The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

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2328-16

Preparatory School to the Winter College on Optics and the Winter College on Optics: Advances in Nano-Optics and Plasmonics

30 January - 17 February, 2012

Applications to bio-sensing

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BLOCH SURFACE WAVES ON PHOTONIC CRYSTALS

APPLICATIONS TO GAS SENSING AND BIOPHOTONICS

SAPIENZA Università di Roma

Department of Basic and Applied Sciences for Engineering

Molecular Photonics Laboratory

Francesco Michelotti

International Centre for Theoretical Physics, Trieste, February 2010

Lecture 4

Applications of BSW to biophotonics (Experimental)

Applications of BSW to biophotonics

We applied the BSW concept to several experimental configurations in the field of biophotonics. Here we shall discuss the following results:

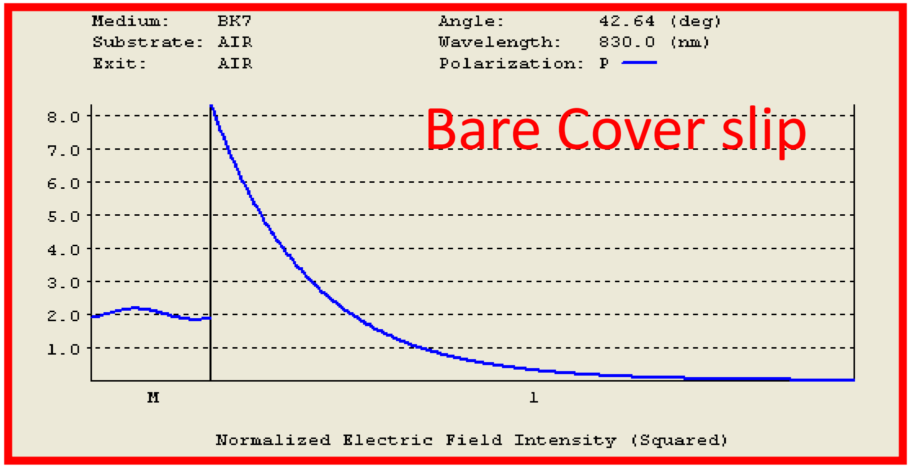
- Experimental determination of fluorescence enhancement by BSW in far and near field experiments.
- Theoretical predictions on the resolution and fluorescence enhancement in Standing Wave – BSW Resonance Microscopy
- Label-Free Biosensing with BSW and its application to the detection of cancer biomarkers

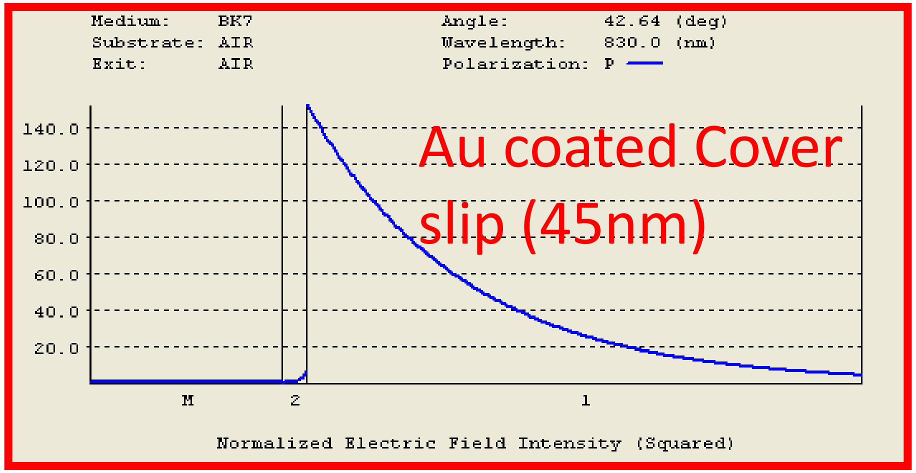
Many other configurations used in biophotonics can take advantage of the properties of BSW but we have not yet investigated them (SERS, SEIRA, TERS, S-TPA , S-SHG, …)

Biophotonics

Experimental determination of fluorescence enhancement by BSW in far and near field experiments

Examples – Fluorescence Imaging





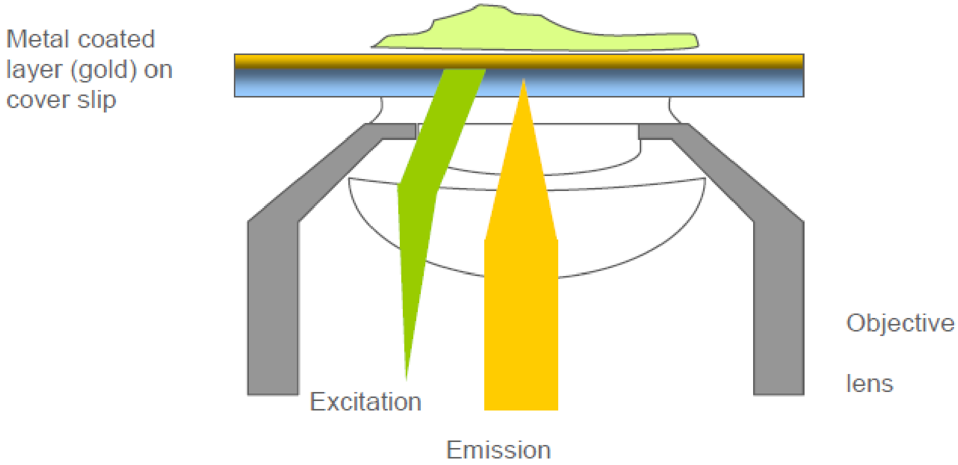
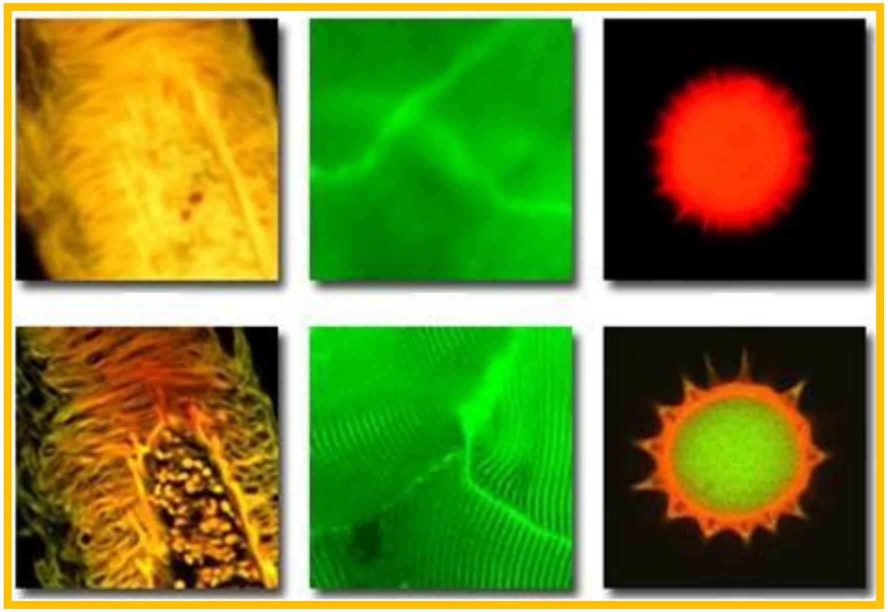


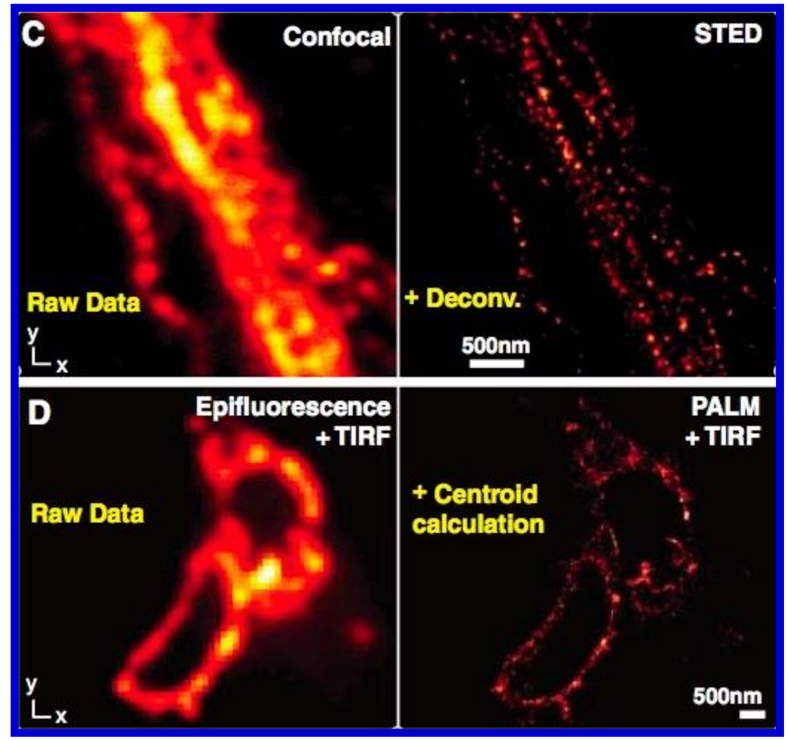
Figure 2-2. An objective-launched set-up for SPCE imaging.

Surface Plasmon Coupled Emission (SPCE)
and
Surface Plasmon Field-enhanced Fluorescence (SPFS)

Fluorescence microscopy

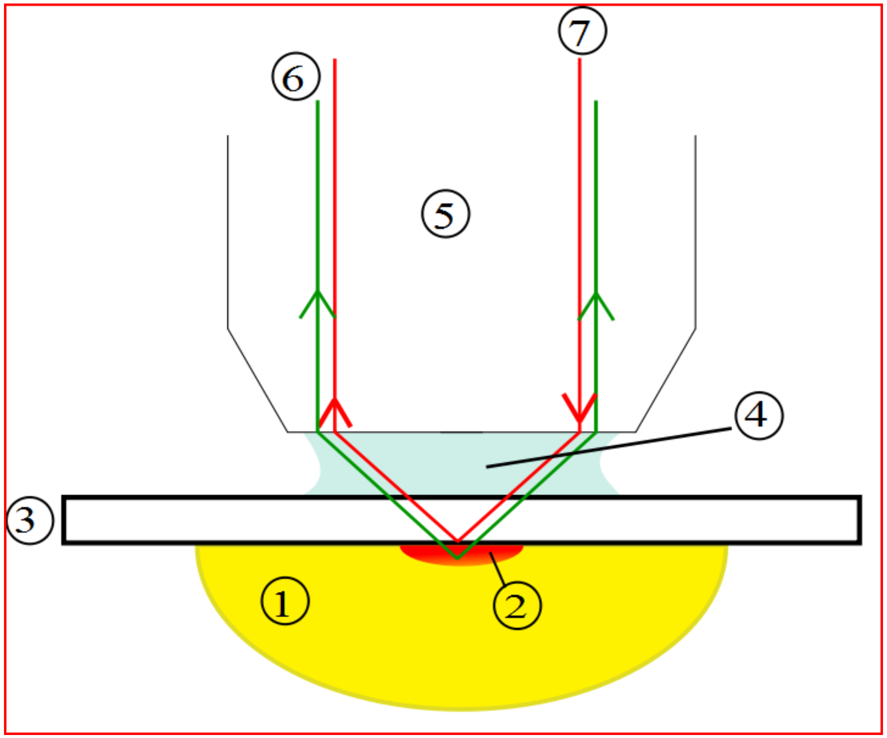


Wide Field Fluorescence Microscopy
vs
Confocal Fluorescence Microscopy



STED and PALM
vs
Confocal and TIRF Microscopies

Fluorescence microscopy



Total internal reflection fluorescence microscopy (TIRFM)

J.R.Lakowicz
Principles of Fluorescence Microscopy
3rd Edition
Chapter 26

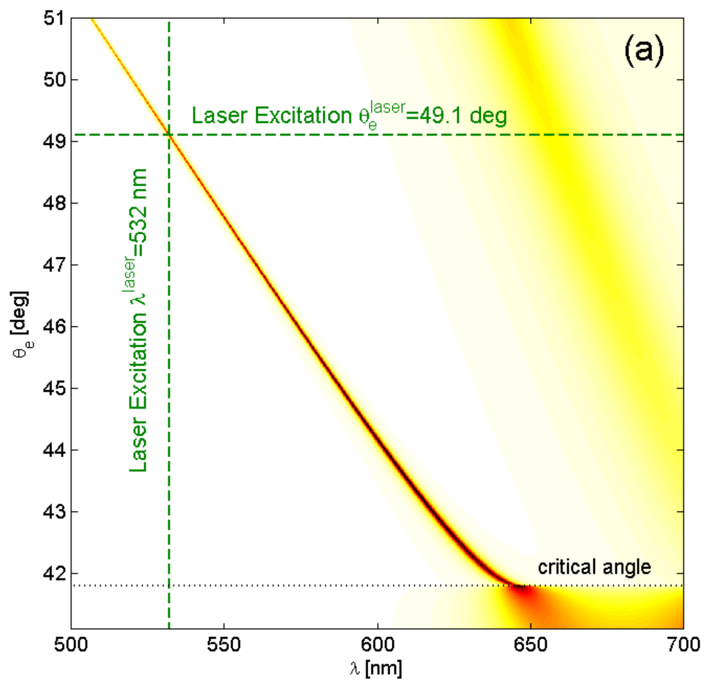
Chapter 26 is the LAST CHAPTER

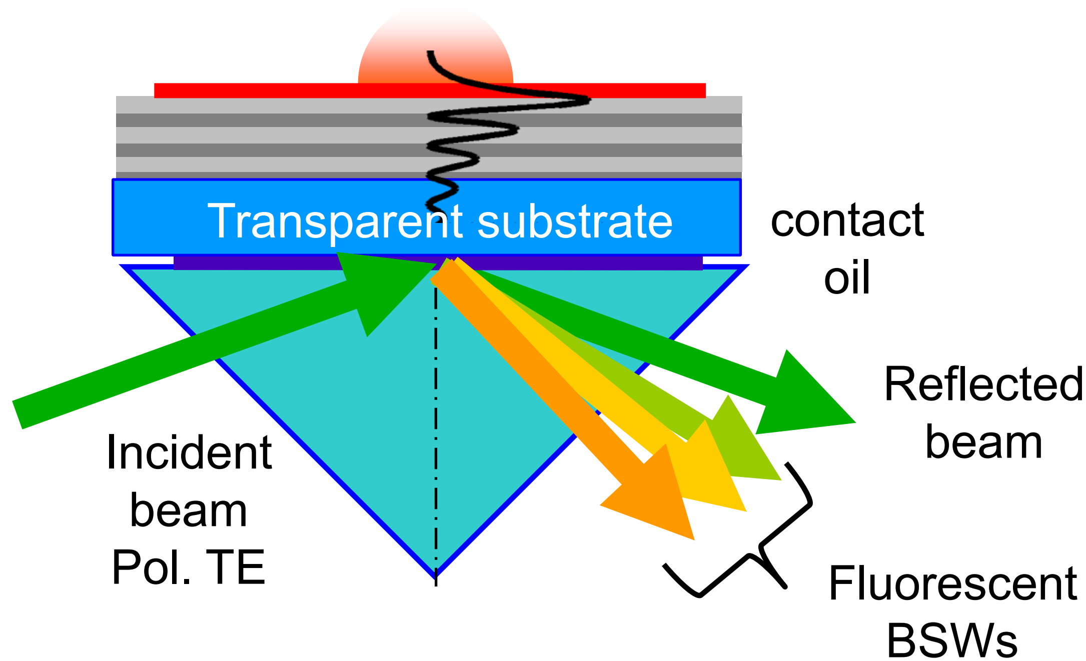
Neumann T, Johansson ML, Kambhampati D, Knoll W. 2002, *Adv Funct Mater* ***12:*** 9–575-586.

SPCE and SPCF Fluorescence with BSW (FF)

Far Field

SPCE and SPCF Fluorescence with BSW (FF)





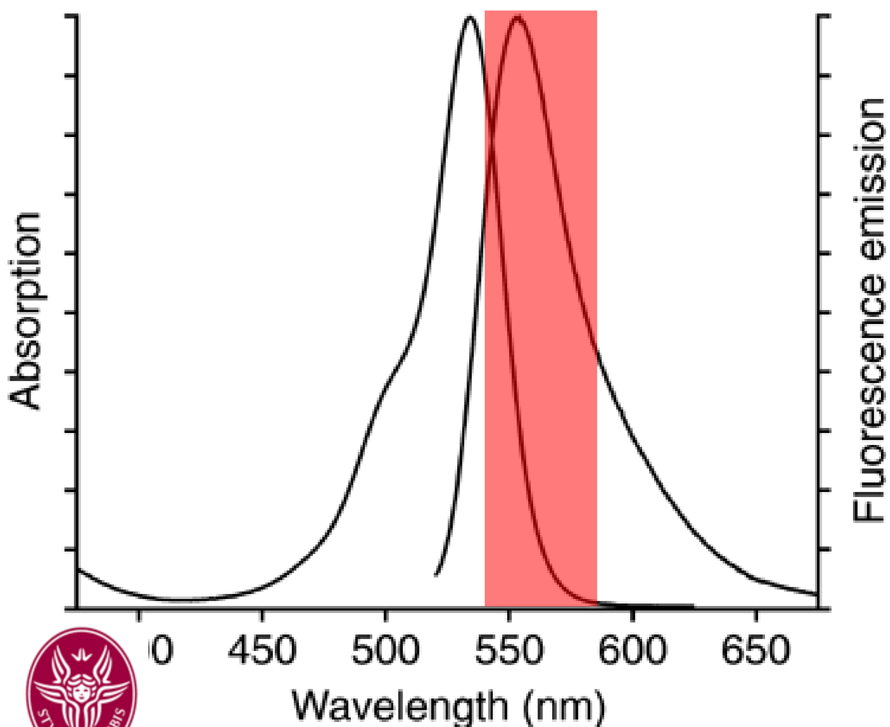
1DPC - Glass / $(HL)^7$ L1 / P / Protein A(AF546) / air

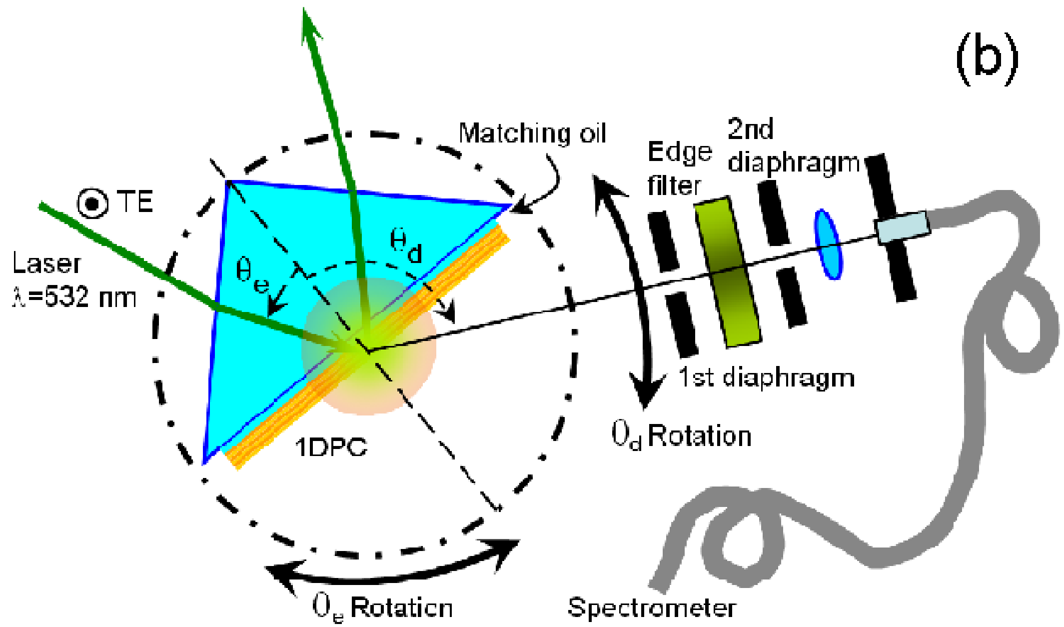
H	(silicon nitride)	n_H=1.99	t_H=79 nm
L	(silicon dioxide)	n_L=1.48	t_L=134 nm
L1	(silicon dioxide)	n_L=1.48	t_{L1}=28 nm
P	(PPAA polymer)	n_P=1.6	t_P=30nm

PPAA was decorated with Protein A labelled with Alexa Fluor 546

Appl. Phys. Lett. 99, 043302 (2011)

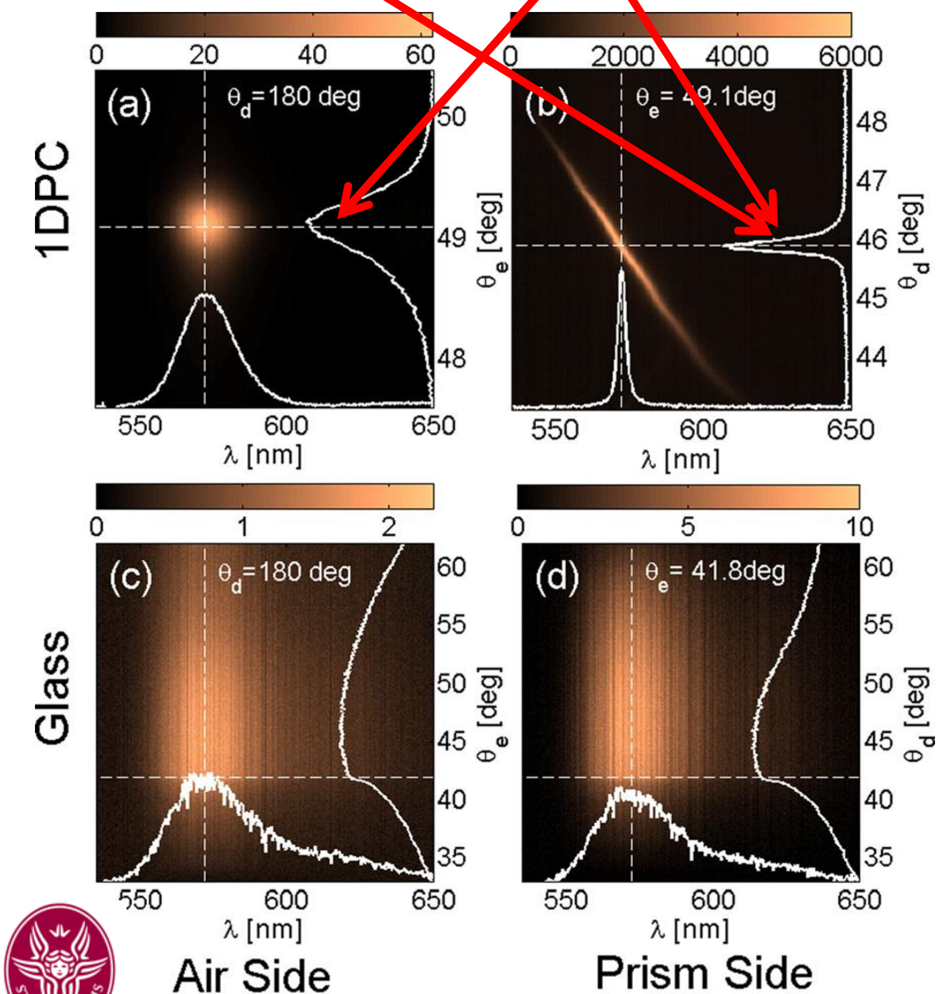
SPCE and SPCF Fluorescence with BSW (FF)

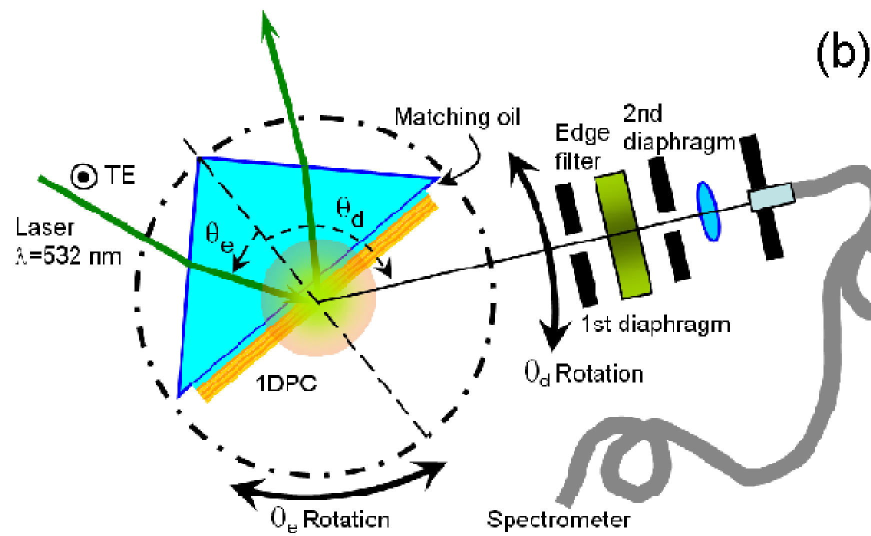




Appl. Phys. Lett. 99, 043302 (2011)

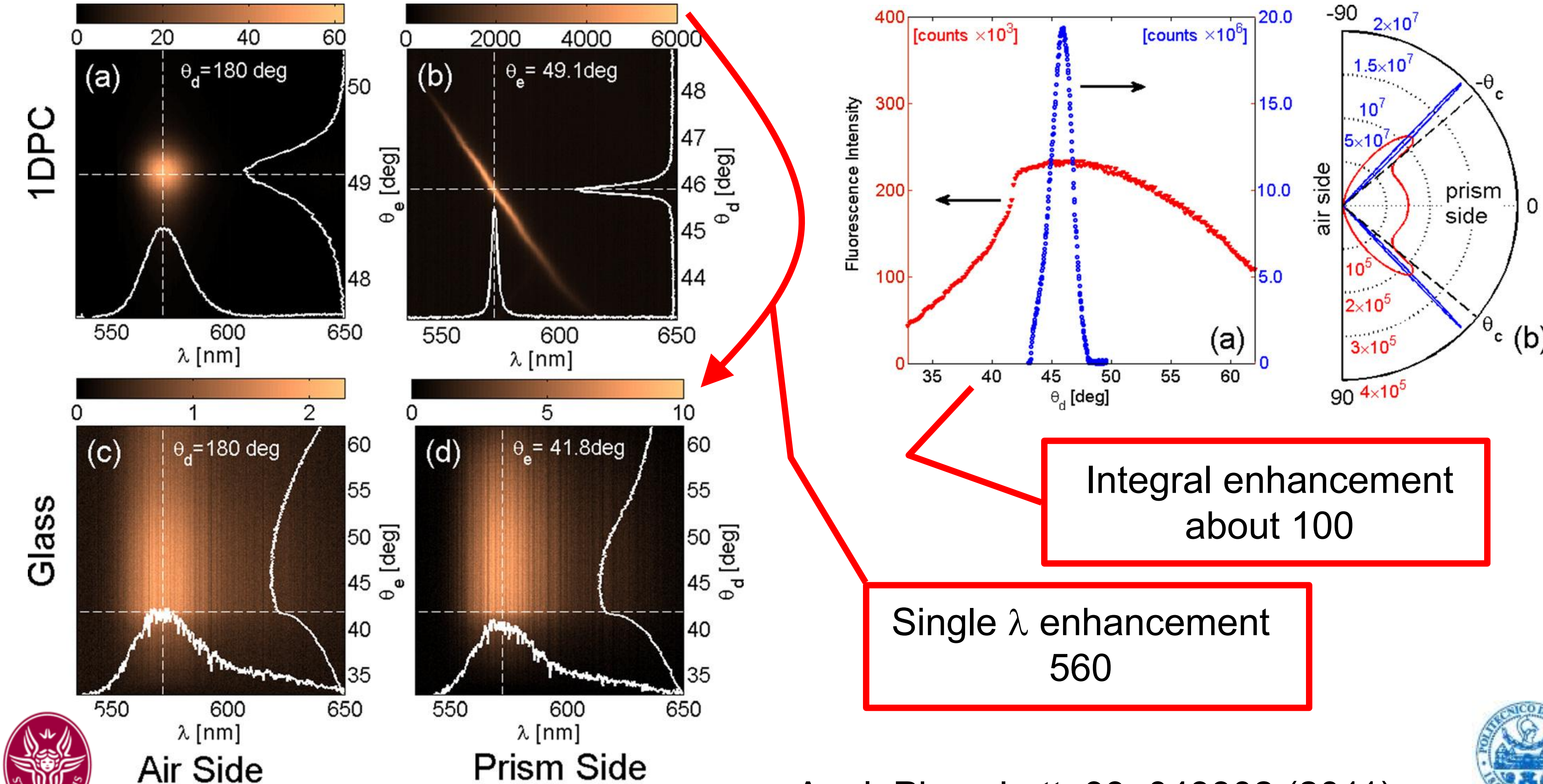
SPCE and SPCF Fluorescence with BSW (FF)





Appl. Phys. Lett. 99, 043302 (2011)

SPCE and SPCF Fluorescence with BSW (FF)



Integral enhancement about 100

Single λ enhancement 560

Appl. Phys. Lett. 99, 043302 (2011)

SPCE and SPCF Fluorescence with BSW (NF)

Near Field

SPCE and SPCF Fluorescence with BSW (NF)

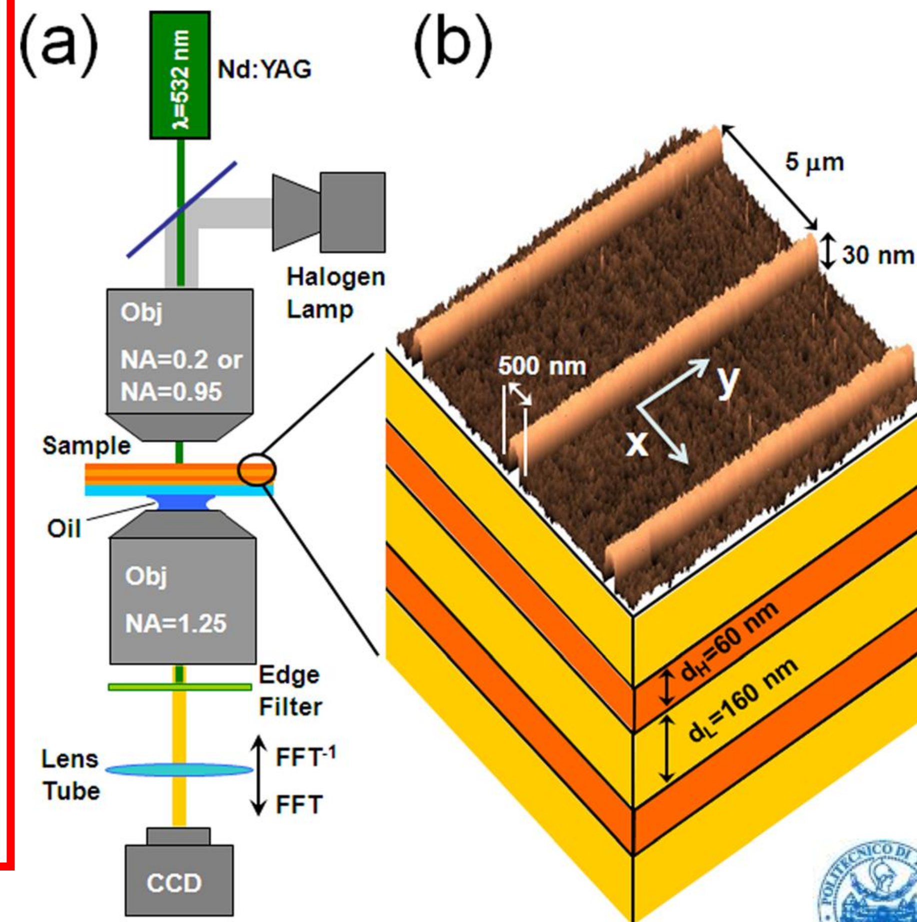
1DPC

170μm cover slip / $(HL)^8$ / P / PtA(AF546) / air

H	(silicon nitride)	n_H=1.99	t_H=60 nm
L	(silicon dioxide)	n_L=1.48	t_L=160 nm
P	(PPAA polymer)	n_P=1.6	t_P=30nm

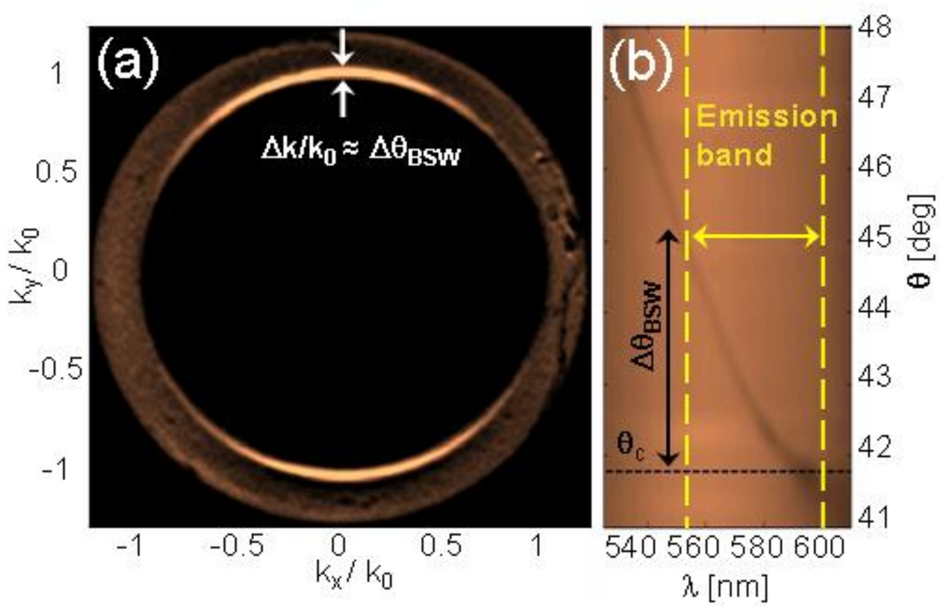
The PPAA polymer layer was patterned by means of standard photo-lithography to get a set of parallel ridges with:

Thickness	30nm
Width	500nm
Separation	5μm

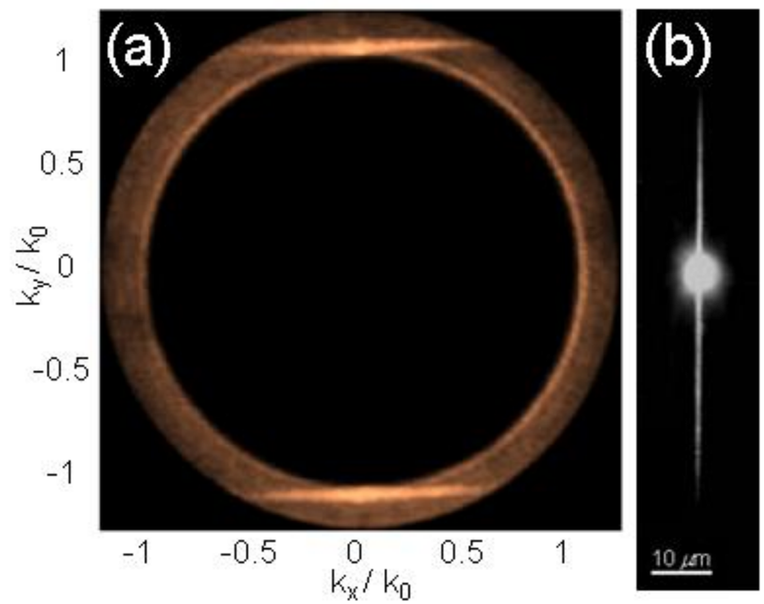


Appl. Phys. Lett. 100, 063305 (2012)

SPCE and SPCF Fluorescence with BSW (NF)



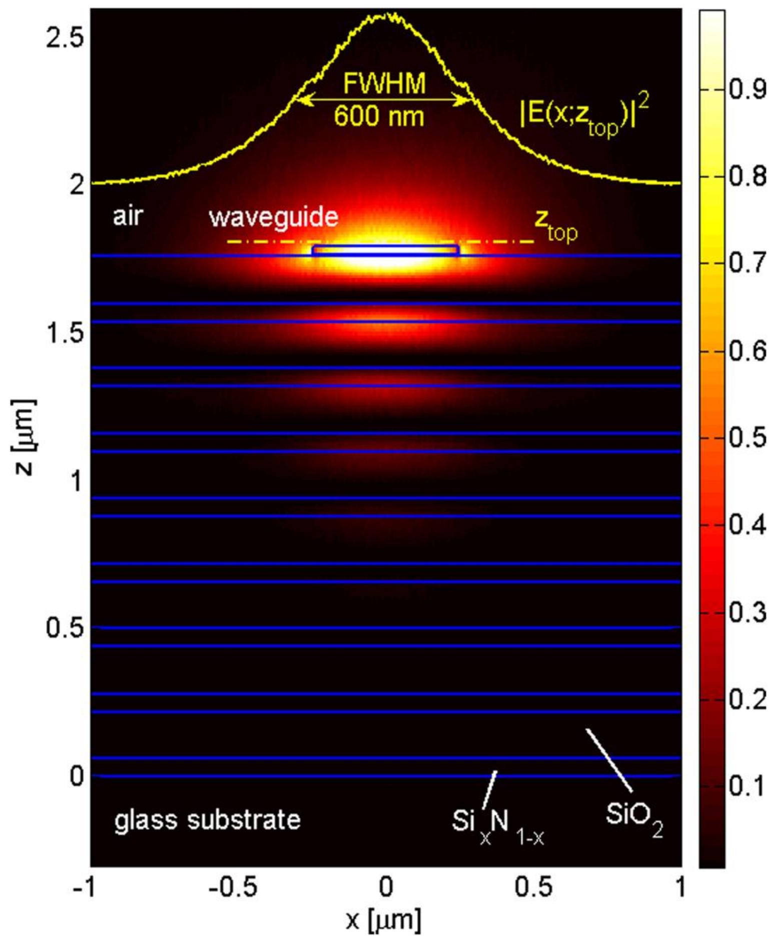
Unpatterned
PPAA coated 1DPC

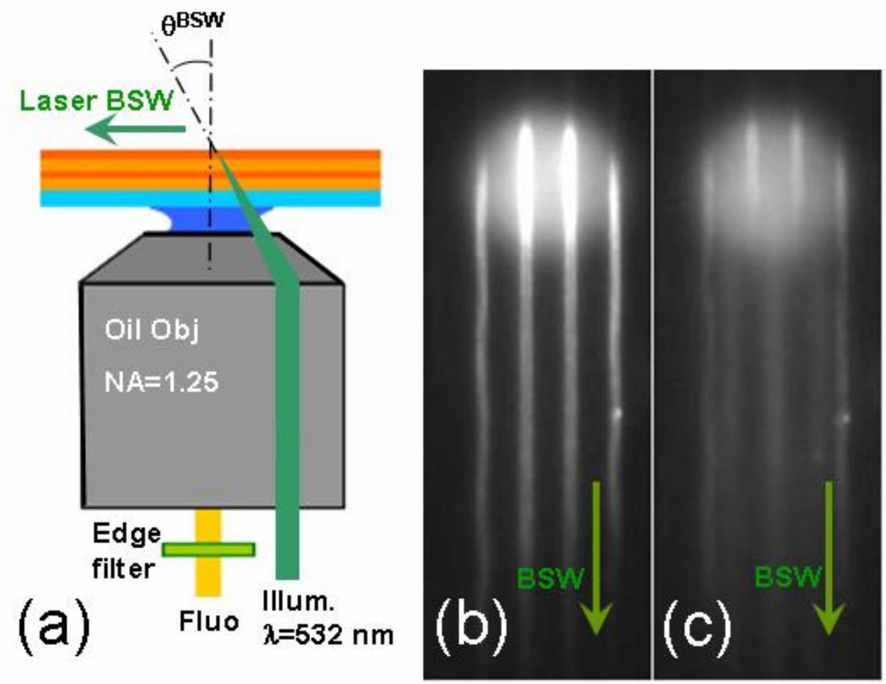


Patterned
PPAA coated 1DPC

Appl. Phys. Lett. 100, 063305 (2012)

SPCE and SPCF Fluorescence with BSW (NF)



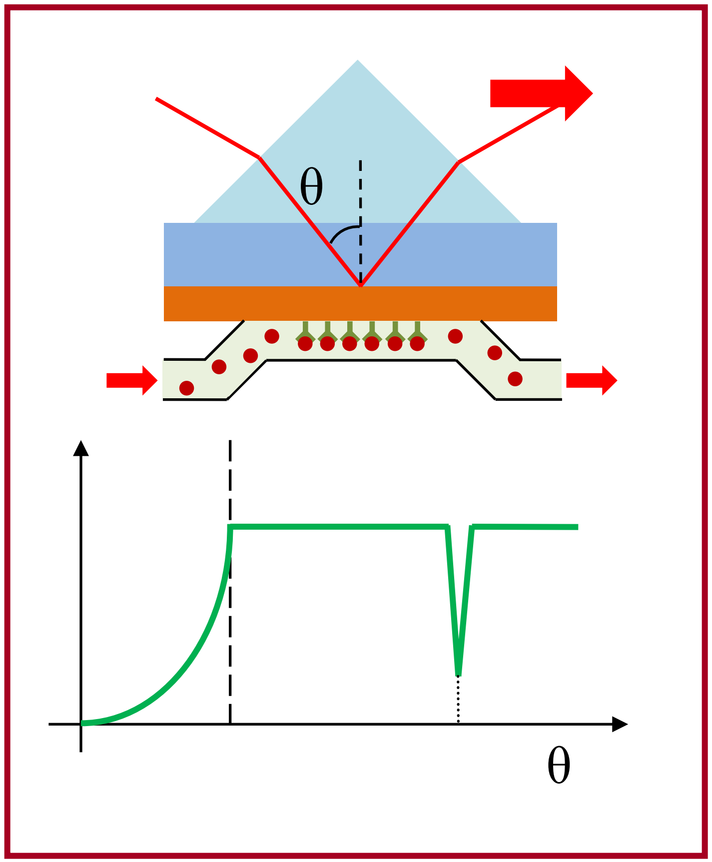


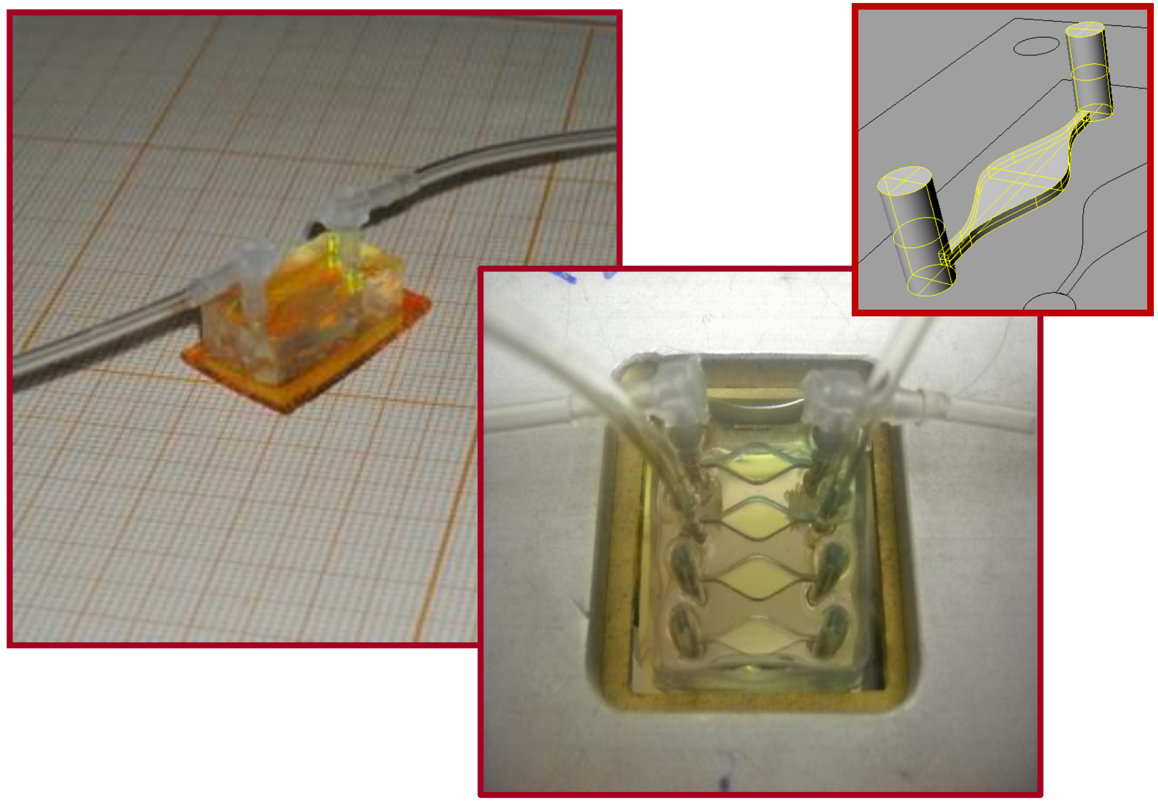
Appl. Phys. Lett. 100, 063305 (2012)

Biophotonics

Label-Free Biosensing with BSW and its application to the detection of cancer biomarkers

Label-Free Biosensing with BSW





PDMS Microfluidics

Label-Free Biosensing with BSW

Available online at www.sciencedirect.com

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Sensors and Actuators B 105 (2005) 360–364

SENSORS AND ACTUATORS B CHEMICAL

www.elsevier.com/locate/snb

Surface plasmon-like sensor based on surface electromagnetic waves in a photonic band-gap material

M. Shinn, W.M. Robertson*

Department of Physics and Astronomy, Middle Tennessee State University, Murfreesboro, TN 37132 USA

Received 6 February 2004; accepted 16 June 2004
Available online 7 August 2004

Label-Free Biosensing with BSW

Anal. Chem. **2007,** *79,* 4729−4735

Photonic Crystal Surface Waves for Optical Biosensors

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Institute of Spectroscopy, Russian Academy of Sciences, Troitsk, Moscow region, 142190, Russia

APPLIED PHYSICS LETTERS **90**, 241116 (2007)

Bragg surface wave device based on porous silicon and its application for sensing

E. Guillermain,[a] V. Lysenko, R. Orobtchouk, and T. Benyattou[b]
Institut des Nanotechnologies de Lyon INL, CNRS-UMR5270, INSA-Lyon, Villeurbanne F-69621, France

S. Roux and A. Pillonnet
Laboratoire de Physico-Chimie des Matériaux Luminescents LPCML, CNRS-UMR5620, Université Lyon1, Villeurbanne F-69622, France

P. Perriat
Matériaux: Ingénierie et Science MATEIS, CNRS-UMR5510, INSA-Lyon, Villeurbanne F-69621, France

Label-Free Biosensing with BSW

APPLIED PHYSICS LETTERS 91, 253125 (2007)

Enhancement of diffraction for biosensing applications via Bloch surface waves

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2318 OPTICS LETTERS / Vol. 34, No. 15 / August 1, 2009

Strong modification of light emission from a dye monolayer via Bloch surface waves

Marco Liscidini,[1,*] Matteo Galli,[1] Molu Shi,[2] Giacomo Dacarro,[1] Maddalena Patrini,[1] Daniele Bajoni,[3] and J. E. Sipe[1,2,3]
[1]*Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia and Department of Physics "A. Volta," University of Pavia, Via Bassi 6, I-27100 Pavia, Italy*
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*Corresponding author: marco.liscidini@gmail.com

Label-Free Biosensing with BSW

Protease detection using a porous silicon based Bloch surface wave optical biosensor

Hong Qiao,[1,2] Bin Guan,[1,2] J. Justin Gooding,[2] and Peter J Reece,[1,*]

[1] School of Physics, The University of New South Wales, Sydney, New South Wales 2052, Australia
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*p.reece@unsw.edu.au

#128081 - $15.00 USD Received 6 May 2010; revised 12 Jun 2010; accepted 24 Jun 2010; published 30 Jun 2010
 5 July 2010 / Vol. 18, No. 14 / OPTICS EXPRESS 15174

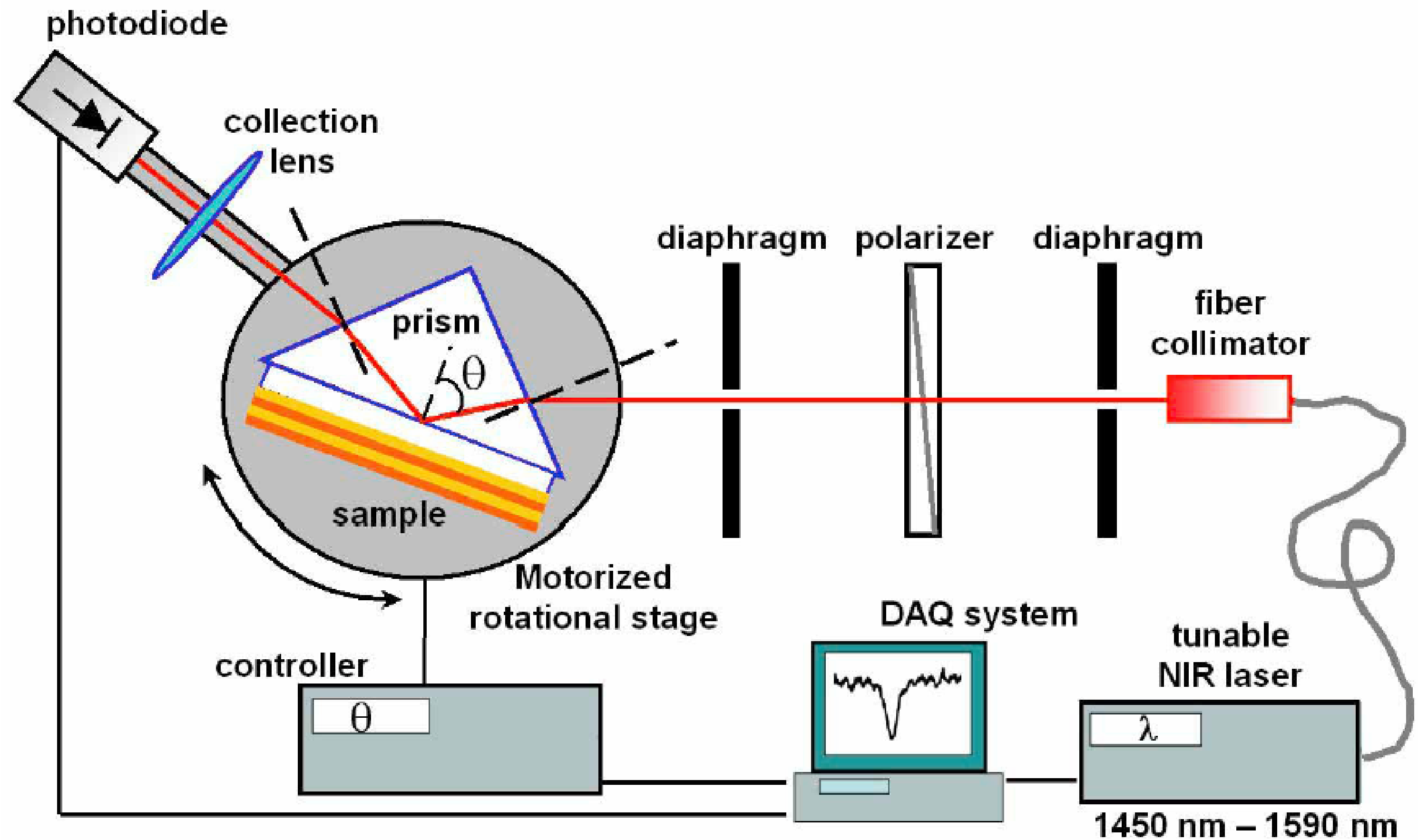
Anal. Chem. **2010,** *82,* 5211–5218

Real-Time Biomolecular Binding Detection Using a Sensitive Photonic Crystal Biosensor

Yunbo Guo,*,†,‡ Jing Yong Ye,†,‡,§ Charles Divin,† Baohua Huang,‡ Thommey P. Thomas,‡ James R. Baker, Jr.,‡ and Theodore B. Norris†,‡

Center for Ultrafast Optical Science, Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan 48109, and Michigan Nanotechnology Institute for Medicine and Biological Sciences, University of Michigan, Ann Arbor, Michigan 48109

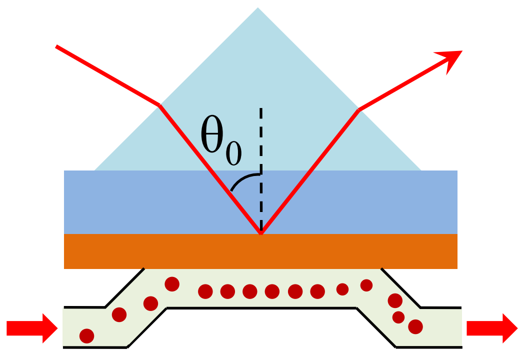
a-$Si_{1-x}N_x$:H based 1D Photonic Crystal



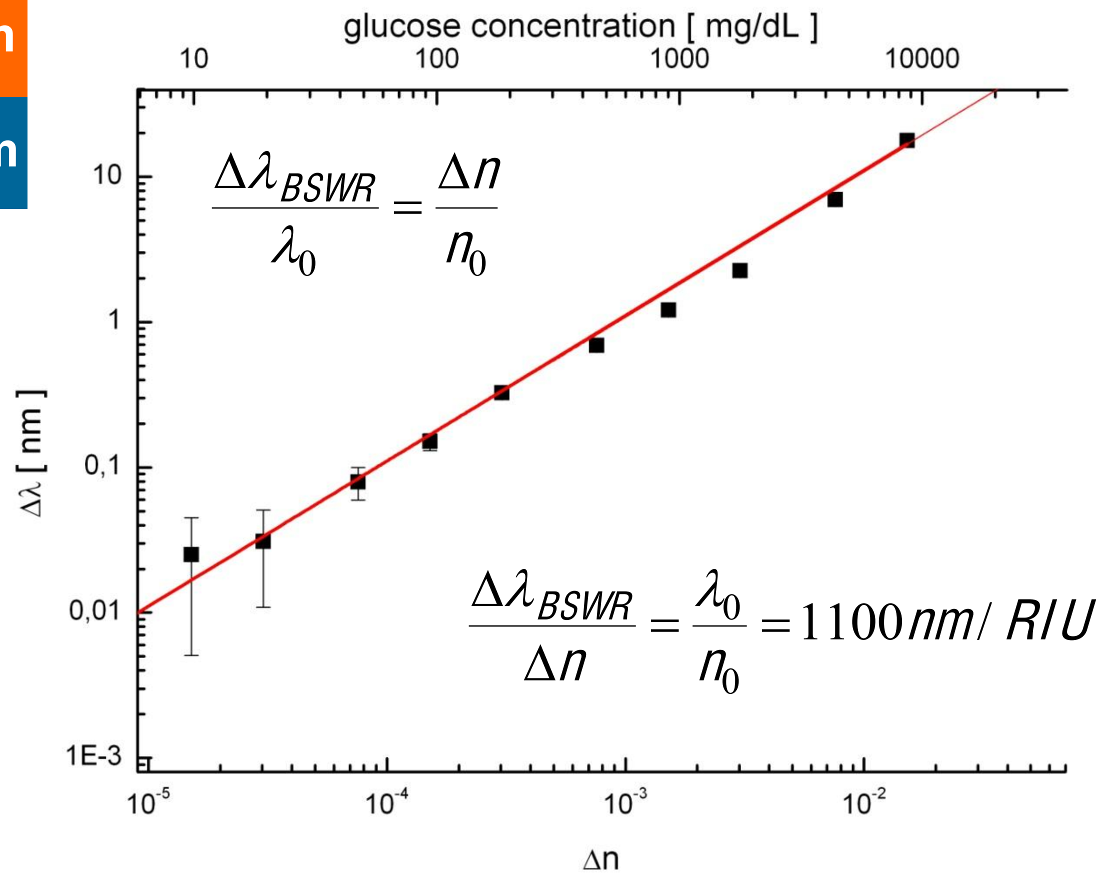
Bio Sensing - Demonstration of sensitivity – Glucose in H_2O

L	t=318nm n=1.72 @ λ=1530nm
H	t=265nm n=2.19 @ λ=1530nm

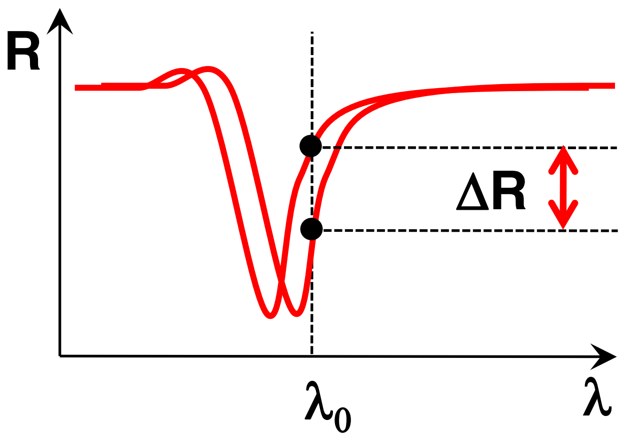
Si_xN_{1-x} - N=10



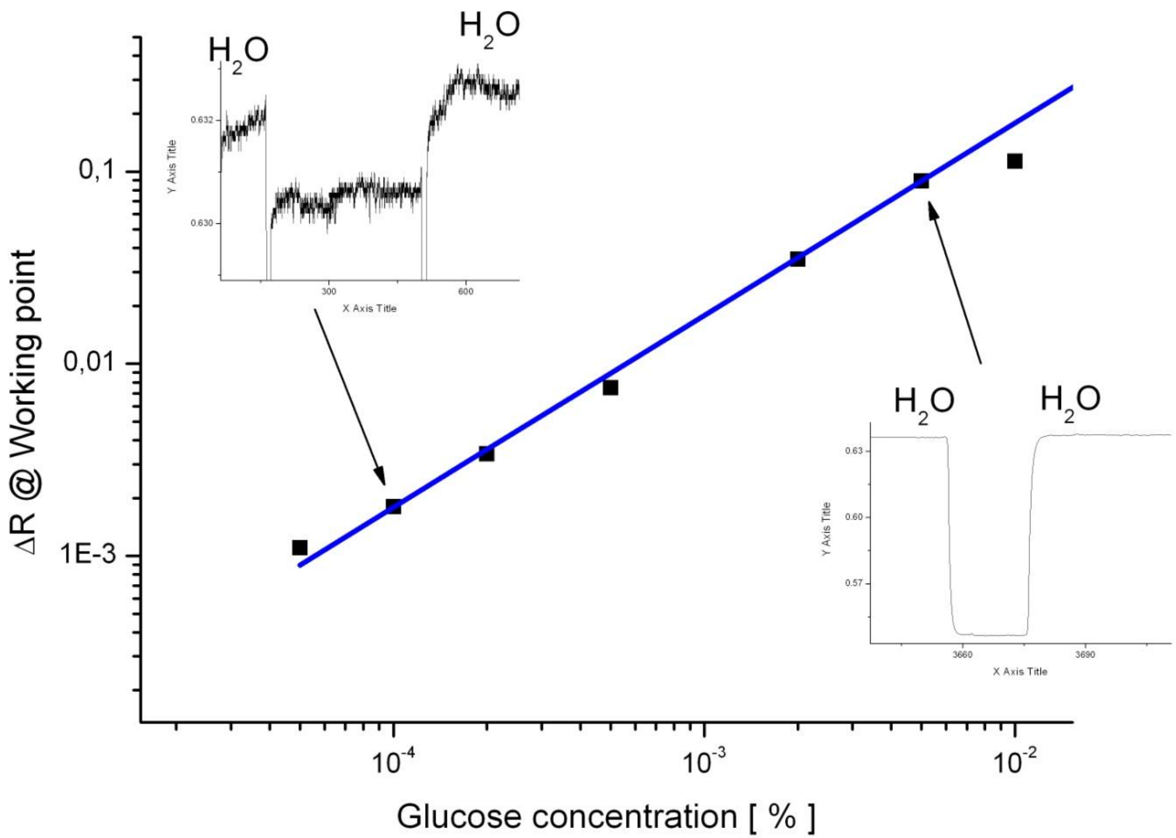
The reflectance spectrum is measured at fixed θ_0 for increasing <u>stationary</u> concentrations of glucose in water



Bio Sensing - Demonstration of sensitivity – Glucose in H_2O



The reflectance spectrum can be dinamically measured in a working point (fixed θ_0 and λ_0) upon injection of a solution of glucose in water



$\Delta n_{min,pub}=3.8\cdot10^{-6}$ (now $\Delta n_{min}=1\cdot10^{-6}$)

Bio Sensing - Demonstration of selectivity – Antibody pairing

Primary / Secondary standard antibody system

Primary Antibody — **Rabbit IgG (AbI)**

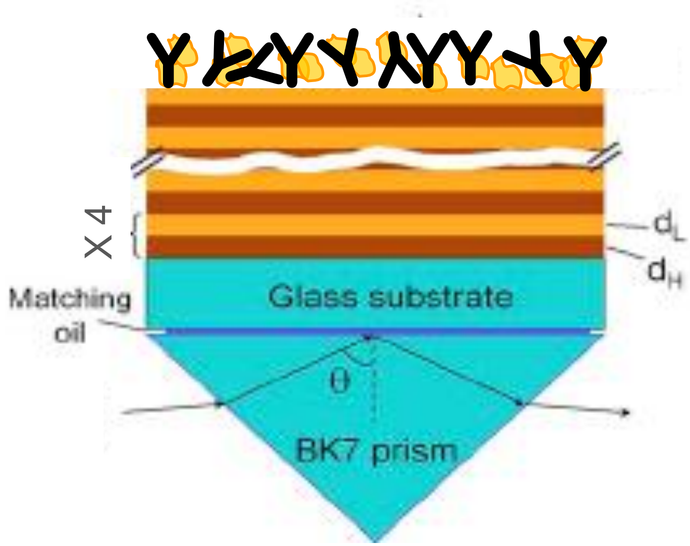
Secondary Antibodies — **Specific Goat Antirabbit IgG – HRP (POSITIVE - AbII)**

Non specific Anti-Mouse IgG – HRP (NEGATIVE)

Both secondary antibodies are marked with horseradish peroxidase (HRP) in order to subsequently perform ELISA assays for quantitative analysis

Bio Sensing - Demonstration of selectivity – Antibody pairing

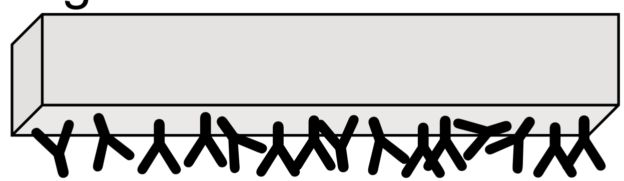
Surface functionalisation



L	t=290nm n=1.74 @ λ=1530nm
H	t=149nm n=3.40 @ λ=1530nm

3) Addition of bovine serum albumin (BSA) solution in ddH_2O (250 μg/mL)

2) Antibodies transfer onto SiN surface by soft printing



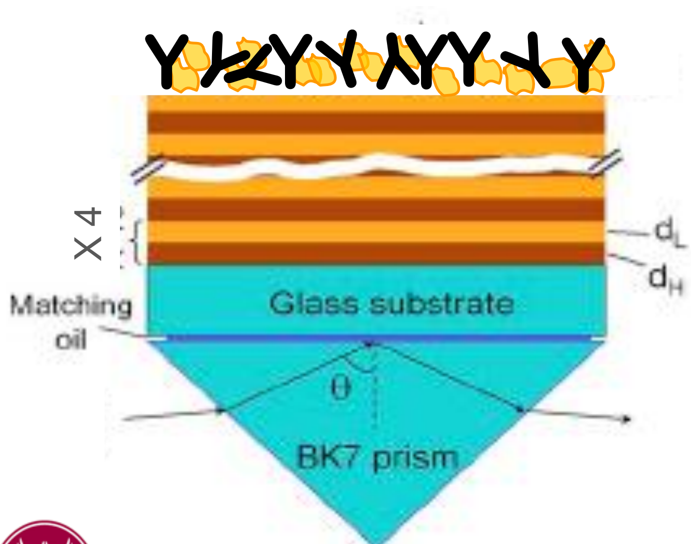
1) PDMS incubation with: Rabbit IgG solution (50μg/mL)

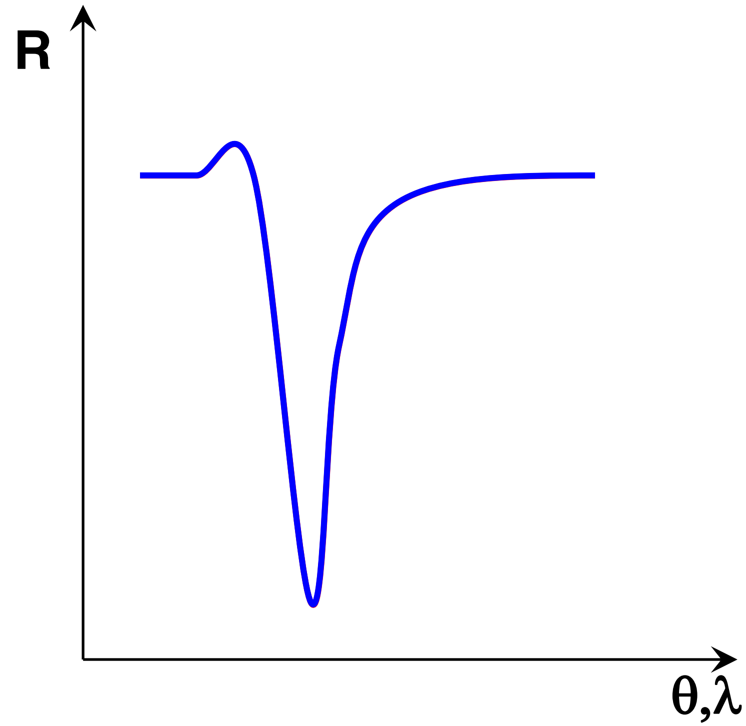
Bio Sensing - Demonstration of selectivity – Antibody pairing

Bio-Sensor operation

The flow cell is filled with Goat specific Anti-Rabbit IgG -HRP in ddH_20

Binding takes place



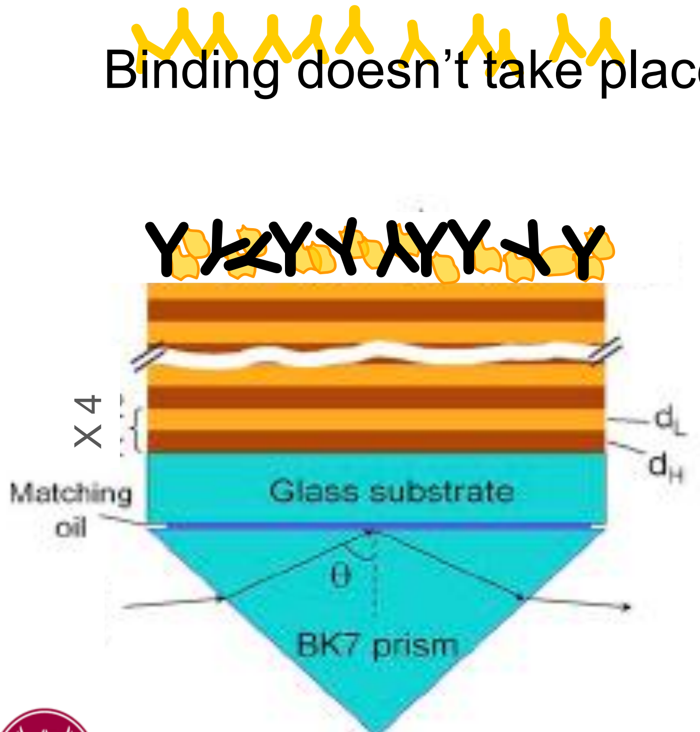


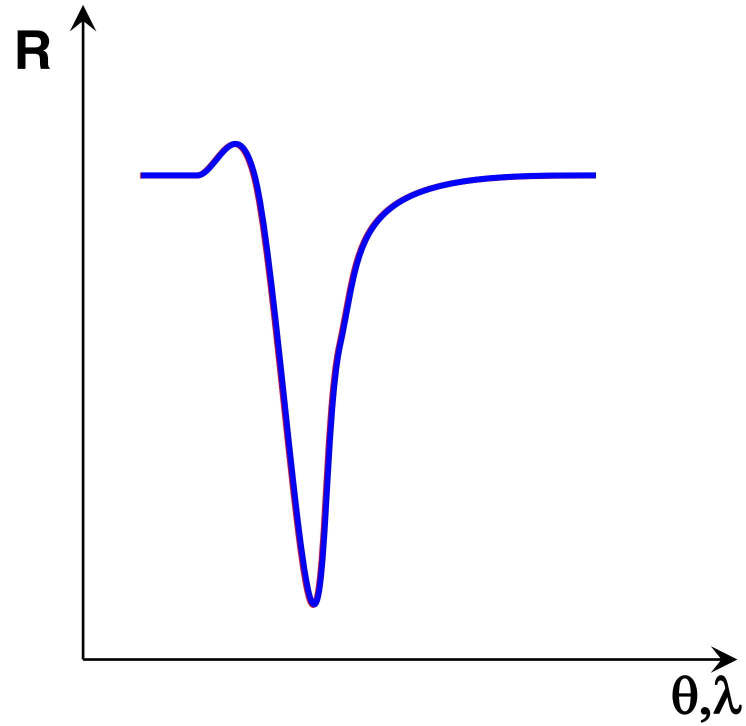
Bio Sensing - Demonstration of selectivity – Antibody pairing

Bio-Sensor operation

The flow cell is filled with Anti-Mouse IgG - HRP in ddH_2O

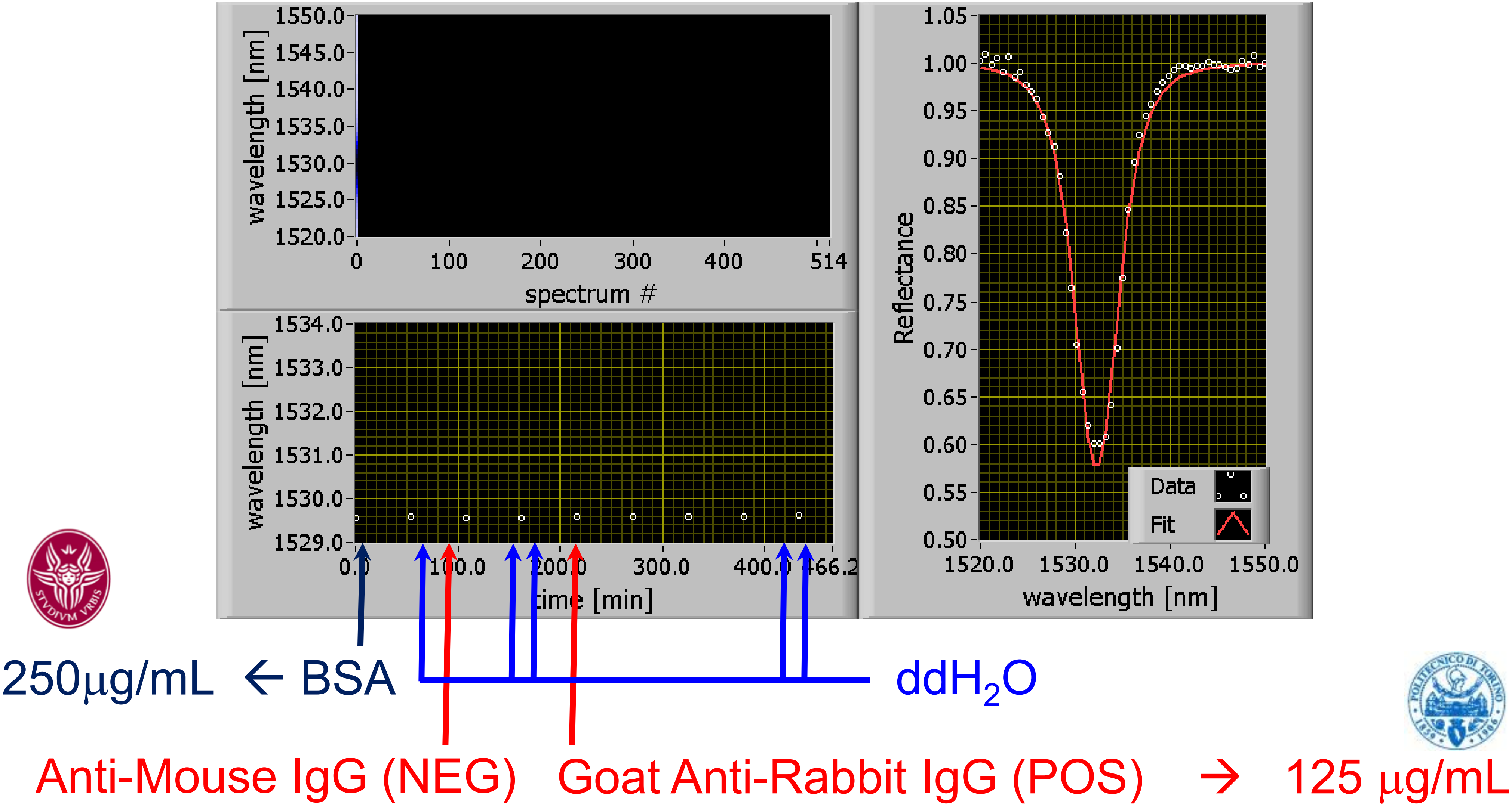
Binding doesn't take place



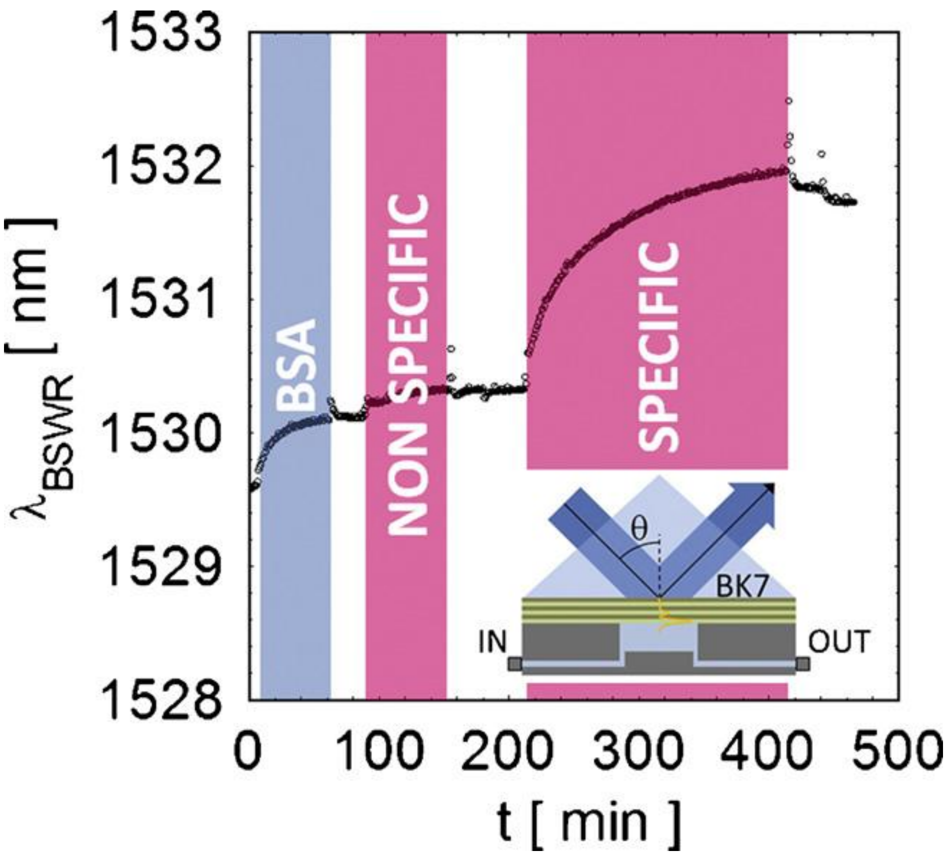


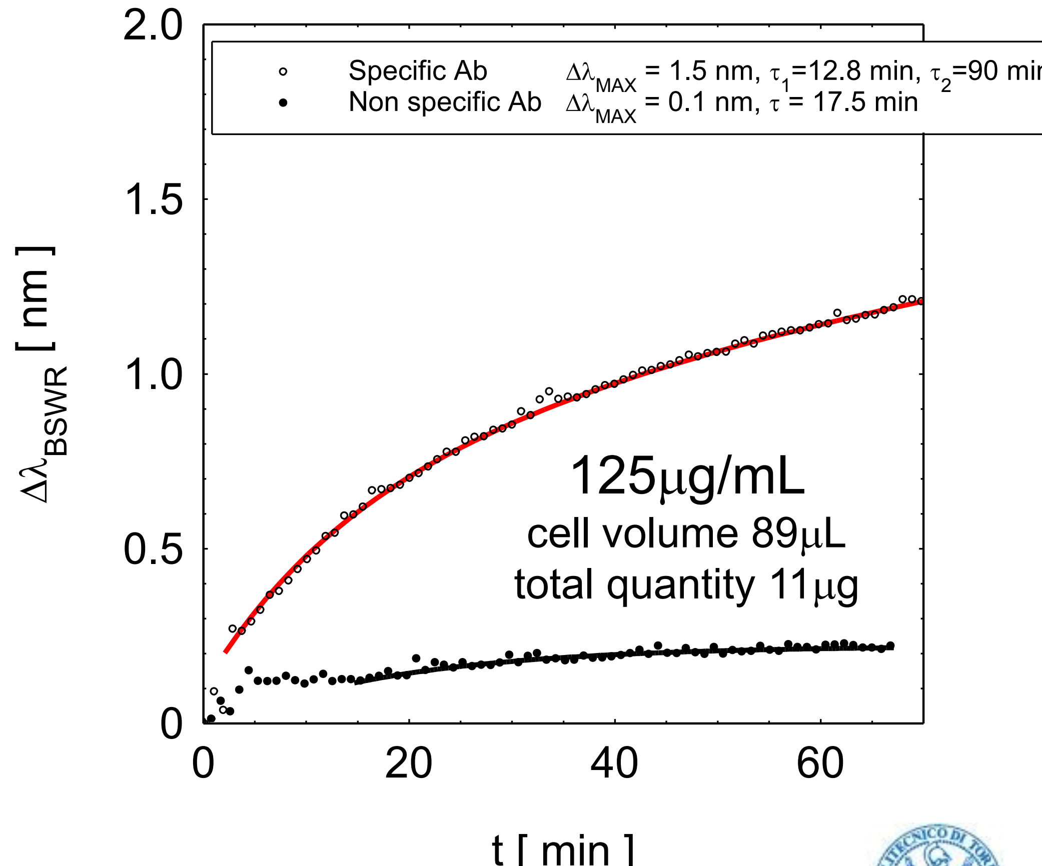
A typical sensing experiment

Bio Sensing - Demonstration of selectivity – Antibody pairing



Bio Sensing - Demonstration of selectivity – Antibody pairing

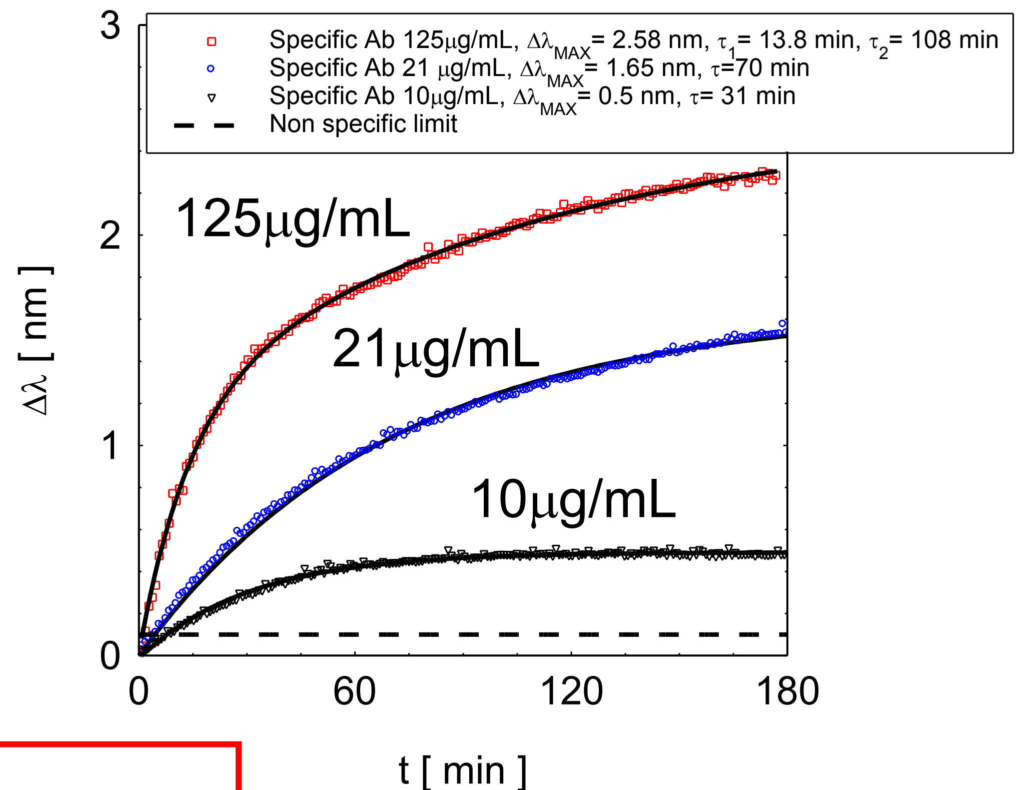




Sensors and Actuators B, 1046–1052 (2012)

Bio Sensing - Demonstration of selectivity – Antibody pairing

Specific AbII concentration [μg/mL]	Fit Parameters	
	τ_1 (τ_2) [min]	$\Delta\lambda_{MAX,1}$ ($\Delta\lambda_{MAX,2}$) [nm]
125	14.0 108.0	1.15 1.43
21	70.0	1.65
10	31.0	0.50



Resolution	with NEG	2μg/mL
	without NEG	0.2μg/mL=1pM

Sensors and Actuators B, 1046–1052 (2012)

ELISA QUANTITATIVE ANALYSIS

Quantitative ELISA carried out on biosensors' surface after Goat Anti-Rabbit IgG - HRP (125 μg/mL) BSW sensing experiments indicate that:

- the number of counted AbII molecules is $5 \cdot 10^8$
- corresponding to an absolute quantity of 2.5 fg of AbII (~attomol)
- Further investigations are on the way.

Side product of the research – Thermal stability of BSW

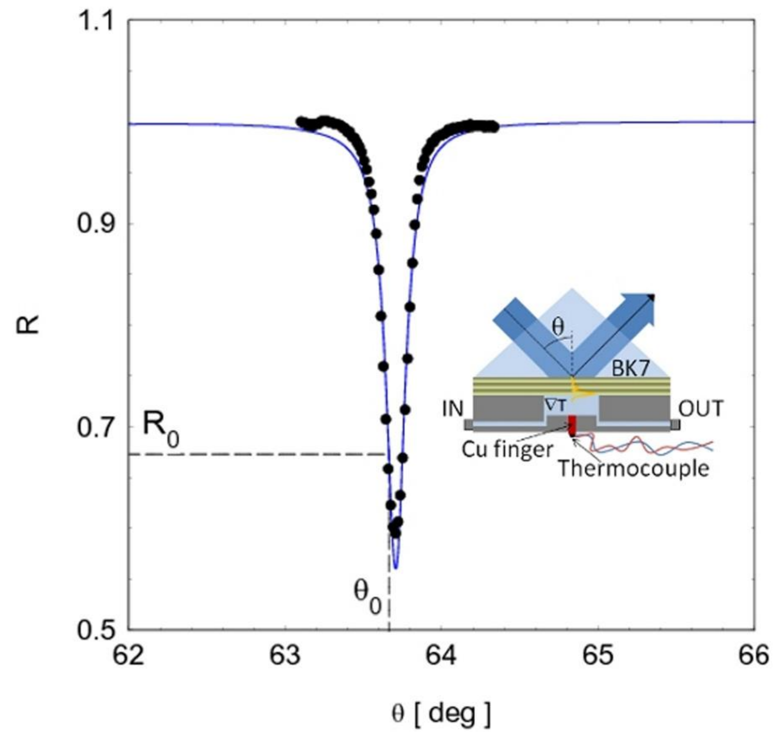
1DPC

Glass/ $(HL)^4$ / P / air

H (a-Si) n_H=3.486 t_H=161 nm
L ($a\text{-}Si_3N_4$) n_L=1.757 t_L=310 nm
P (PPAA polymer) n_P=1.514 t_P=20nm

The PPAA polymer is needed to fuctionalize the sensor surface with the proper markers receptors

PPAA is deposited by plasma polymerisation



Side product of the research – Thermal stability of BSW

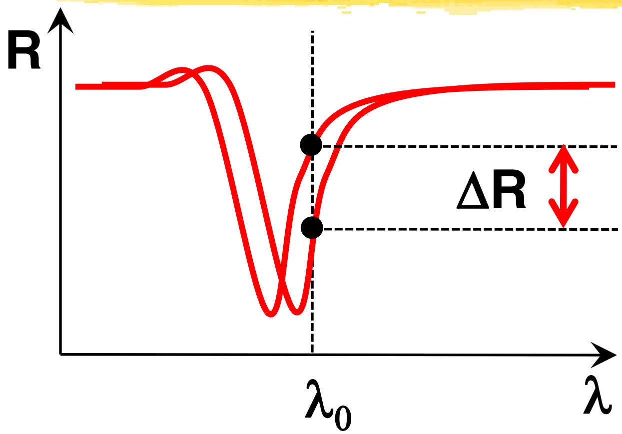
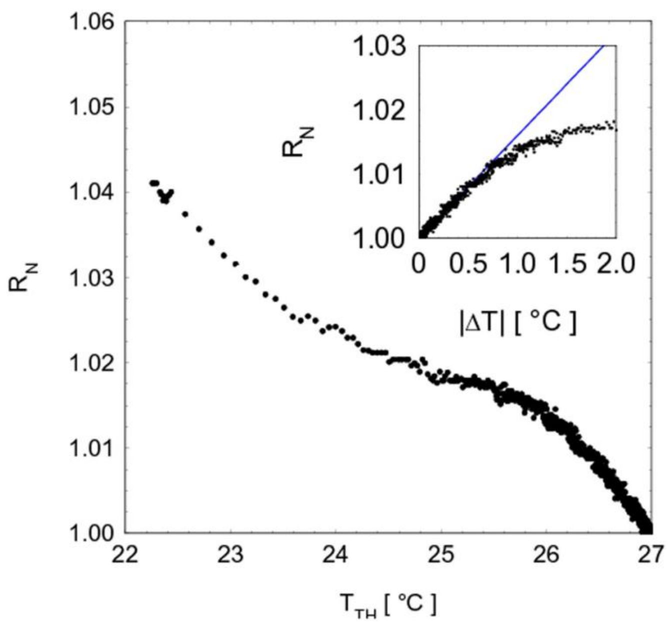
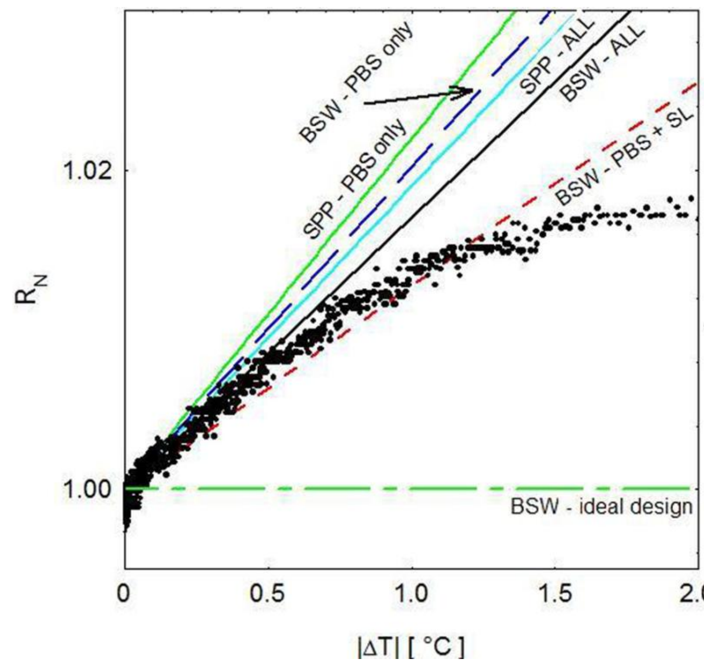


TABLE I. Complex thermo-optic coefficients used in the numerical simulations.

Material	$d\tilde{n}/dT$ (10^{-4} °C^{-1})	λ (nm)	Ref.
PBS	−0.76	1475	12
a-Si:H	+2.3	1550	13
a-Si_3N_4:H	+0.2	1550	14
PAA	−2.0	1550	15
Au	6.2+j(−1.8)	810	16





Appl.Phys.Lett.99, 231107 (2011)

Application to cancer biomarkers detection

BSW application to the detection of cancer biomarkers

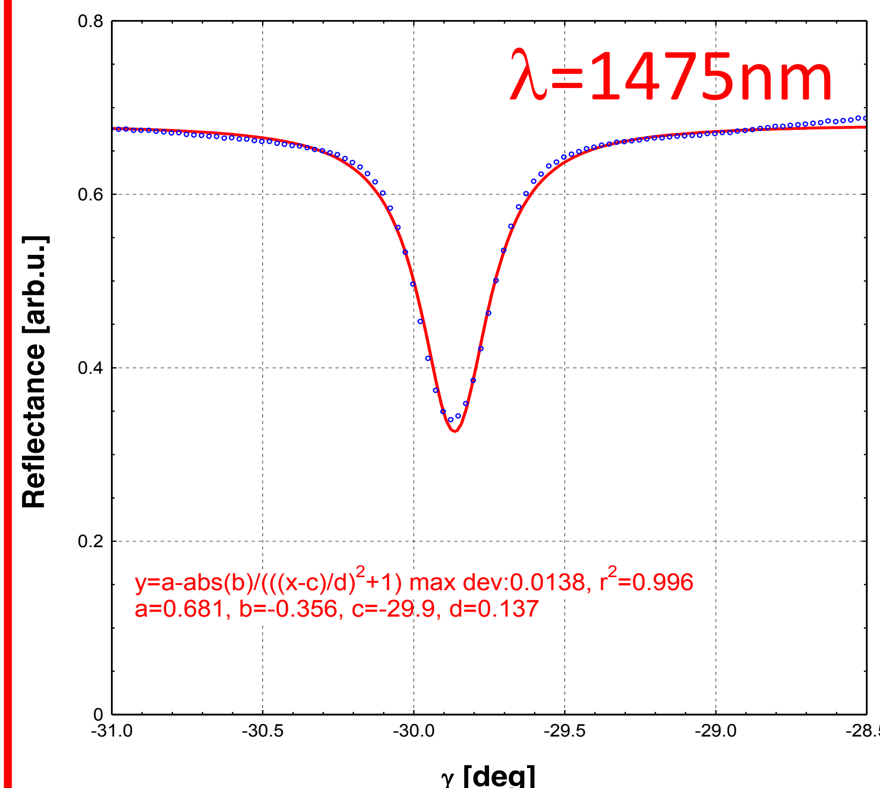
1DPC

Glass / (HL)^8 / P / PtA(AF546) / air

H (a-Si) n_H=3.486 t_H=168 nm
L (a-Si_3N_4) n_L=1.757 t_L=323 nm
P (PPAA polymer) n_P=1.514 t_P=20nm

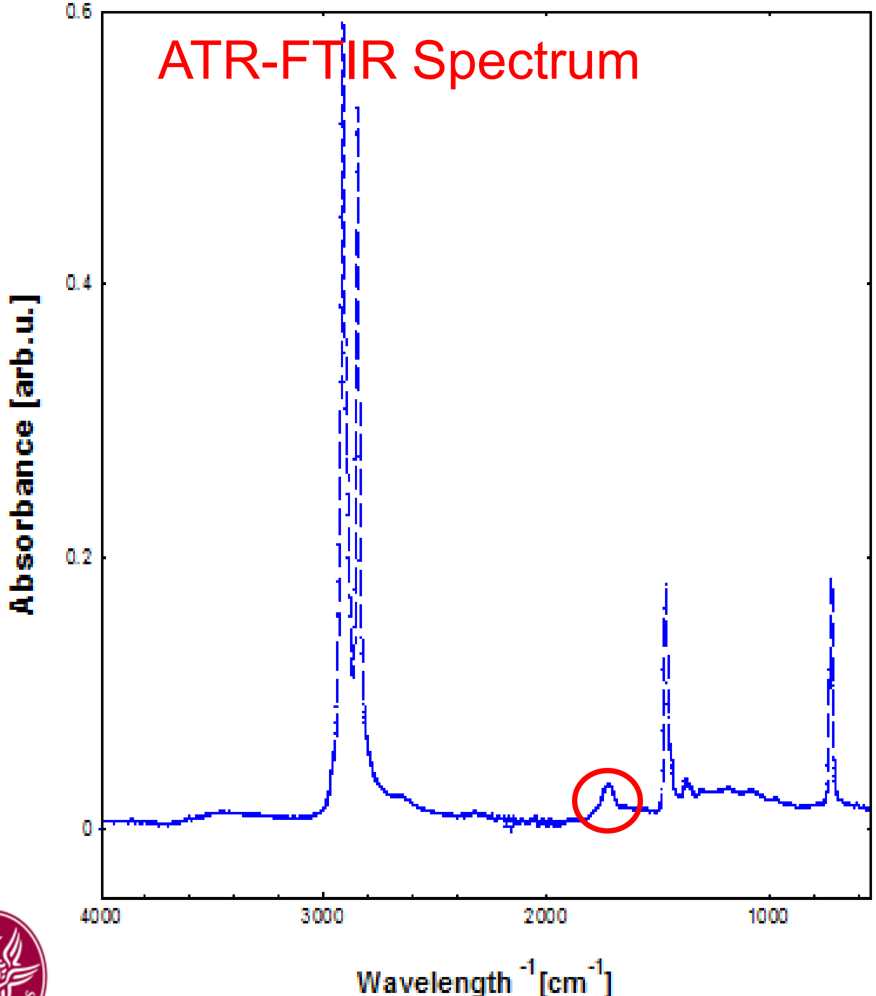
The PPAA polymer is needed to fuctionalize the sensor surface with the proper markers receptors

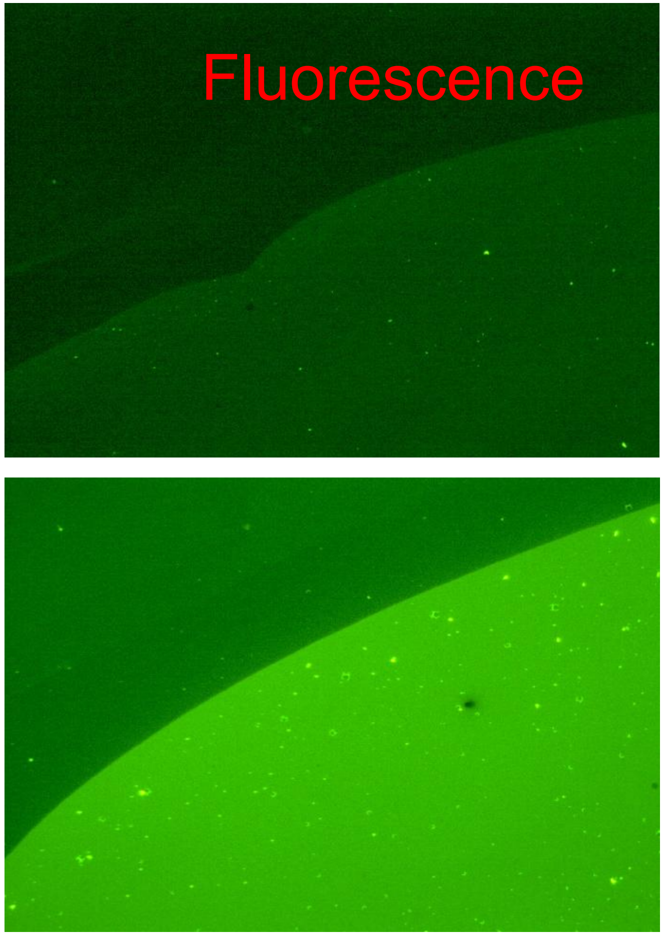
PPAA is deposited by plasma polymerisation



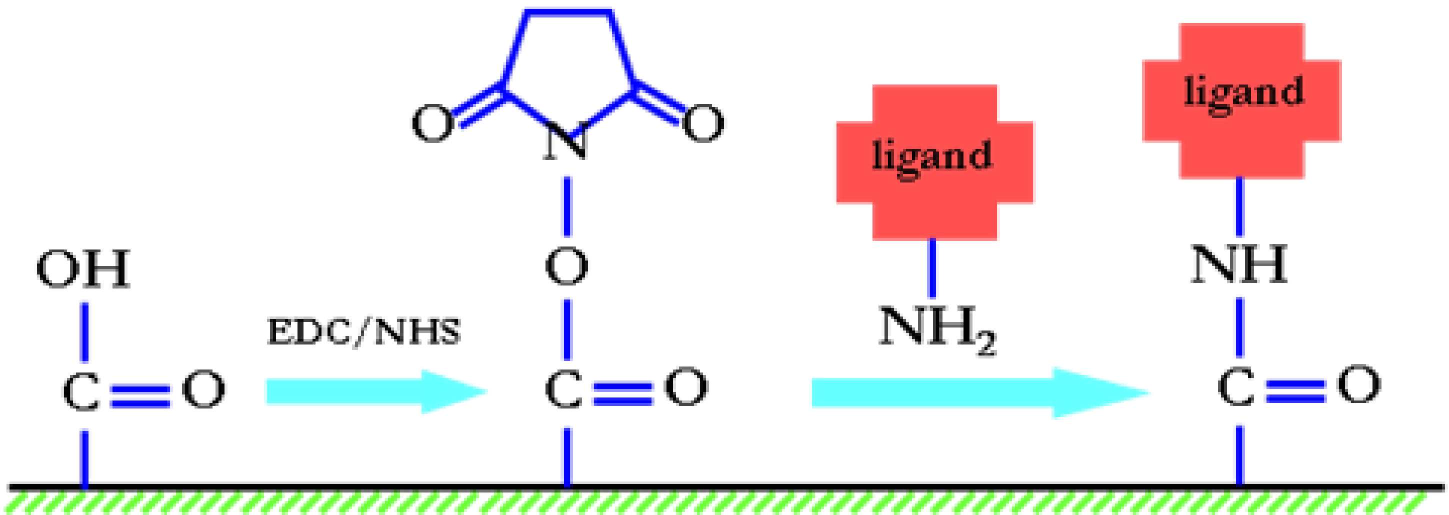
PBS - pH 8

BSW application to the detection of cancer biomarkers



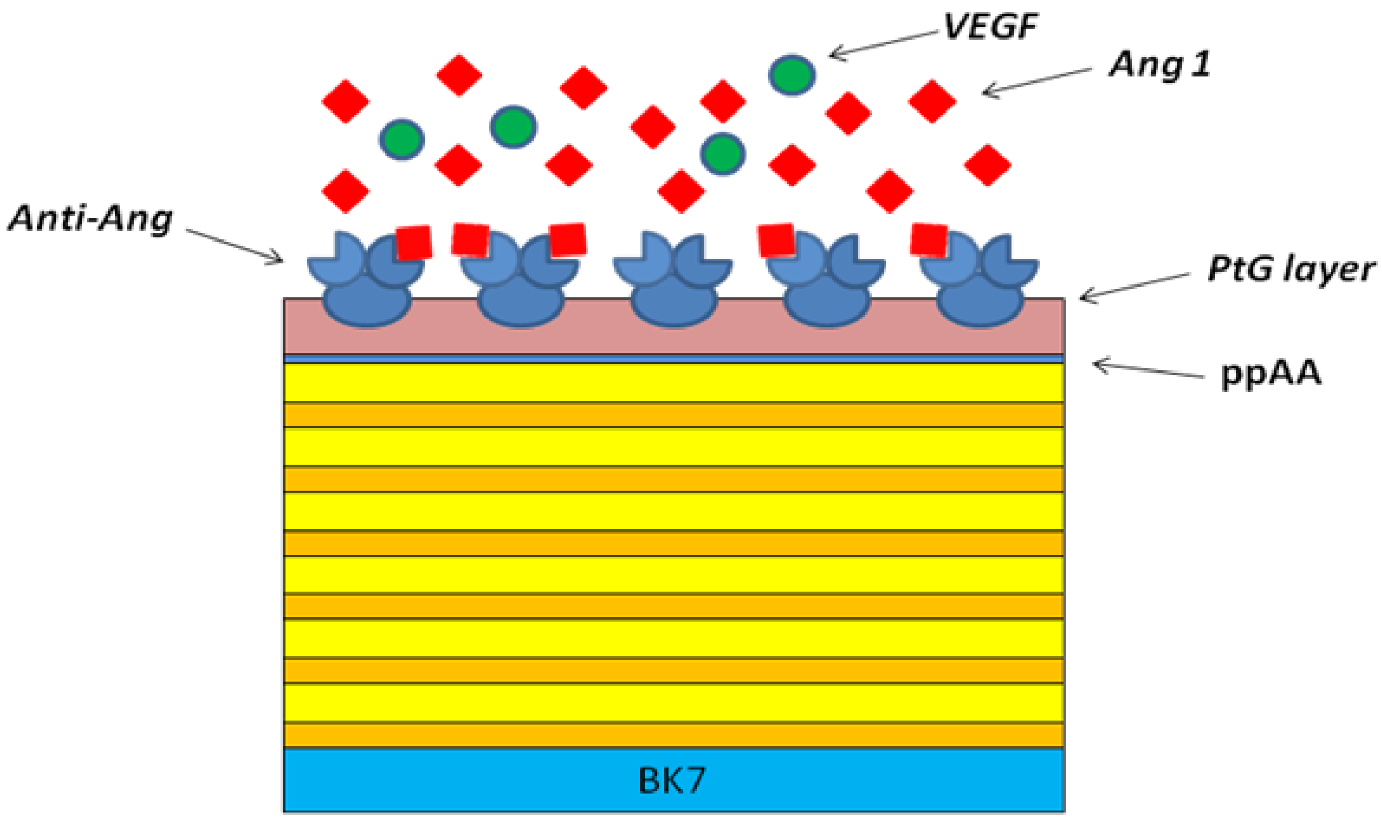


BSW application to the detection of cancer biomarkers



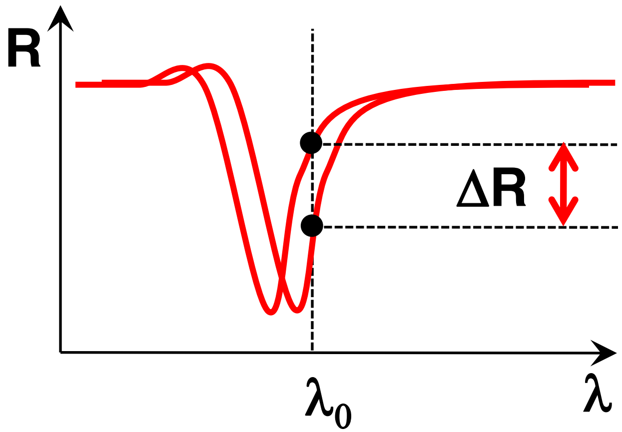
The carboxilic COOH groups of PPAA must be activated with EDC/NHS

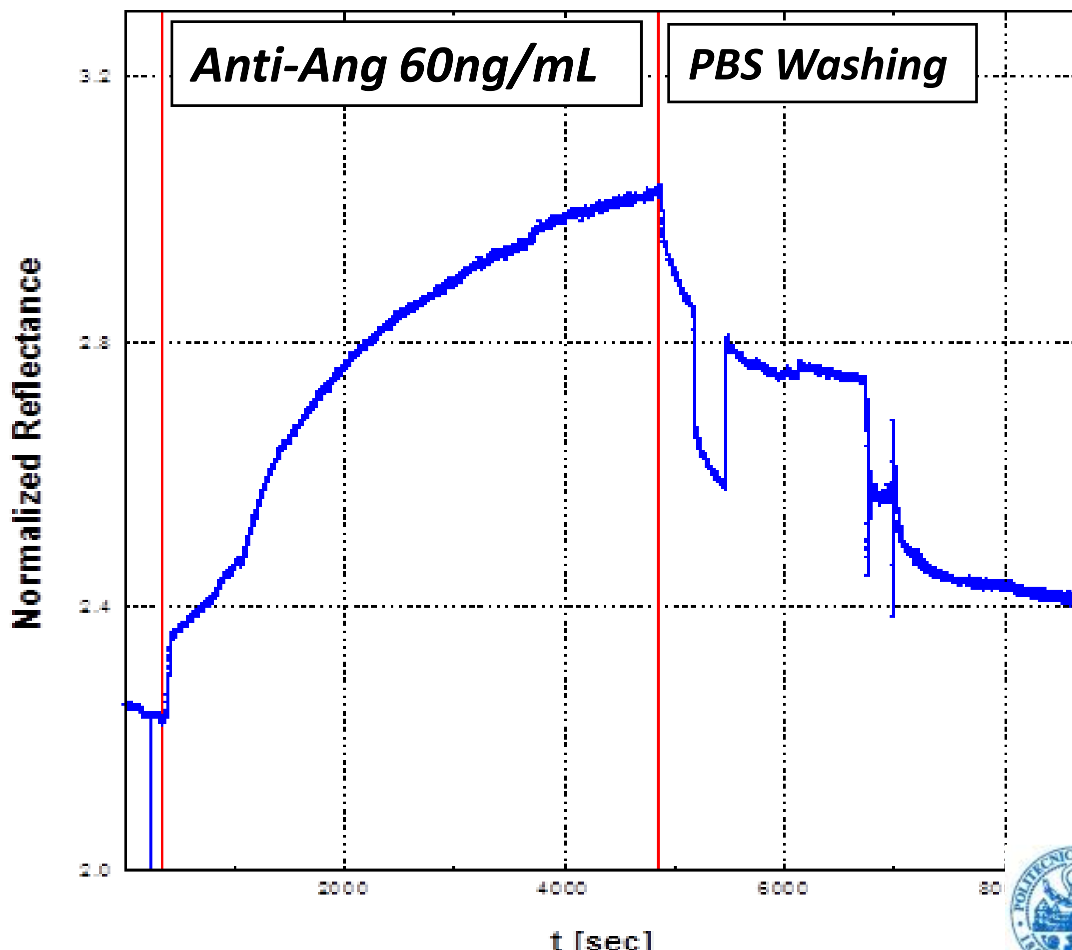
BSW application to the detection of cancer biomarkers



Recognition protocol

BSW application to the detection of cancer biomarkers





The surface was incubated before with Protein G with concentration
100 μg/mL

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