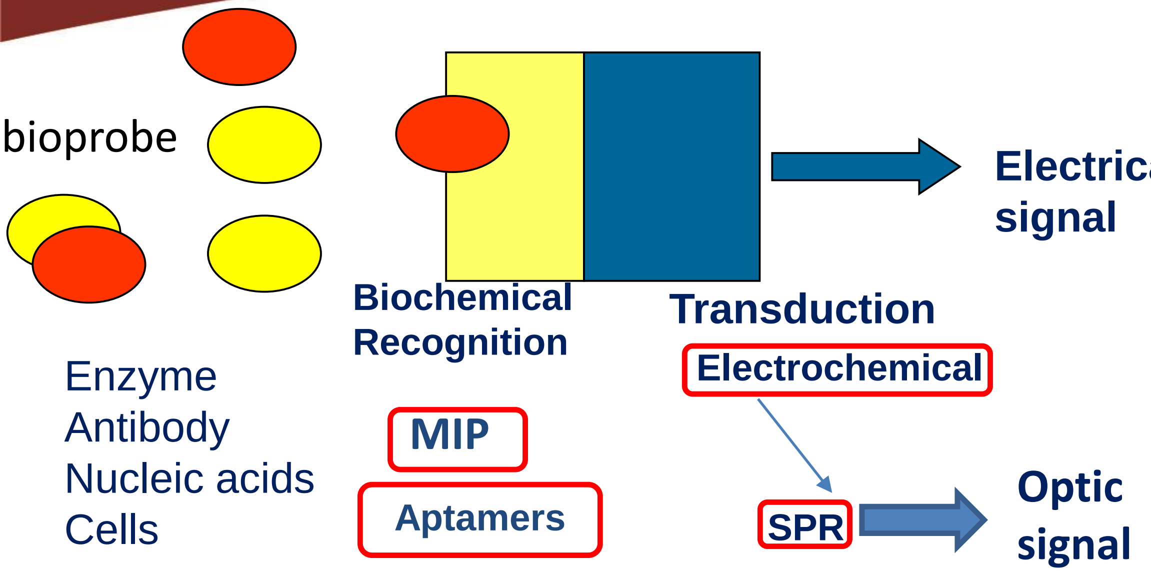
Electrochemical sensors principle



- Aptamers as recognition elements in sensors – short fragments of nucleic acids (DNA or RNA), can assume stable secondary structures and that they can be easily synthesized in vitro and functionalized that bind to specific targets with high affinity
- *Advantages*:
  - ✓ High specificity for the target (max selectivity)
  - ✓ Stability
  - ✓ Resistance to denaturation
  - ✓ Reduced batch-to-batch variations in Chemical Manufacturing Processes (cell-SELEX)

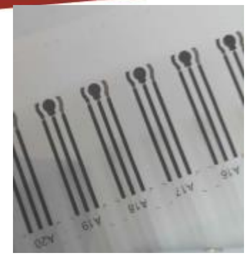
(Mascini-Aptamers in Bioanalysis- 2009)

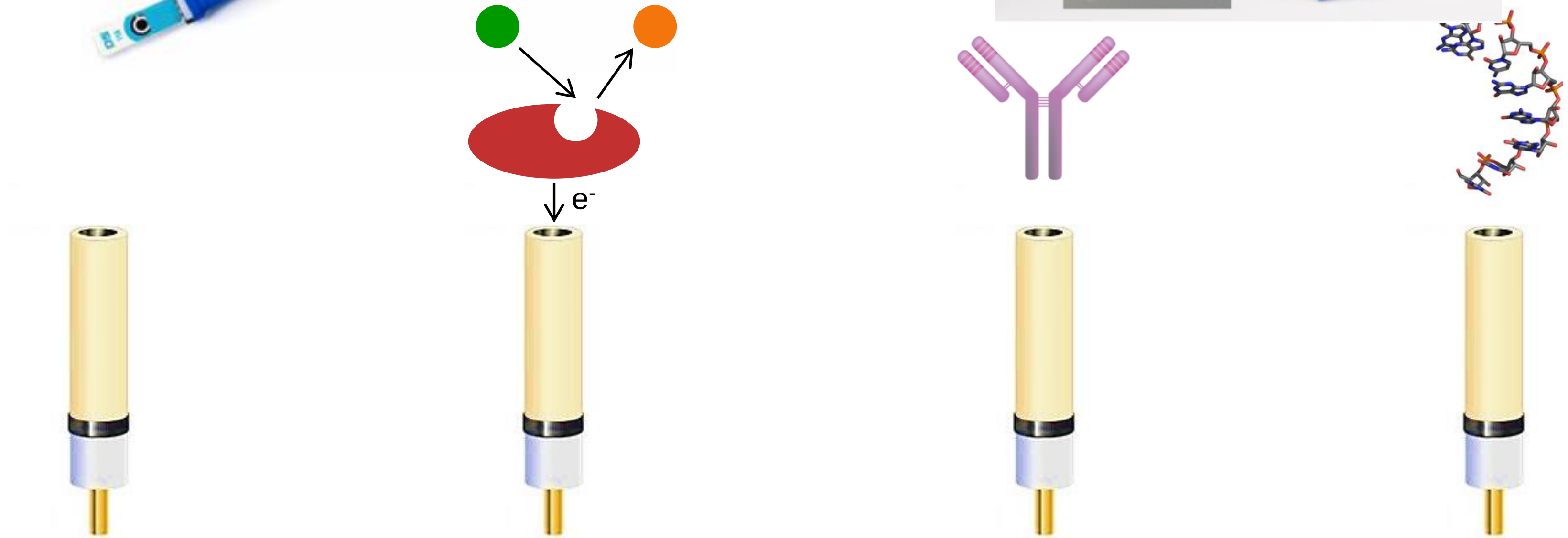
✓ A chemical sensor is a device that transforms *chemical information* into an *analytically useful signal.*

✓ Sensors contain **two basic functional units**:

- ***a receptor***, respond to a stimulation: chemical information → into a form of energy (high degree of selectivity) which may be measured ***by the***
- ***transducer***, which is capable of transforming the energy carrying the chemical information about the sample → a useful analytical signal.

Screen printed electrodes

Direct detection

- ✔ cheapest
- ✗ lacks selectivity

Enzymatic amperometric sensors

- ✔ selective
- ✗ special conditions

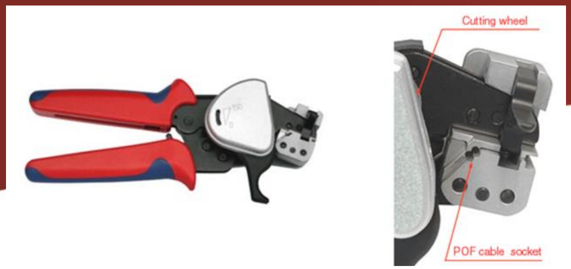
Immunosensors

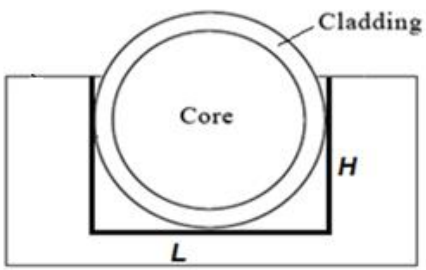
- ✔ specific
- ✗ special conditions
- ✗ expensive

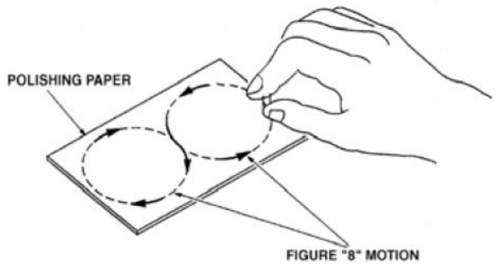
Aptasensors

- ✔ specific
- ✔ stable
- ✔ cheaper

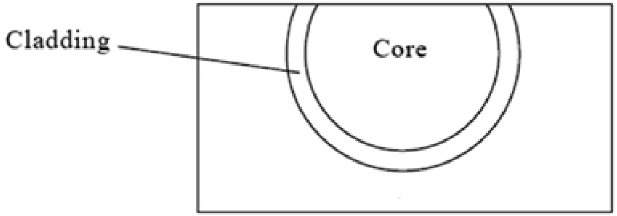
A simple optical platform: SPR in POF



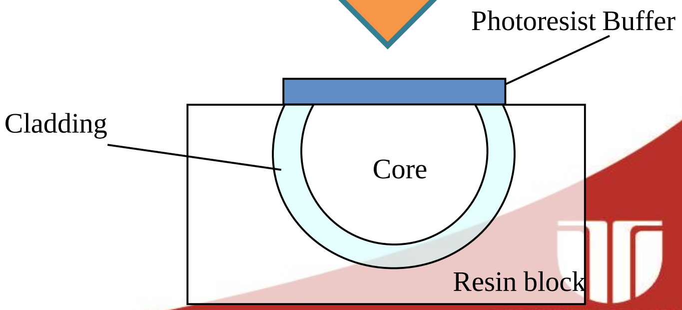


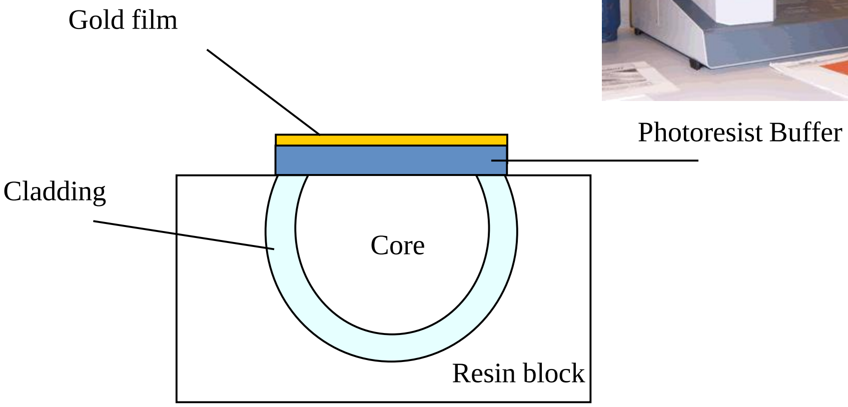


Spin coater



Sputter coater





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Design: SPR in side emitting fiber

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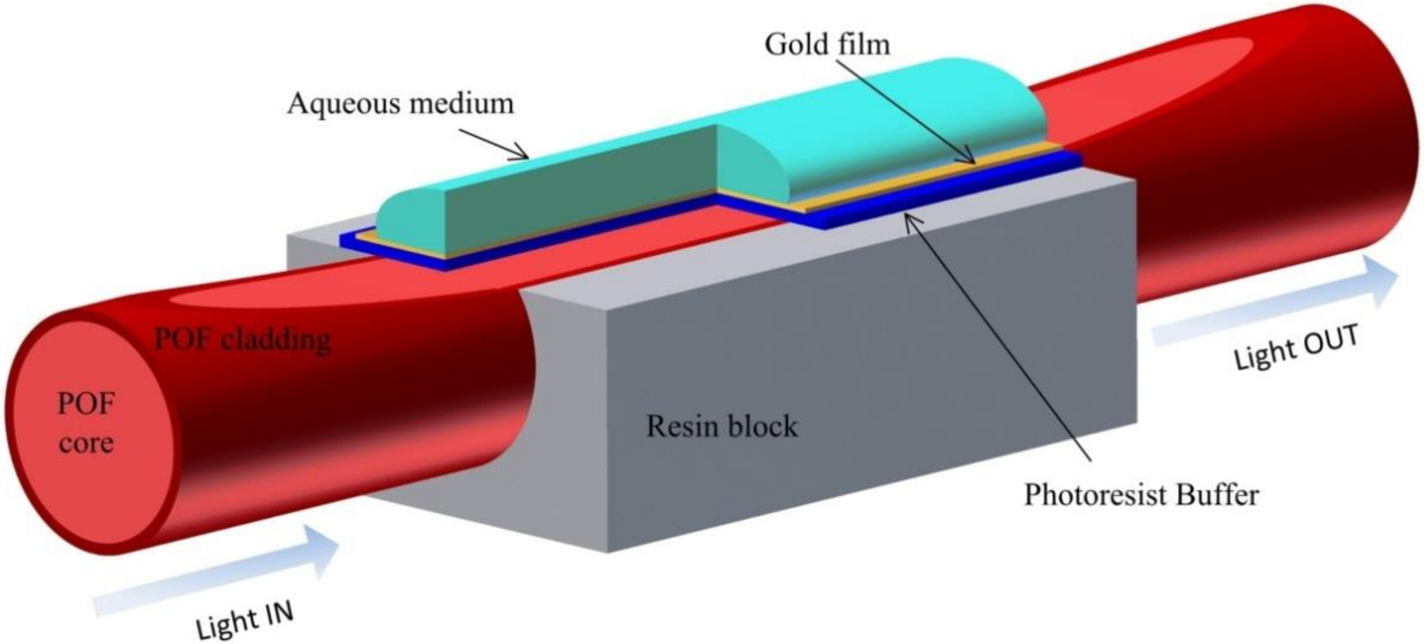
- Core (PMMA) 980 µm ; RI=1.49
- Fluorinated cladding 20 µm; RI=1.41
- Microposit S1813 Photoresist 1.5 µm; RI=1.61
- Gold film 50 nm



POFs are especially advantageous due to their excellent **flexibility**, easy manipulation, great **numerical aperture**, large **diameter**, and the fact that plastic is able to withstand smaller **bend radii** than glass!

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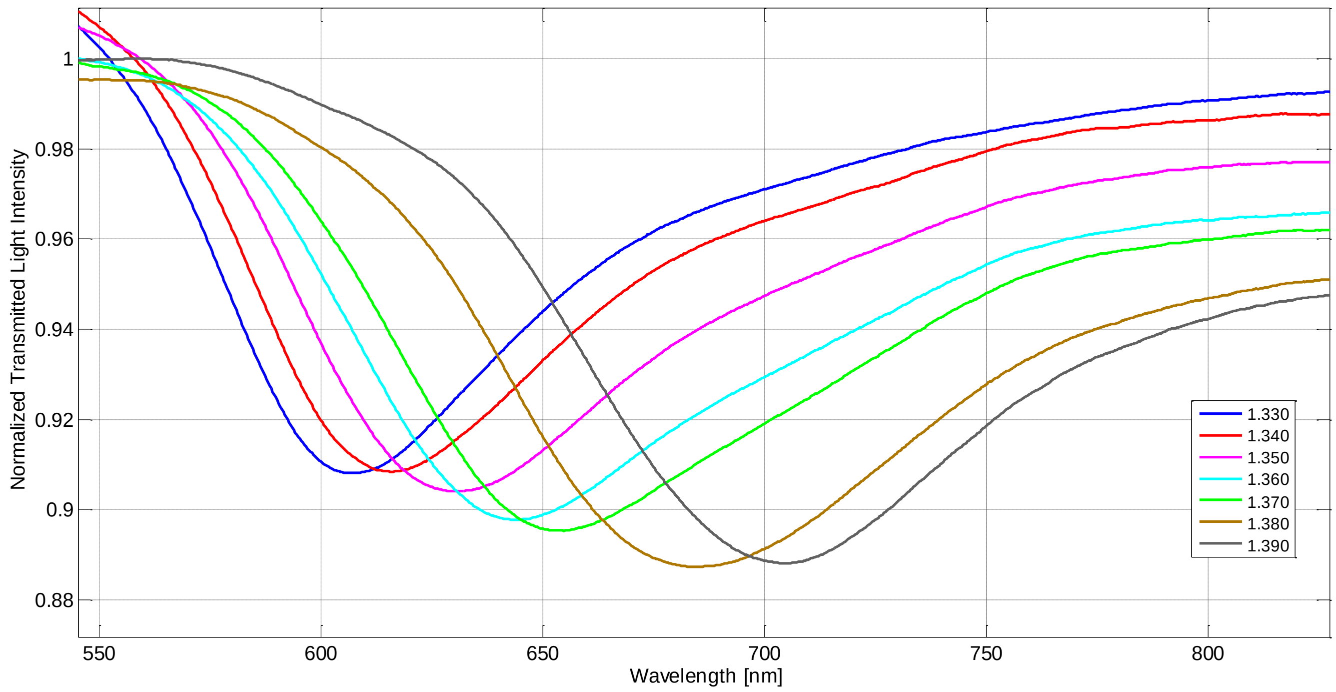
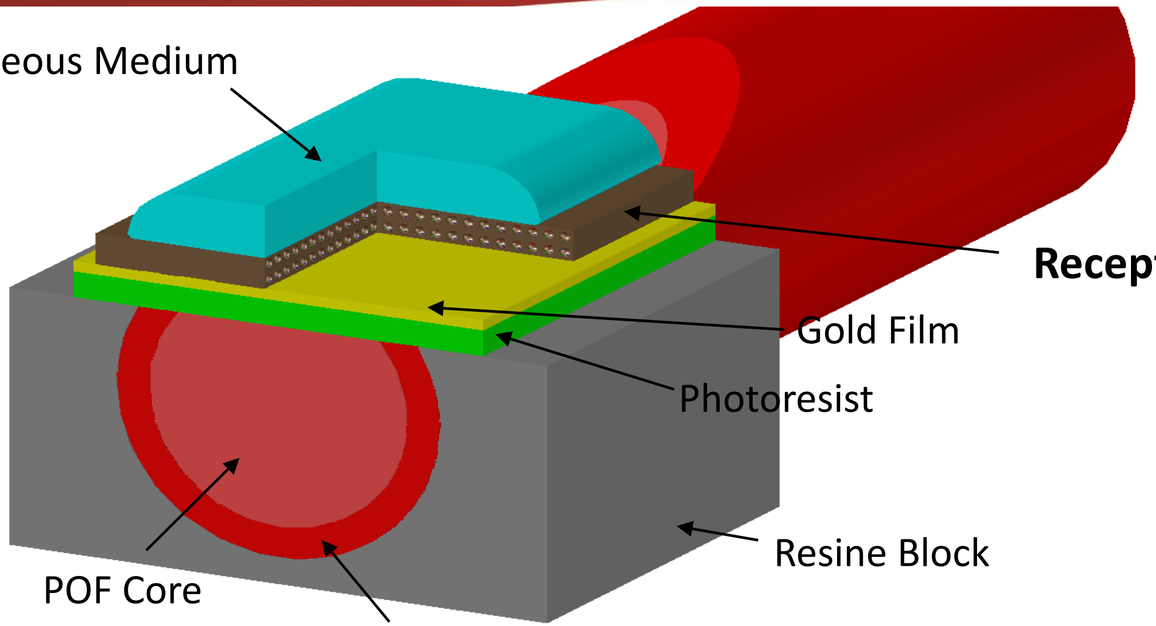
Basic platform characteristic



S = 10 $^{-3}$ ÷ 10 $^{-4}$ [nm/RIU]

SPR Bio-chemical sensors app



Platform exploiting a suitable receptor layer

Results have been achieved on the selective detection of:

- **TNT/** Trinitrotoluene exposive for **security applications**
- **Furfural** (furan-2-carbaldehyde) for **industrial applications**
- **Butanal** for **environmental monitoring** & **food safety**
- **Transglutaminase/anti-transglutaminase antibodies (celiac disease), Fe(III), L-nicotine and Vascular**
- **Endothelial Growth Factor (VEGF)** for **clinical applications** & **cancer diagnosis**

Ref: An easy way to realize SPR aptasensor: A multimode plastic optical fiber platform for cancer biomarkers detection, Talanta · August 2015 , https://www.ncbi.nlm.nih.gov/pubmed/26048828

Electrochemical sensor development and SPR sensor preliminary results

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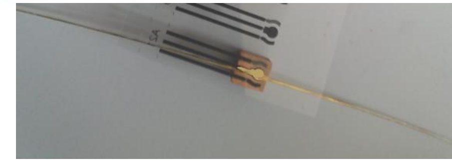


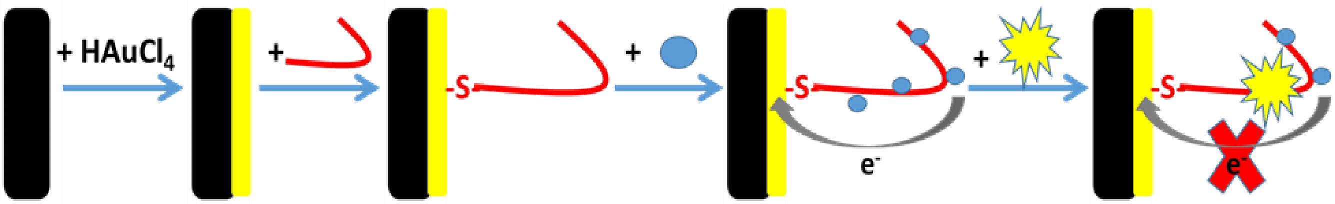
Chloroauric acid
60 µL solution
of 0.6 mM

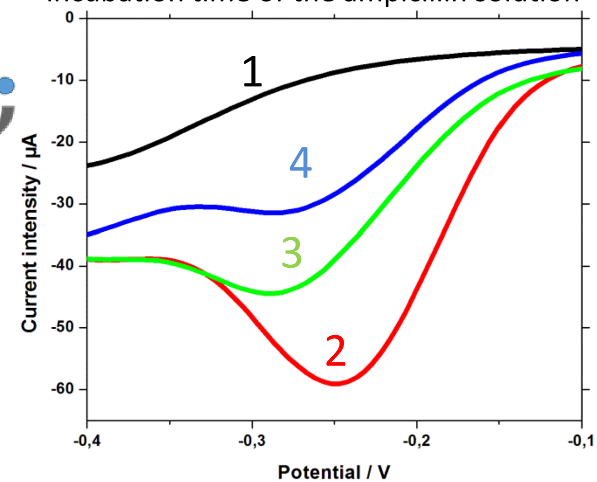
ampicillin-selective aptamer
that contains a thiol group
With high affinity with gold layer

100 µM ampicillin

The attenuation signal is influenced by the
- amount of ampicillin bound by the aptamer,
-which is dependent of the
concentration and
incubation time of the ampicillin solution

1 2 3 30min 4 110min





cycling voltammetry

Aptamer =

a homogenous layer of
gold nanoparticles
at the level of the
working electrode

Au-S covalent bonds
prior to its immobilization,
the aptamer solution was
heated at 93° C for 3 min
in order to unfold the aptamer

Methylene blue =

labeling of the ampicillin aptamer
immobilized on the electrode with
methylene blue, a redox-active label
(incubation for 15 minutes)

Ampicillin =

Resistance variation at the electrode surface

DPVs (**differential pulse voltammetry**) of PBS (phosphate buffer solution) recorded at C-SPE (screen-printed electrode)modified with AuNPs-aptamer (**black**), modified with Au-NPs-aptamer-methyle blue without ampicillin incubation (**red**) and with ampicillin incubation for 30 min (**green**) or for 110 min (**blue**)

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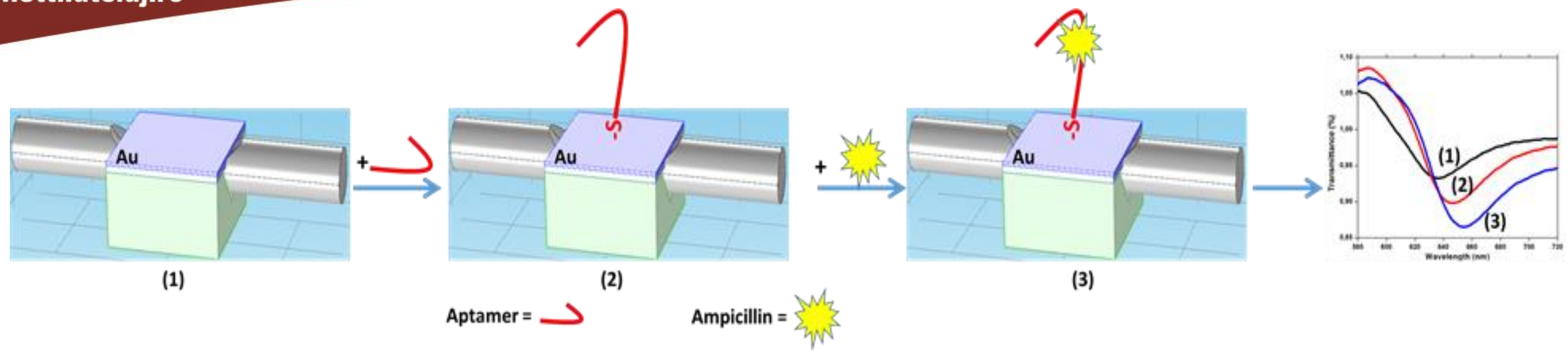
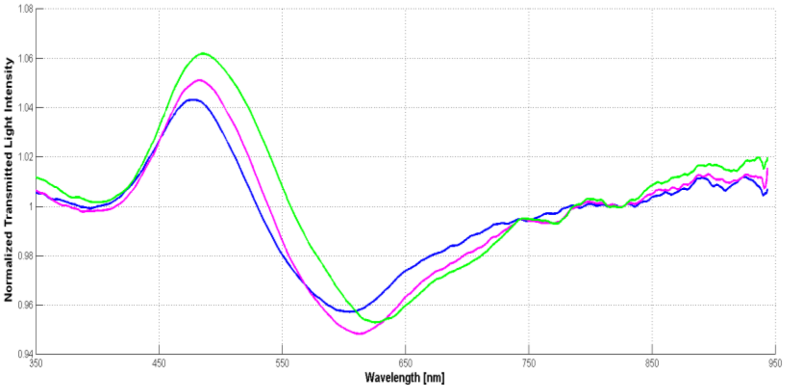
Optical platform for biosensor implementation





- Gold-based SPR sensor using the ampicillin-selective aptamer
- The modification and ampicillin detection procedures are simpler:
  - the aptamer labeling is not needed
  - the AuNPs deposition is necessary to enhance the SPR response for small molecules

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Conclusions 1

- In this paper we presented the development of electrochemical aptasensor for the detection of ampicillin.
- Using methylene blue as label, we proved the immobilization of the aptamer at the surface of the electrochemical sensor working electrode and its capacity in these conditions to bind the ampicillin molecules.
- This approach could be used also for a cost effective and portable hybrid fiber optic SPR biosensor platform based on smart phone data analysis.
- The functionalization protocol for aptamer in electrochemical configuration can be used on hybrid SPR with gold chip . The light-weight optical components (fluorescent fiber and portable spectrometer) and electrochemical electrodes are connected to a plastic optical fiber cell sensor.
- The SPR platform was evaluated by detecting activation process of the chip surface, for different aqueous solutions as analyte. The resonance wavelength can occur due to adsorption of molecules on the Au chip surface. The kinetic parameters (concentration of the substance and rate of reaction) can be estimated from the optical response curves obtained.
- Preliminary results of hybrid sensor tests, confirm the feasibility of the proposed optical approach. The wavelength based SPR sensors are portable and economical however the resolution and sensitivity need to be improved (100nM~ 10nm).
- Therefore for **further improvements** the sandwich technique with gold nanoparticles (nano-mole), as well as the use of biomimetic approaches like micro-imprinted or molecular imprinted polymer (MIP) could be use (femto-mole).

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Thanks to working groups
Areas of expertise:

UMF group: www.umfluj.ro

- Bioelectrochemistry and separation techniques; imuno-, apta- and genosensors for a wide variety of analytes (food, environmental and pharmaceutical samples); biomedical analysis, rapid tests for early cancer diagnosis, brain electrochemistry.

ICS group

- **Photonics and optoelectronics**– the modelling and simulation of large mode area (LMA) fibres (Patent, **COST 299**), rare earth doped fibres (Liekki LAD), microring optical amplifiers **(UNIZAR*),** bending effects and non-linear effects at transmission through optical fibres, optical plasmonic sensors (**Postdoctoral project**),** biosensors (**PED69, COST *MP1401*****), distributed optical sensors (**DAM-FU**), international photonics projects (Horizon2020- COST TD1001 TD1205 MP1307).

***Femtosecond-laser Assisted Self-Organization Processes for Photonics: Design of Photonic Devices and Experimental Characterization (FASOP-Design, 2015-2018)**

**** Algorithms and methods for optical signal processing, 4D-POSTDOC**

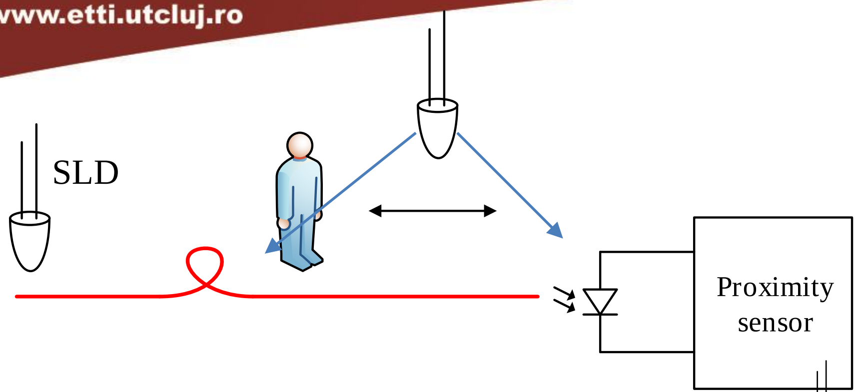
***** COST MP1401 Management Committee –"Advanced fibre laser and coherent source as tools for society, manufacturing and lifescience"**

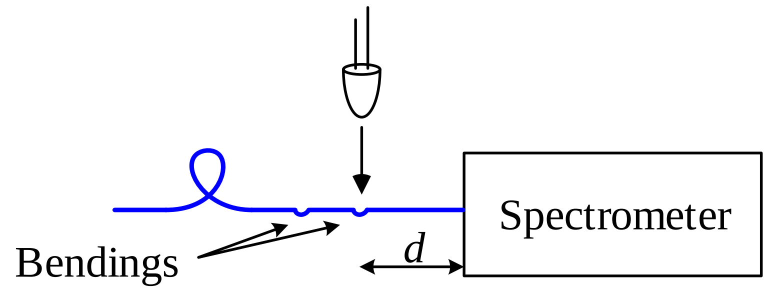
- **Advanced design techniques of analog and digital integrated circuits** – the design of complex electronic circuit structures under the Mentor Graphics design environment: reconfigurable circuits with applications in auditory prosthesis, transmission of the biomedical parameters over an electromagnetic link, radiofrequency receptors, low-power integrated circuits.

- **Design of mixed analog/digital circuits for telecommunication systems** – the study and the development of some analog adaptive circuits, aimed for the practical realization of the "software defined radio" concept. The emphasis is on the development of some reconfigurable filter architectures with programmable parameters, digital control through evolutionary methods.

- **Design of analog circuits with computational intelligence techniques** – the development and implementation in Matlab of automatic design (sizing) algorithms for some analog modules with optimization methods based on fuzzy logic and genetic algorithms. Performance evaluation is performed by including some pre-designed fuzzy models of the performance functions, or an analog circuit simulator, into the optimization loop.

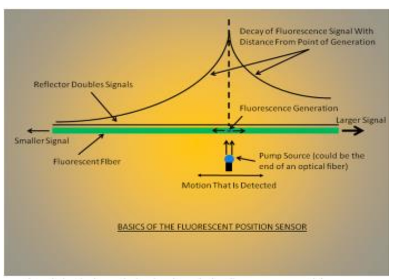
II. Fluorescent position sensors

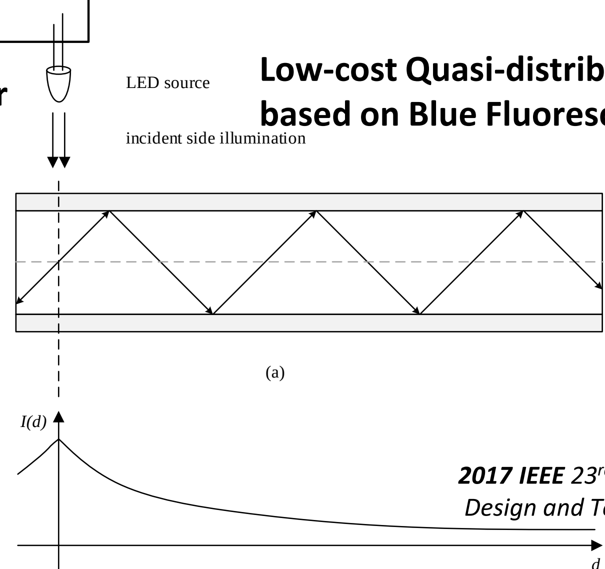




Distributed fluorescent optical fiber proximity sensor

Laguesse89, Laguesse91





Low-cost Quasi-distributed Position Sensing Platform based on Blue Fluorescent Optical Fiber

***2017 IEEE** 23rd International Symposium for Design and Technology in Electronic Packaging (**SIITME**)*

XIVth International Conference on Molecular Spectroscopy

http://www.icms.agh.edu.pl/, 3.09-7.09.2017 - Białka Tatrzańska, Poland

[1] *Bases of Electronics Department, Technical University of Cluj-Napoca, Str. Memorandumului nr. 28, Romania,*

[2]*Department of Power Engineering Photonics and Lighting Technology, Białystok Technical University, Bialystok, Poland,*

[3] *TOL - Laser & Optical Technologies, I3A, University of Zaragoza, Spain.*

M. F. Laguesse, "Optical potentiometer using fluorescent optical fiber for position measurement", Applied Optics, Vol. 28, No. 23, pp. 5144-5148, De

P. Aiestaran, V. Dominguez, J. Arrue, J. Zubia, "A fluorescent linear optical fiber position sensor", Optical Materials, Vol. 31, No. 7, pp. 1101-1104, Ma

M. F. Laguesse, M. J. Bourdinaud, "Characterization of fluorescent plastic optical fibers for x-ray beam detection", Proceedings of SPIE – Plastic Optic

Fluorescent Optical Position Sensor, US Patent #6,965,709.

Motivation

- The fluorescence is useful is in many fields of methrological applications
- The polymers are attractive as a low cost and good optical properties materials for new applications
- Excitation and environmental conditions influence in fluorescence signal transmission in polymeric optical fibers (POF)
- Numerous construction of POF fibre sensor have beeen developed so far (UV, temperature, chemical specices, distance, displacement)
- Distributed sensing is possible using optical fibre technology

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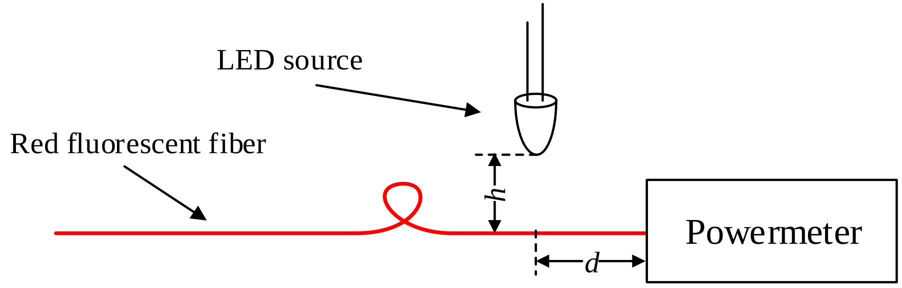
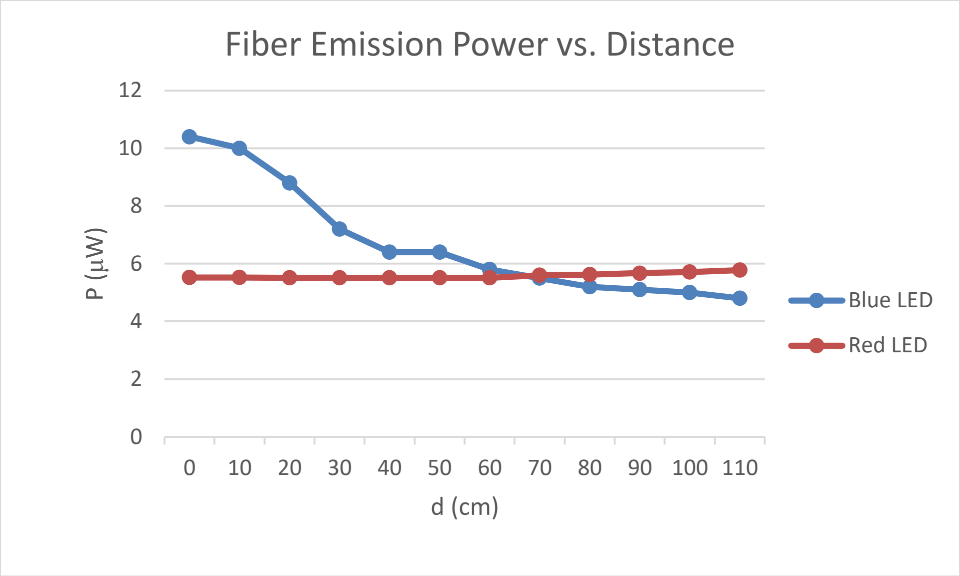
Characterization of the fluorescent fiber

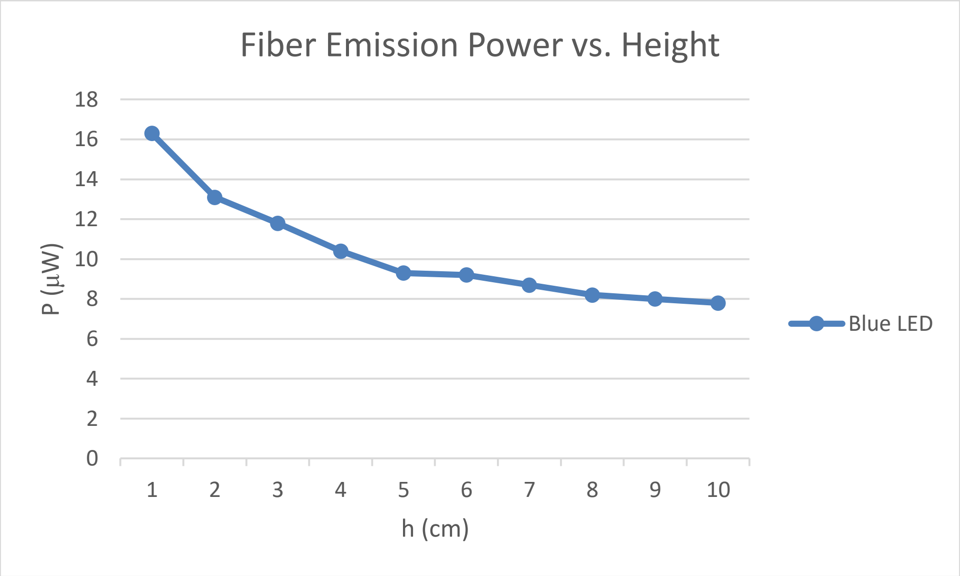


Test setup for the determination of the fiber emission power vs. side illumination parameters

Different excitation wavelength can be used for increasing the sensor accuracy.



Variation of the fiber emission power vs. distance



Variation of the fiber emission power vs. height

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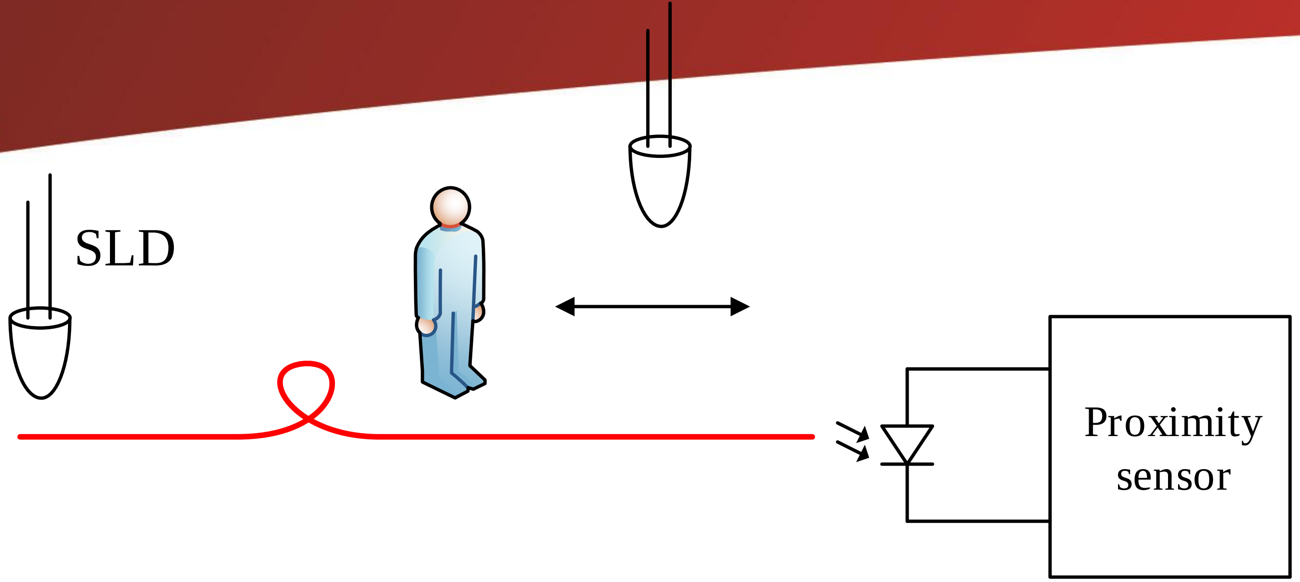
The intruder detection



Proximity sensing scenario following complementary logic proximity sensing

(a)

(b)

(c)

Laboratory implementation of the proposed proximity sensor: (a) top view and (b) side view (c) with photodiode driver

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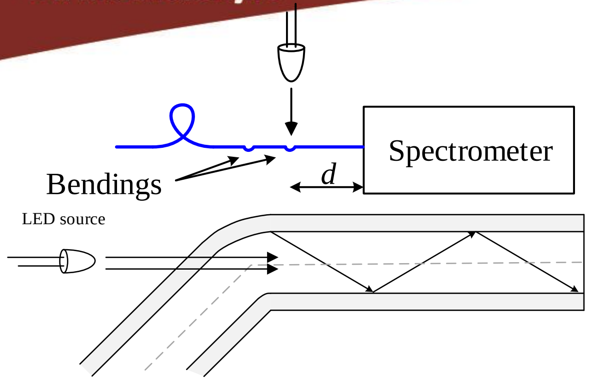
Thus, for short distances d < 40 cm, the position sensor exhibits a fine resolution for distance measurement, given by the resolution of the spectromet

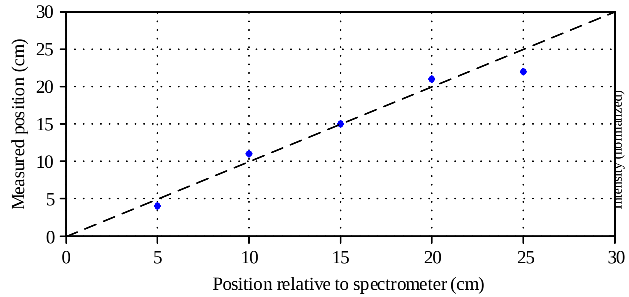
$$\Delta d = \frac{1}{\alpha} \ln \frac{I_t^{d=40cm}}{I_t^{d=40cm} + \Delta I_t} \quad (4)$$

where $I_t^{d=40cm}$ is the radiation intensity at distance d = 40 cm and ΔI_t is the spectrometer resolution for intensity measurement.



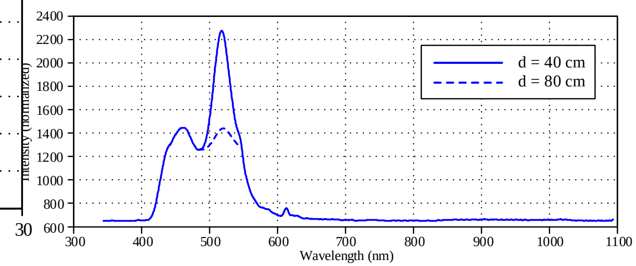
Application of incident light to a fiber bending

Position measurement results for d < 40cm with blue incident light

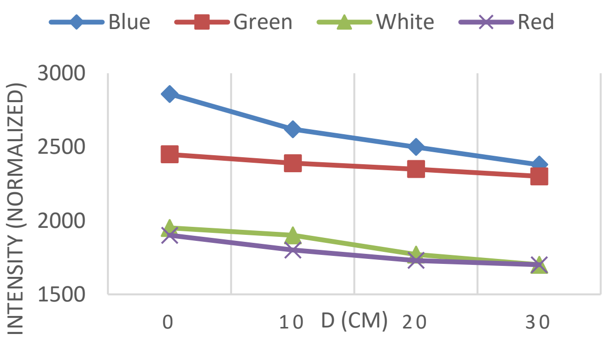


with red incident light

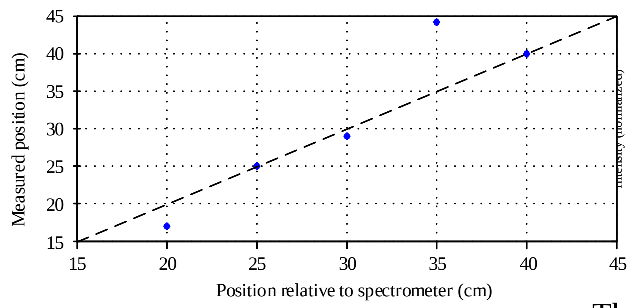
Position measurement results for d > 40cm



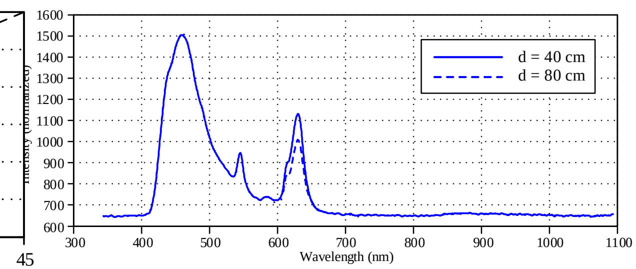
The fluorescent radiation spectrum in the case of green light applied axially via the fiber bindings



Variation of fluoresence intensity vs. distance



with green incident light



The fluorescent radiation spectrum in the case of red light applied axially via the fiber bindings

position sensing is performed by monitoring the wavelength and the intensity of the fiber fluorescence

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Conclusions 2

- **The fluorescence is useful is in numerous sensor applications**
- **Lateral excitation allow low instrumentation cost at efficient fluorescent dye excitation**
- **The proximity sensor based on 81 0087 (red, fluorescent) fibre structure can be used to obtain some specific luminescence properties**
- **The different wavelengths can be used for fluorescence excitation and signal monitoring to obtain accurate and robust measurements**

Thank you for your attention!