



Optoelectronic Division, Engineering Department

University of Sannio, Benevento, Italy

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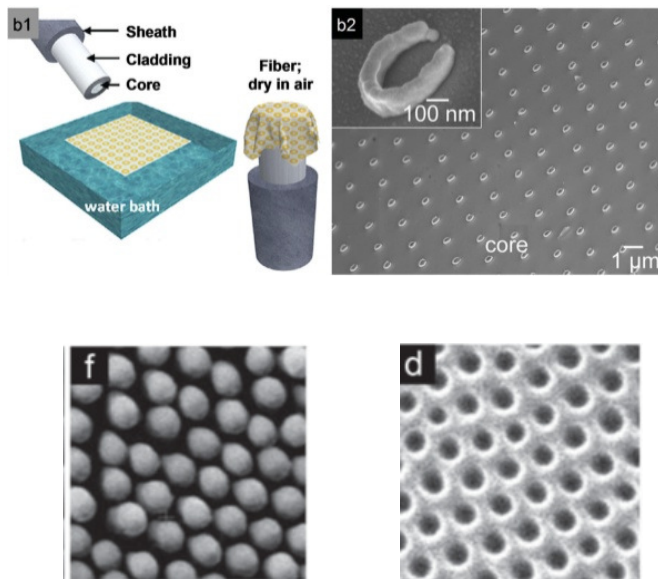
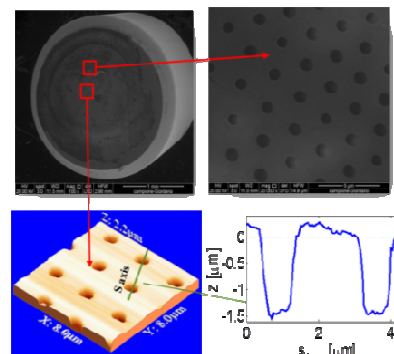
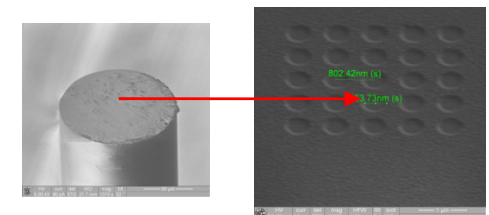
- ❑ OMICS Group signed an agreement with more than 1000 International Societies to make healthcare information Open Access. OMICS Group Conferences make the perfect platform for global networking as it brings together renowned speakers and scientists across the globe to a most exciting and memorable scientific event filled with much enlightening interactive sessions, world class exhibitions and poster presentations
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New Functionalities in Optical Fibers using “Lab on Fiber” Technology

Andrea Cusano

Optoelectronics Division,
Engineering Department,
University of Sannio, Benevento, Italy

2nd International Conference and Exhibition on
Lasers, Optics & Photonics
September 08-10, 2014 Hilton Philadelphia Airport, USA



Photonic
Crystal
Sensor

Standard Single Mode Fiber

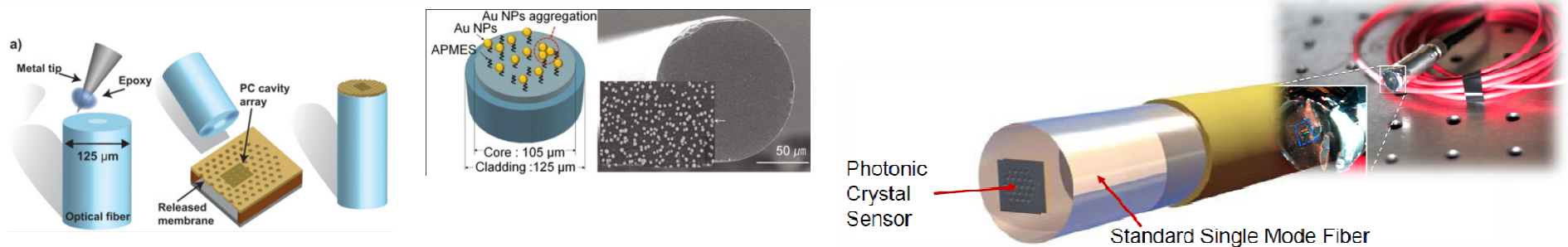


OUTLINE

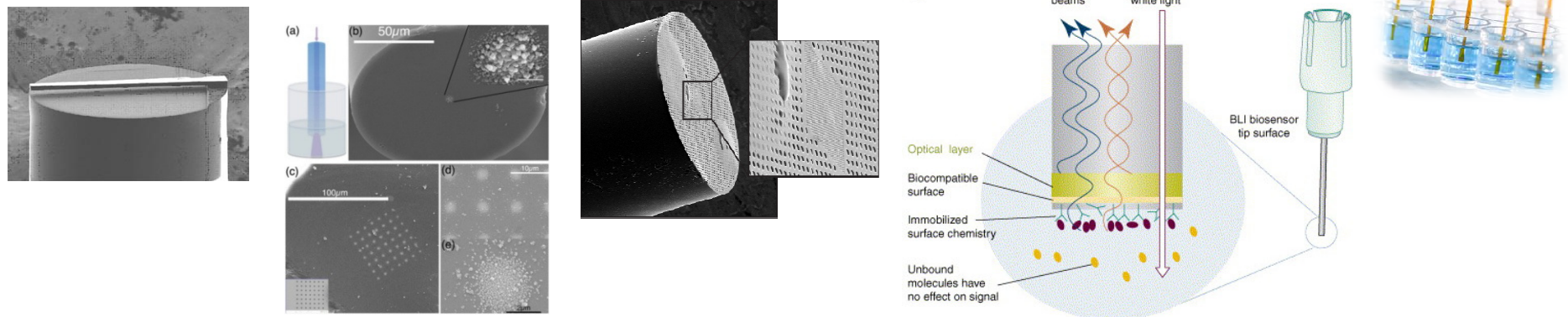
- ✚ *LAB-ON-FIBER TECHNOLOGY*
- ✚ *LAB ON FIBER AT UNIVERSITY OF SANNIO*
- ✚ *FIBER OPTIC NANO-PROBES: PRINCIPLE OF OPERATION AND SENSING FEATURES*
- ✚ *CONCLUSIONS*

LAB ON FIBER TECHNOLOGY: towards integrated and multifunctional nano-probes

Integration and patterning at micro and nano scale of different functional materials with desired optical, physical and chemical properties



Increased light matter interaction and creation of a technological world completely integrated within optical fibers with significant advantages in terms of functionality, performances, miniaturization, robustness, cost effectiveness and power consumption



MAIN ISSUE: Definition of a reliable *fabrication procedure able to integrate and process, at micro- and nano-scale*, several materials onto unconventional substrates such as the optical fibers.

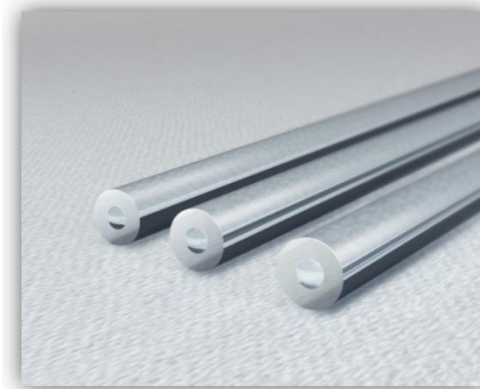
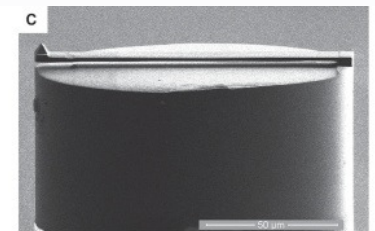
THE FIBER TIP: A UNIQUE LIGHT COUPLED PLATFORM FOR MICRO AND NANO TECHNOLOGIES

Unique and Unconventional Platform

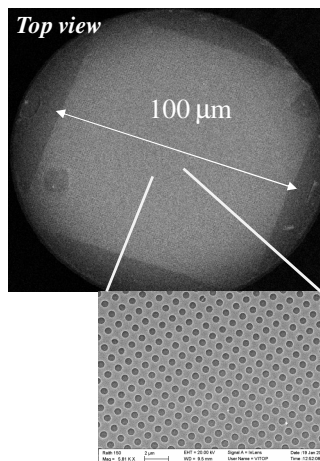
Microscopic Cross Section and large aspect ratio

Inherently Light Coupled

Biocompatible

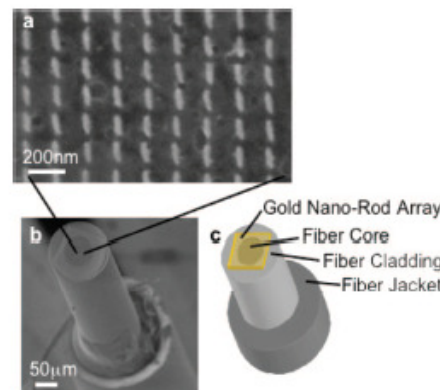


Opto-mechanical Systems
(AFM and near field probes,
Pressure and
Acoustic sensors)



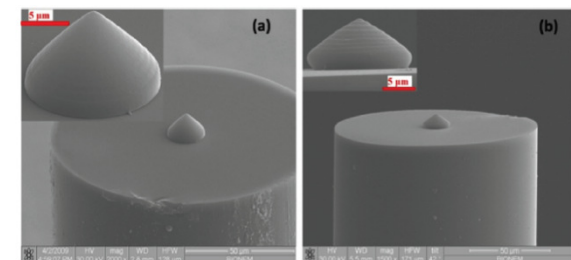
Nanophotonics

(Nanodevices, diffractive filters, High Plasmonics,
manipulation)



Biophotonics

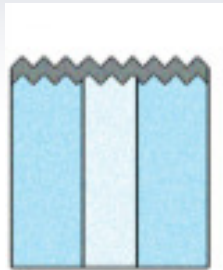
(Surgical tweezers, Nanosensors)



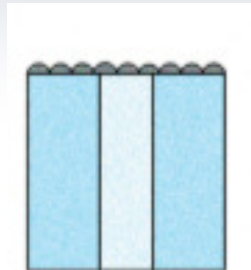
Micro-optics and Beam Shaping

Op

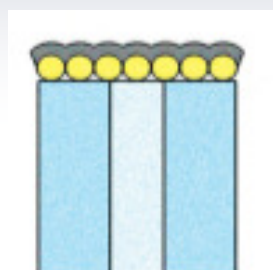
EARLIER DEVELOPMENTS DRIVEN BY SERS



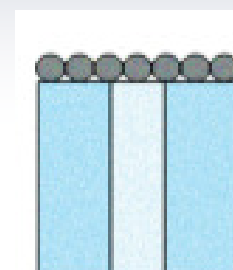
Roughening by
mechanical abrasion
Mullen 1991



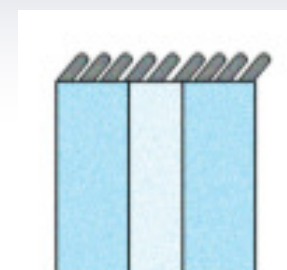
Island growth during
thin film deposition
Viets and Hill, 1998



Self-assembly of
colloidal templates
Vo Dinh, 1995

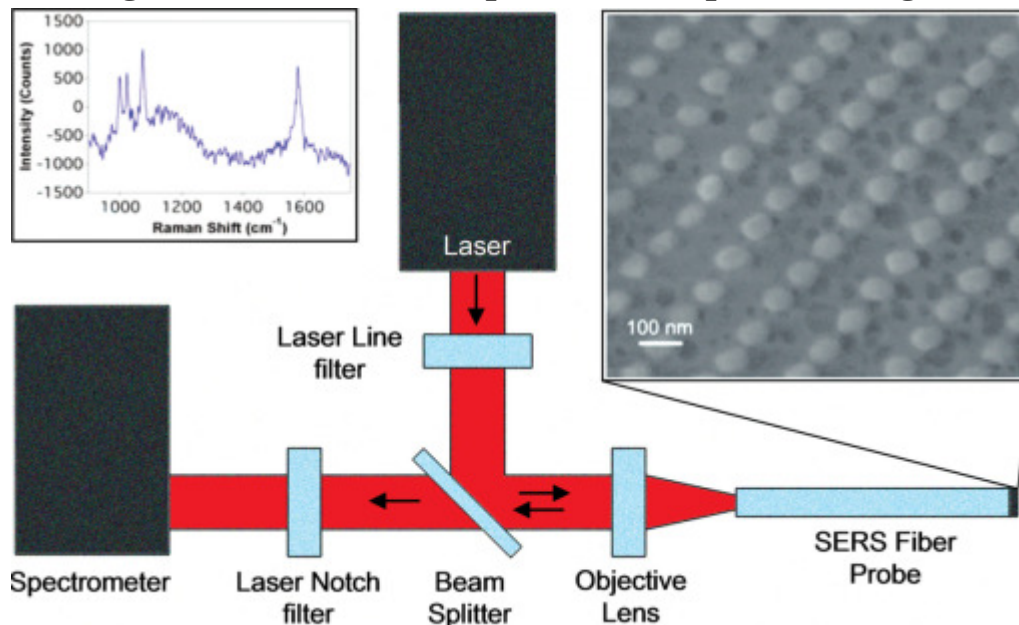


Coating with metal
nanoparticles
Sadler, 2000



Nanorods formed by
glancing angle deposition
Zhao, 2006

Interrogation of a fiber SERS probe in the optrode configuration



Gorgi Kostovski et al.
Advanced Materials 2014
DOI: 10.1002/adma.201304605

Technologies:

Earlier development mainly rely on the use
of decoration and self assembly techniques

Advantages:

Simple and low cost fabrication techniques
Ready access to the nano-regime

Main Issue

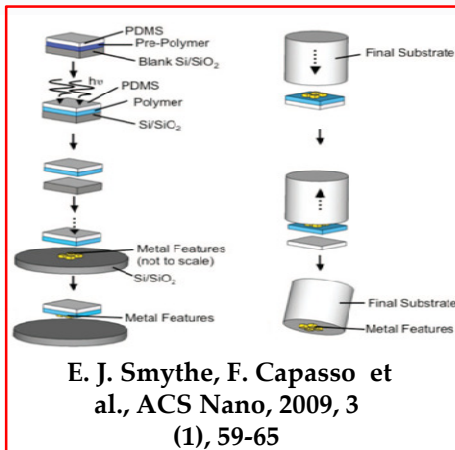
Stochastic deposition affects the order and
regularity of the final nanostructure



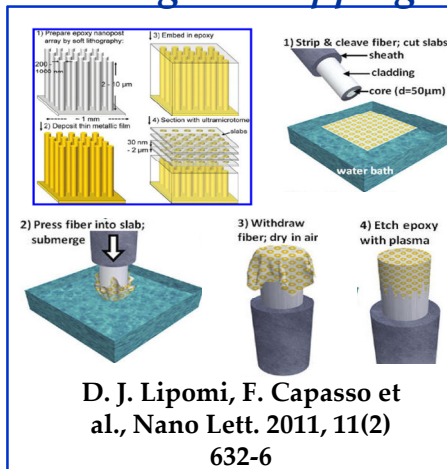
TOWARDS ENGINEERED NANOSTRUCTURES INTEGRATION

Nano-fabrication on planar substrates and transferring onto optical fibers

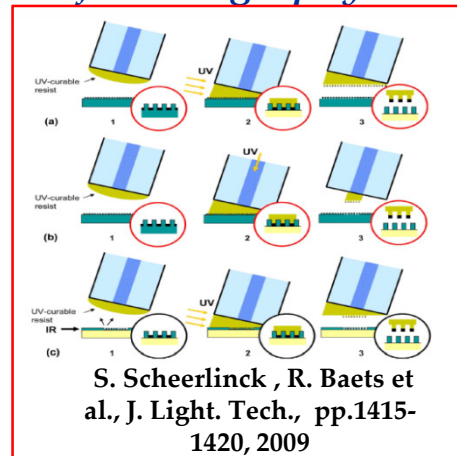
EBL and soft lithography



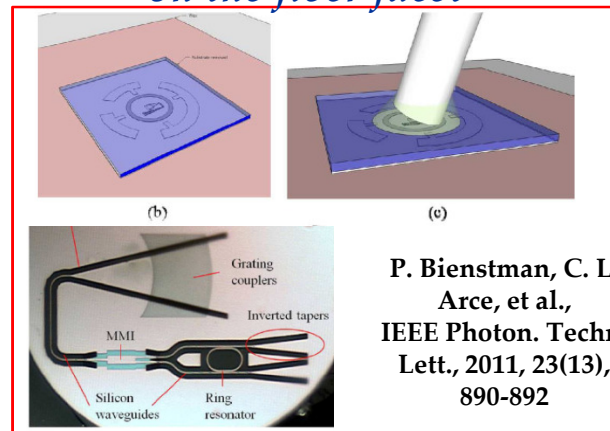
Soft lithography, nano-skiving and dipping



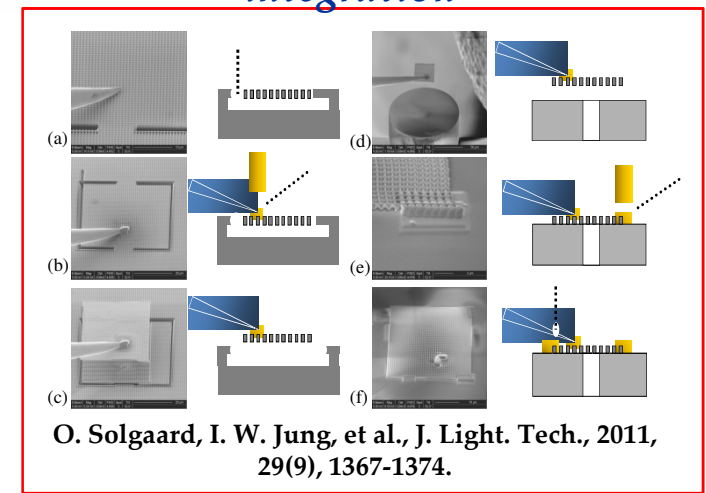
UV nano imprint and transfer lithography (NITL)



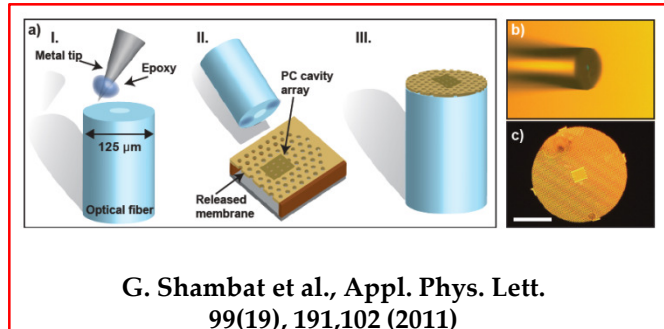
Soi microring resonator integrated on the fiber facet



Monolithic silicon photonic crystal integration

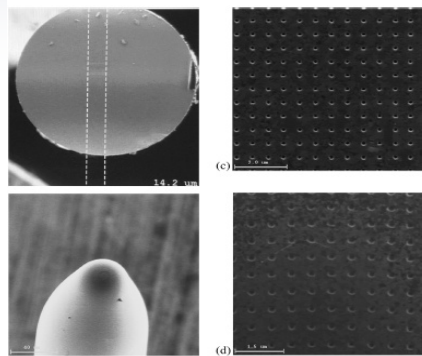


Photonic crystal cavity transfer



OVERCOMING THE TRANSFERRING APPROACH

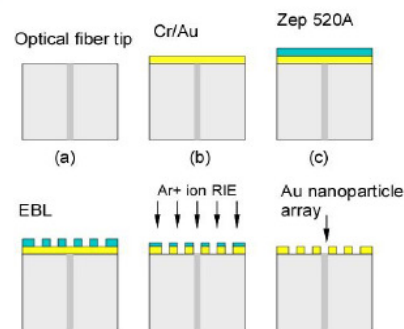
FIB milling



A. Dhawan et al., Sens. J.
IEEE 2008, 8, 942-950

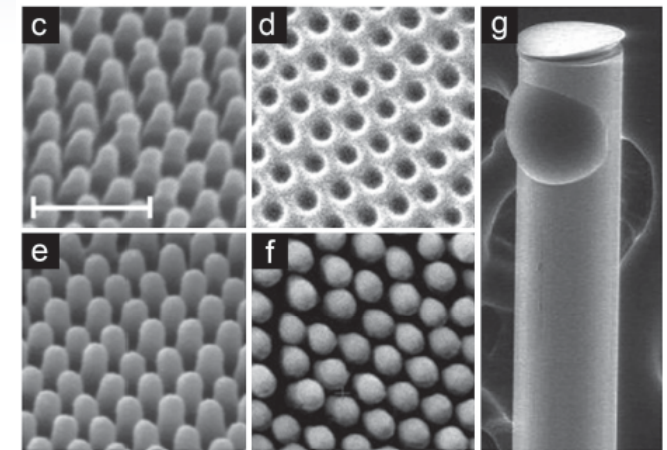
Direct-writing

EBL and Reactive Ion Etching



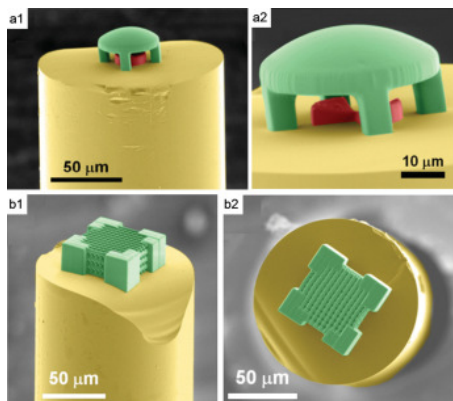
Y. Lin, R. G. Lindquist et
al., Biomed Opt Express. 2011;
2(3): 478-484.

Nanoimprint lithography



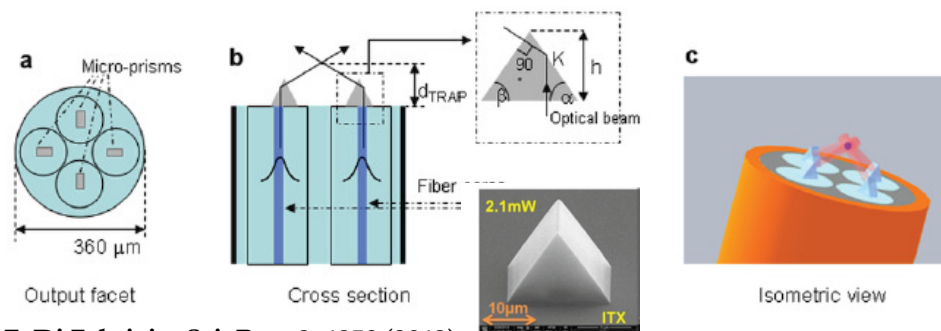
G. Kostovski , et al.,
Biosensors Bioelectron. 2009, 24 , 1531

Micro-optics using two-photon direct laser writing



H. E. Williams et al., Opt. Express 2011, 19, 22910

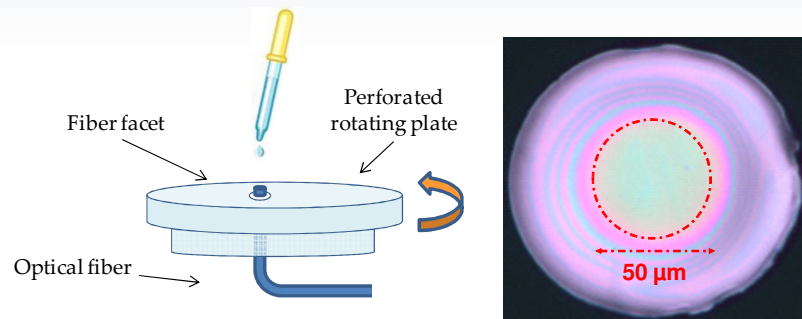
Optical tweezers using two photon lithography



E. Di Fabrizio, Sci. Rep. 3, 1258 (2013)

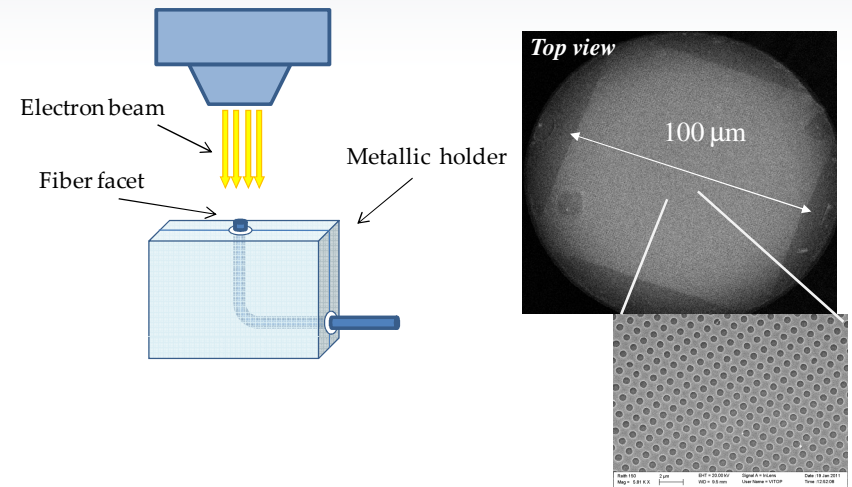
EBL DIRECT WRITING

1) Electron-resist spin coating

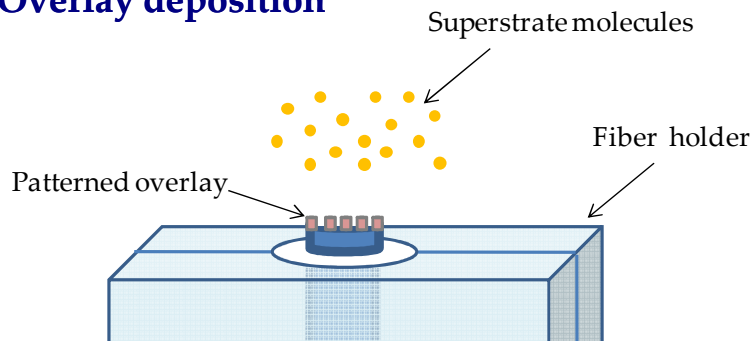


100-400nm thick (ZEP) overlay can be reproducibly obtained

2) EBL patterning



3) Overlay deposition



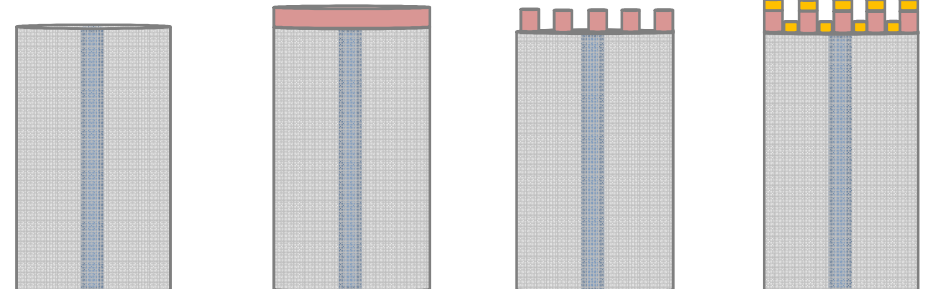
Different materials (metallic or dielectric) can be easily deposited

Optical
fiber tip

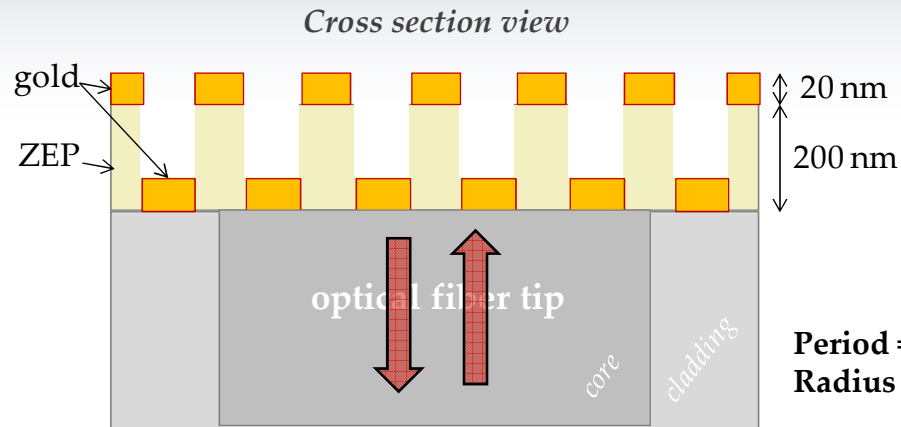
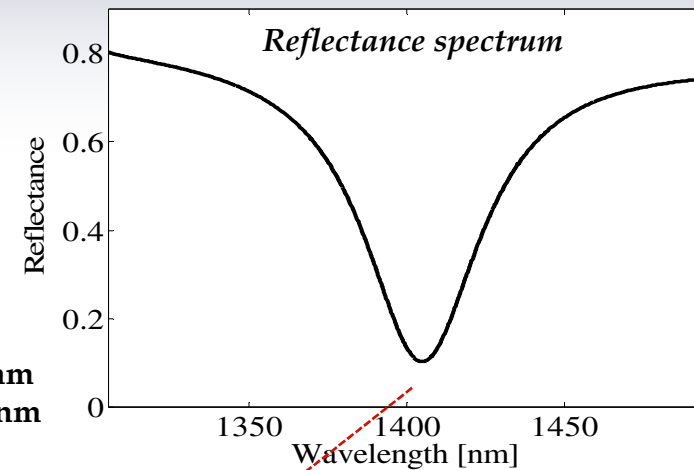
ZEP layer
deposition

ZEP overlay
patterning

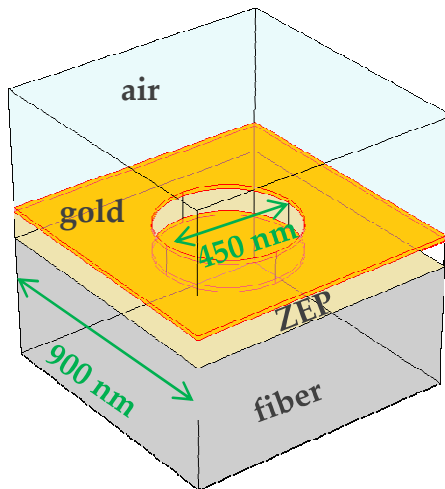
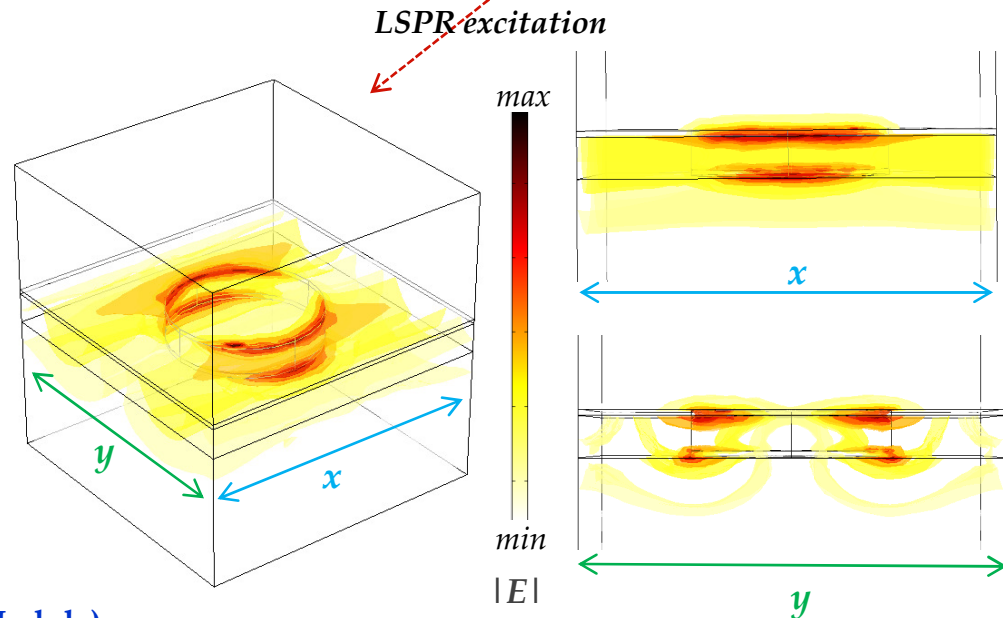
Au superstrate
deposition



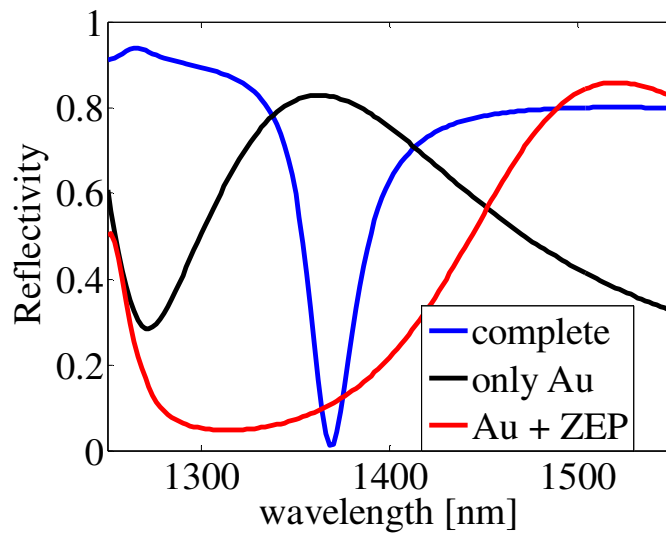
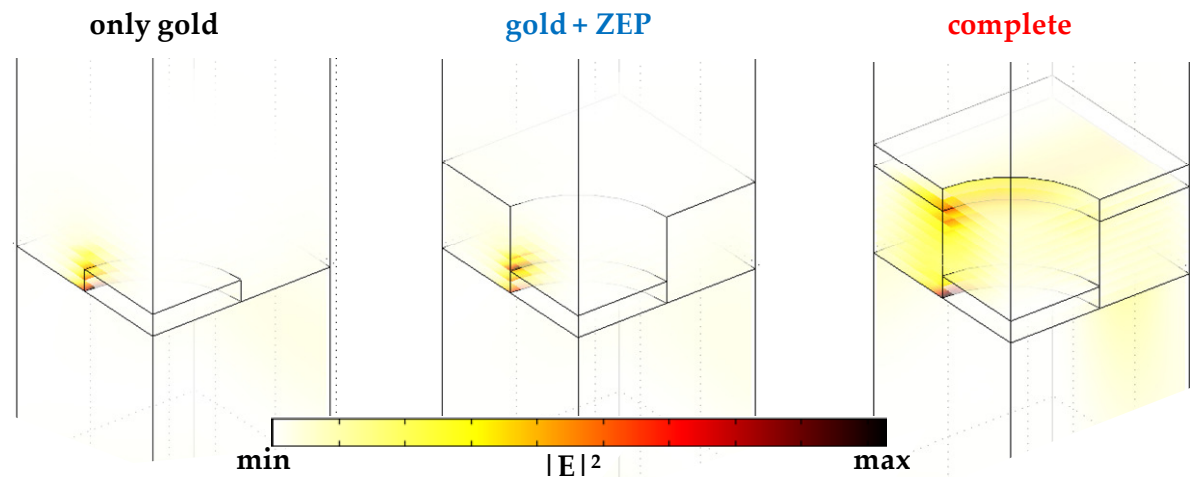
NANOPLASMONICS WITHIN OPTICAL FIBERS



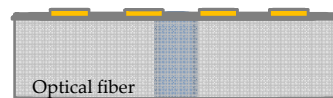
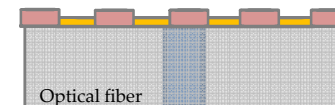
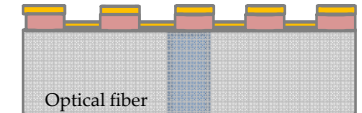
3D computational domain (unit cell)



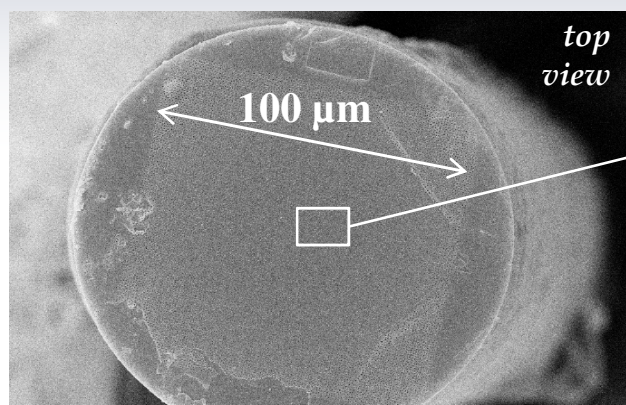
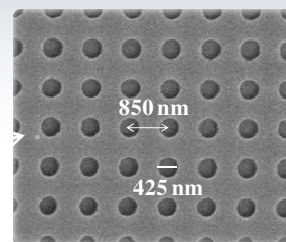
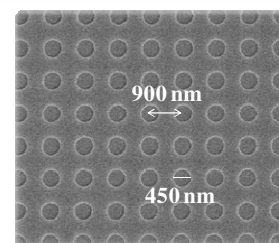
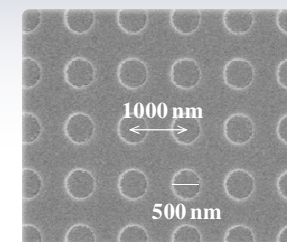
THE WHOLE IS BETTER THAN THE SINGLE PARTS



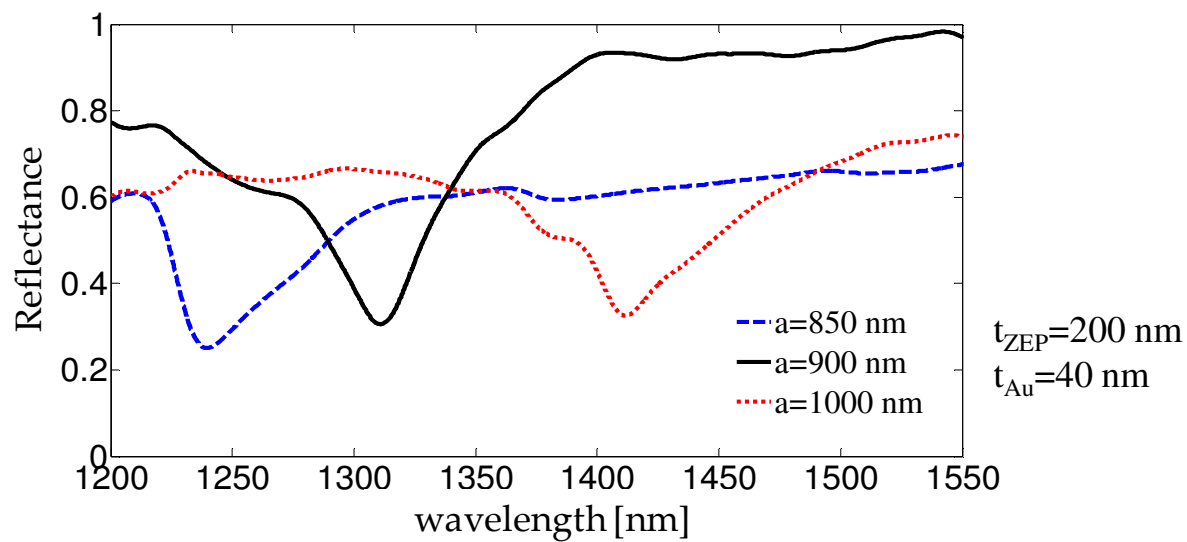
Enhancement of Field
Intensity up to 7 times



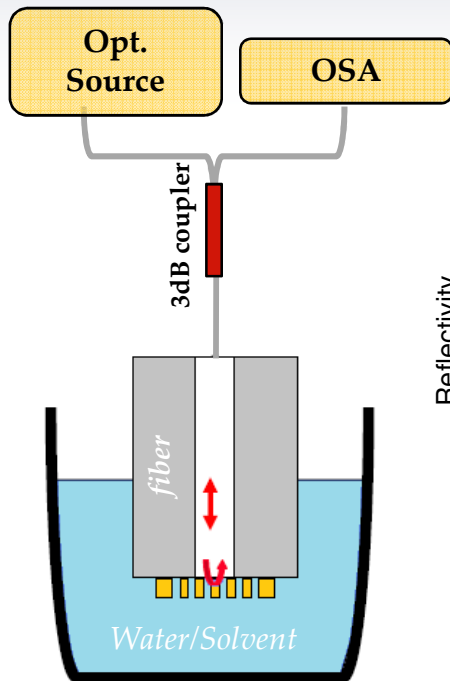
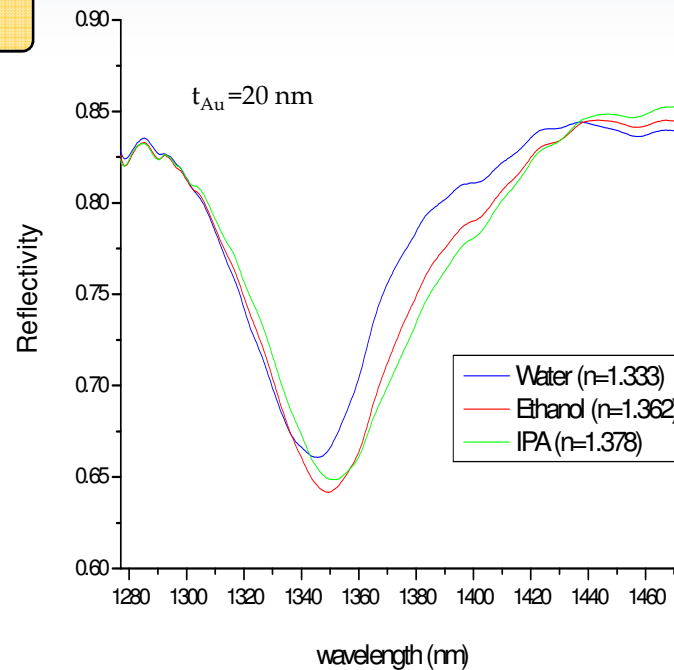
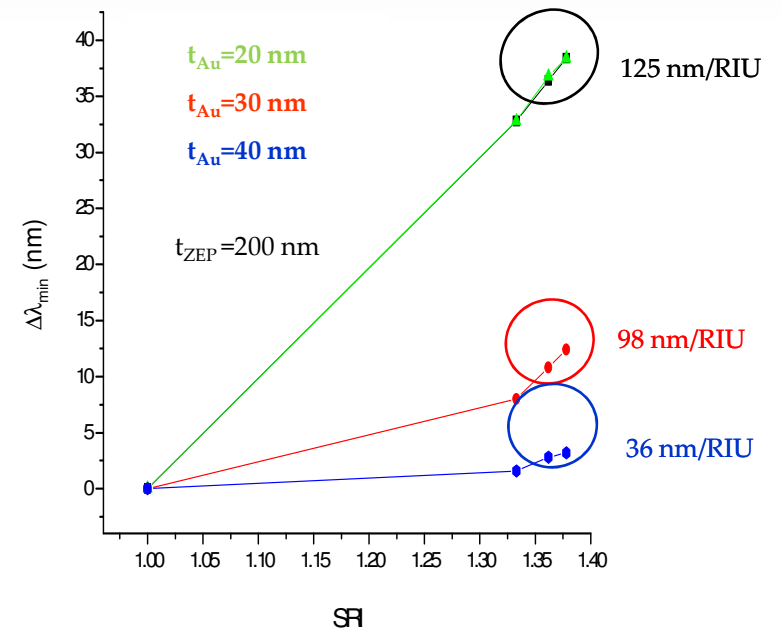
EXPERIMENTAL REALIZATION



Increasing period $a - r/a=0.25$



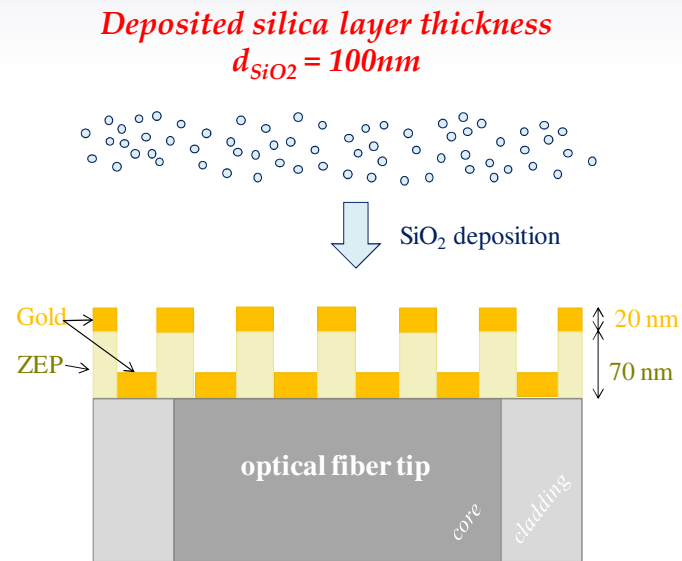
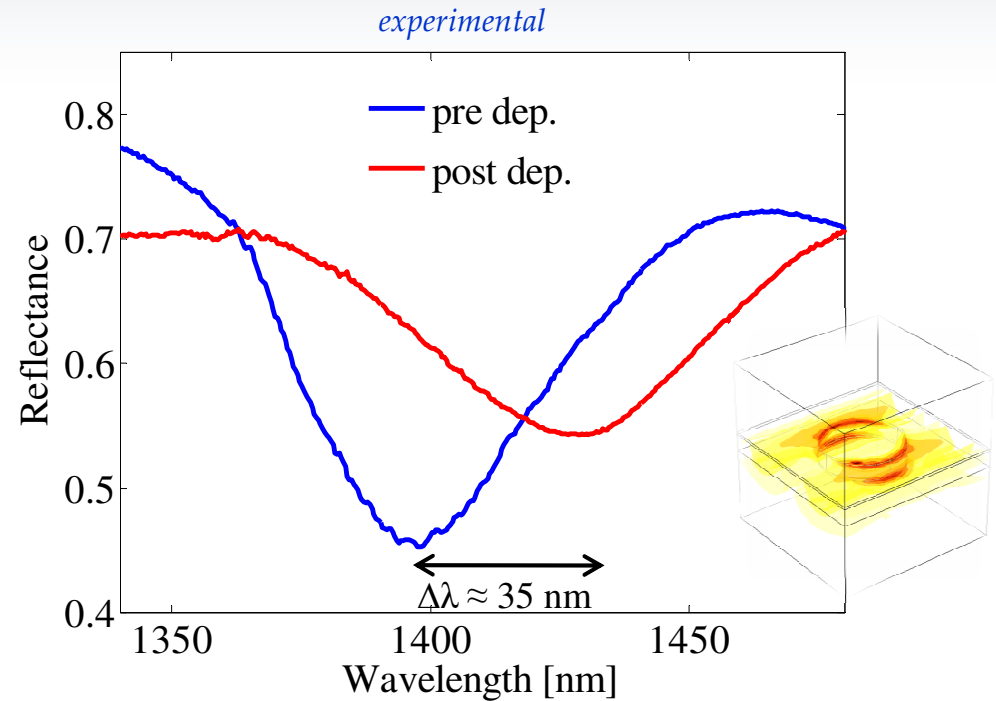
REFRACTIVE INDEX (BULK) SENSITIVITY



Further optimization margins exist acting on the large degree of freedom exhibited by the platform

By adjusting the gold and resist thickness, the lattice tiling, SRI sensitivities of the order of $\sim 500 \text{ nm/RIU}$ are expected

SURFACE SENSITIVITY

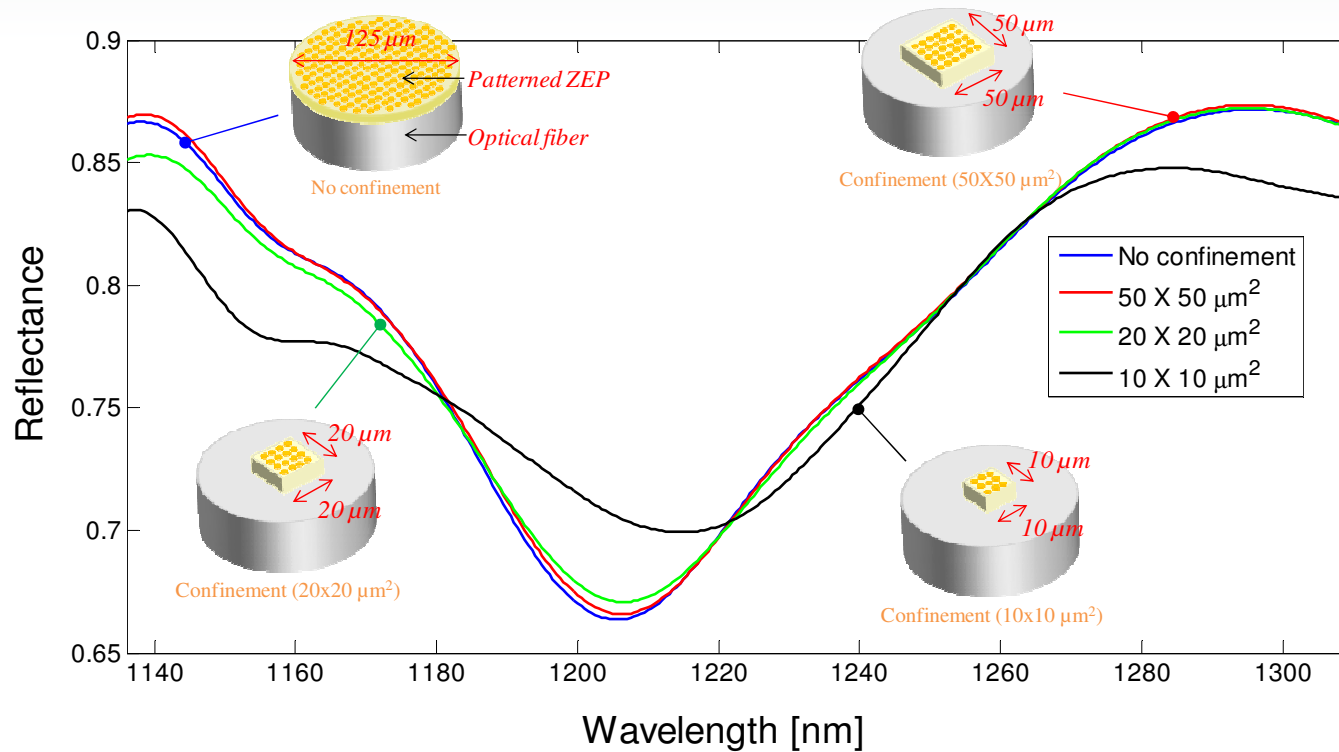


The surface sensitivities (in terms of resonance shift per nanometer of SiO₂ overlay) is 0.35

Considering the typical sizes of biological molecules (3.8-5.2 nm), the binding of a single biological monolayer generates a resonance shift of ~ 1.3-1.8 nm, which may be easily detected.

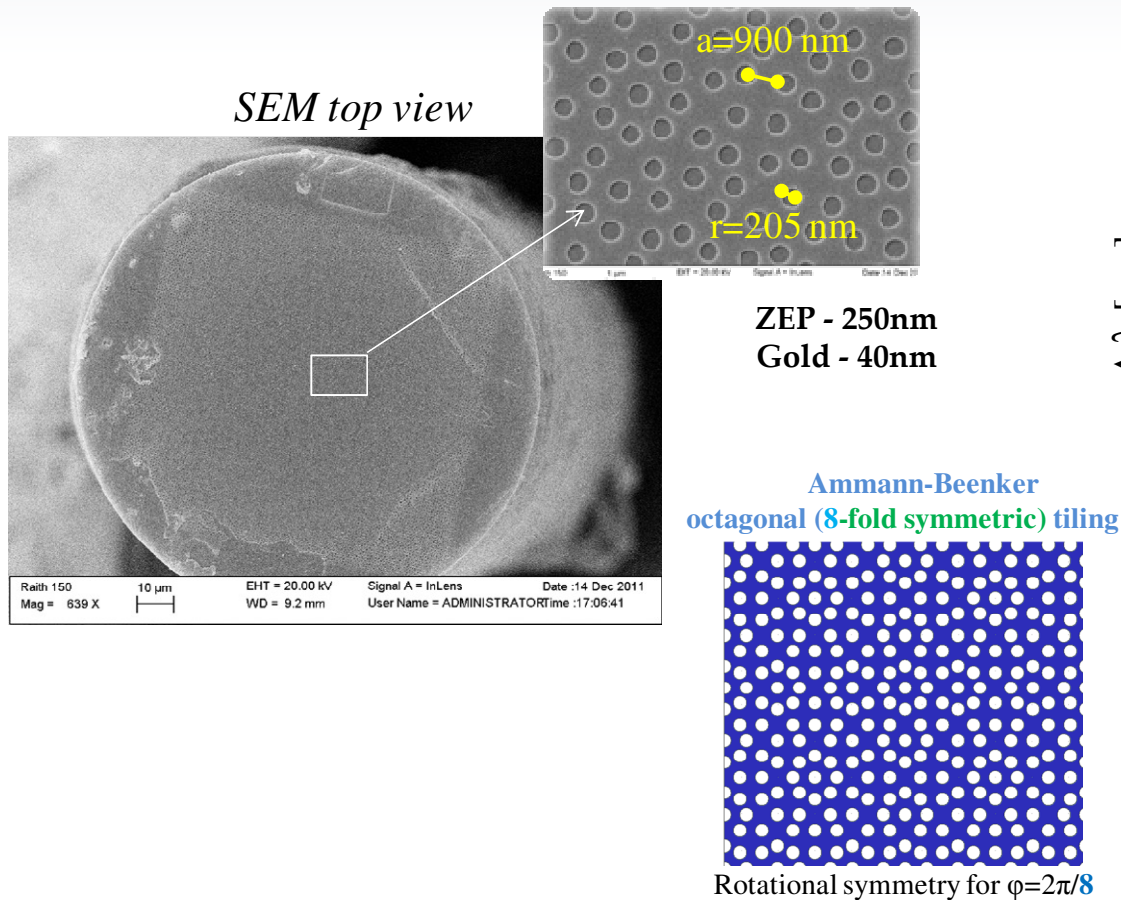
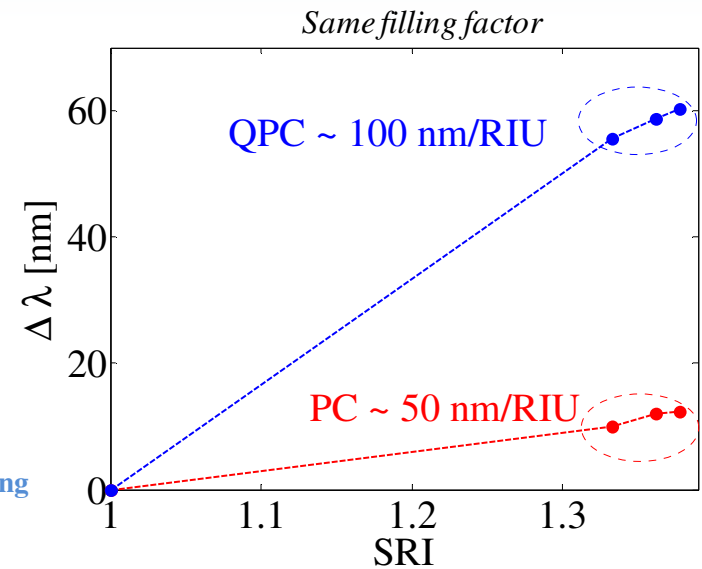
THE SENSING AREA

Structural confinement has been done on the same sample by using a laser micromachining ablation process



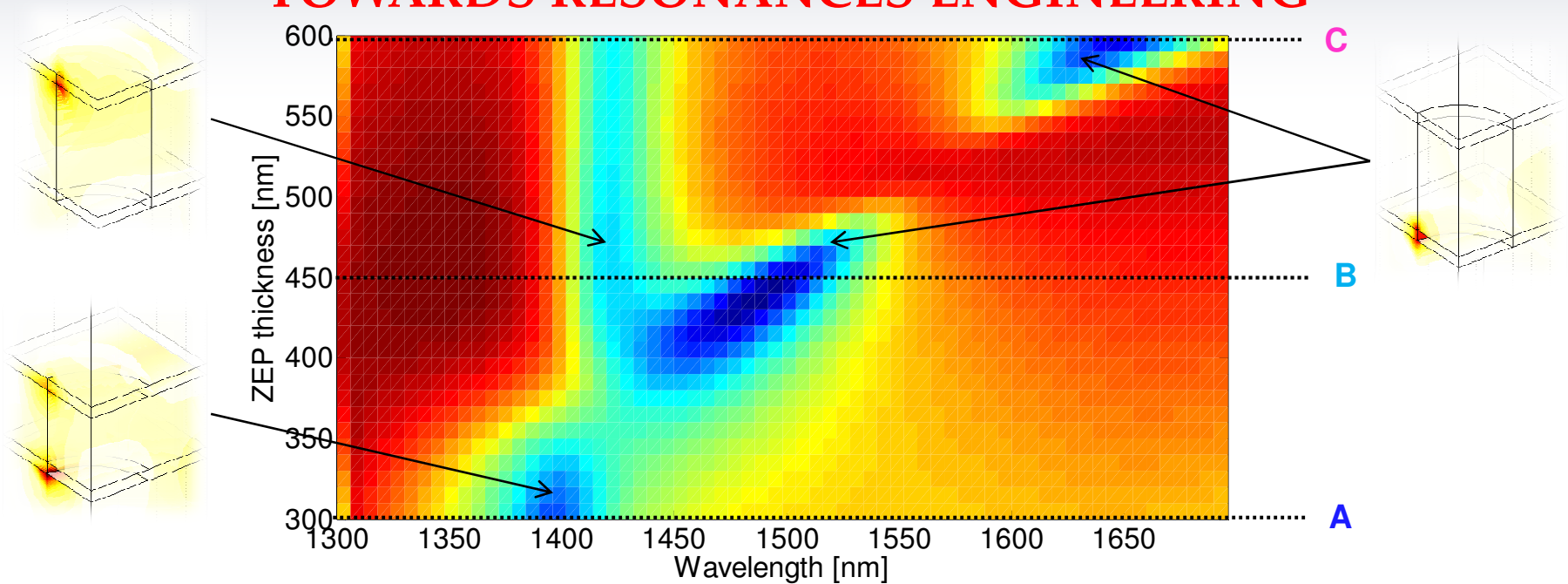
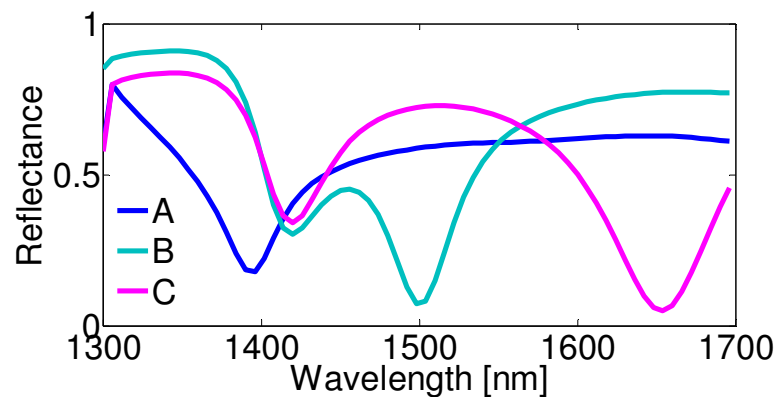
The sensing area can be reduced down to $20 \times 20 \mu\text{m}^2$ without affecting the spectral features (and thus the sensitivity)

RI SENSITIVITY ENHANCEMENTS WITH QUASICRYSTALS



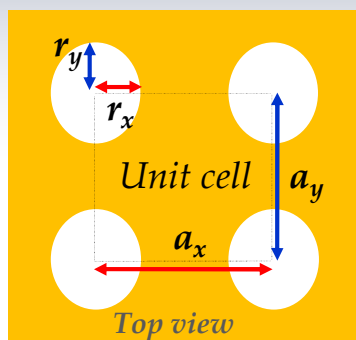
For a given filling factor and equivalent period, QC can outperform the periodic counterpart

DIELECTRIC THICKNESS TUNING : TOWARDS RESONANCES ENGINEERING



A. Cusano et al. Optical Fiber Technology 2013; 19 (6), Part B, pp. 772-784
(Invited Paper)

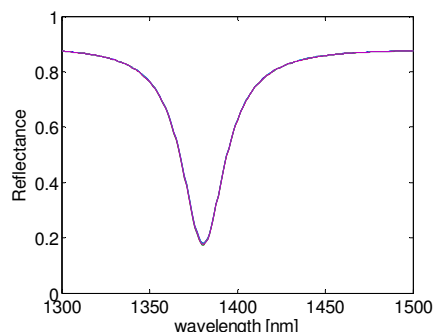
TOWARDS POLARIZATION SENSITIVE DEVICES



Symmetric

$$r_y = \eta r_x, \eta = 1, r_y = 225 \text{ nm}$$

$$a_x = a_y = 900 \text{ nm}$$

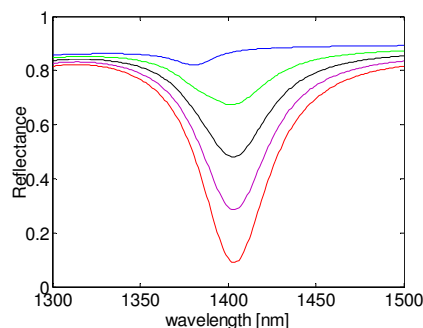
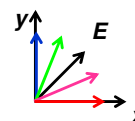
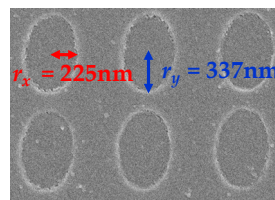
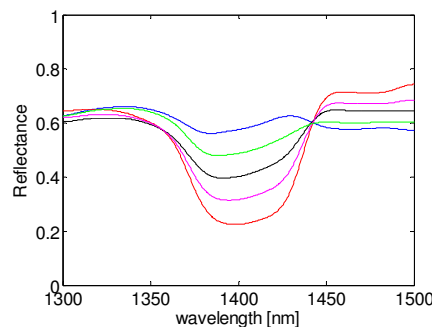


$$t_{ZEP} = 100 \text{ nm} \quad t_{Au} = 17 \text{ nm}$$

Hole ellipticity

$$r_y = \eta r_x, \eta = 1.5$$

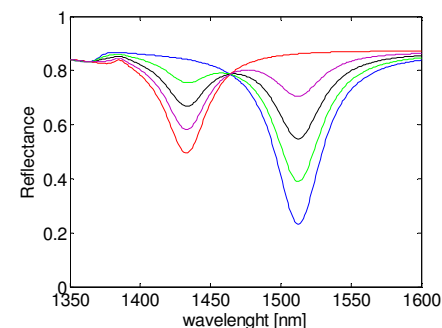
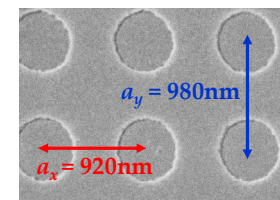
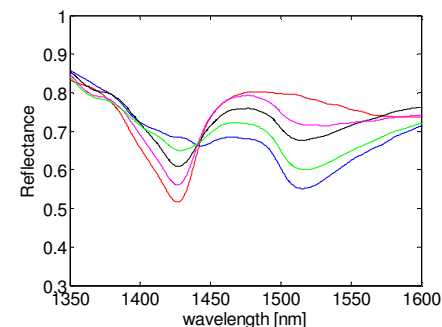
$$a_x = a_y = 900 \text{ nm}$$



Period Asymmetry

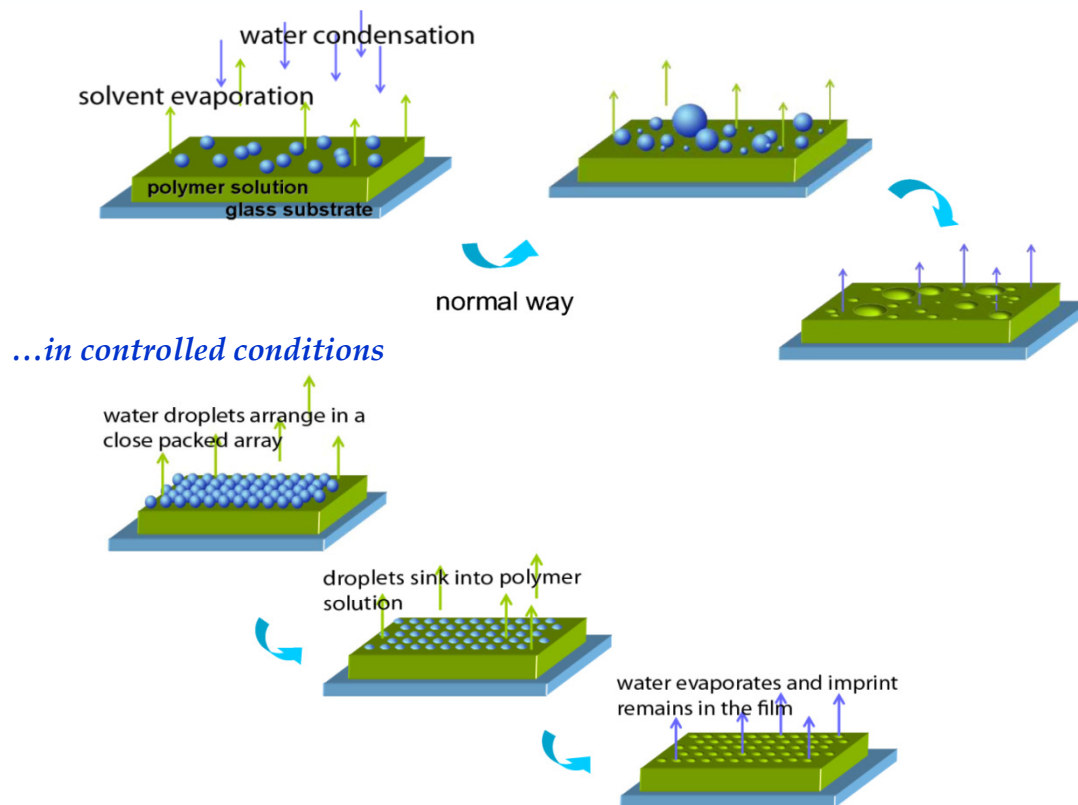
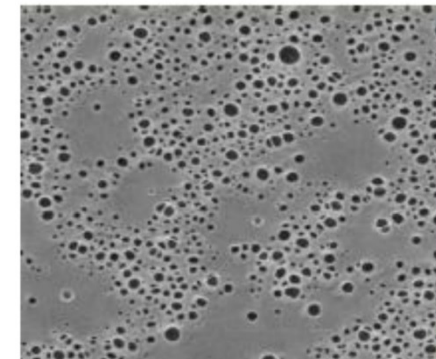
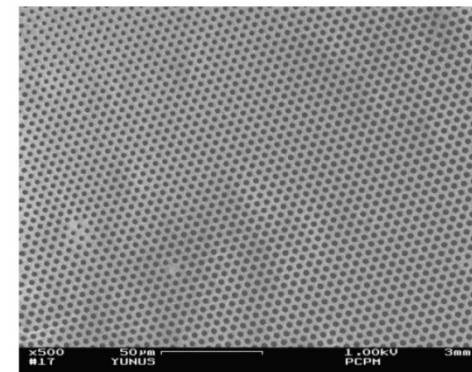
$$r_y = \eta r_x, \eta = 1, r_y = 250 \text{ nm}$$

$$a_x = 920 \text{ nm}, a_y = 980 \text{ nm}$$



BREATH FIGURE TECHNIQUE FOR RAPID AND COST EFFECTIVE PROTOTYPING

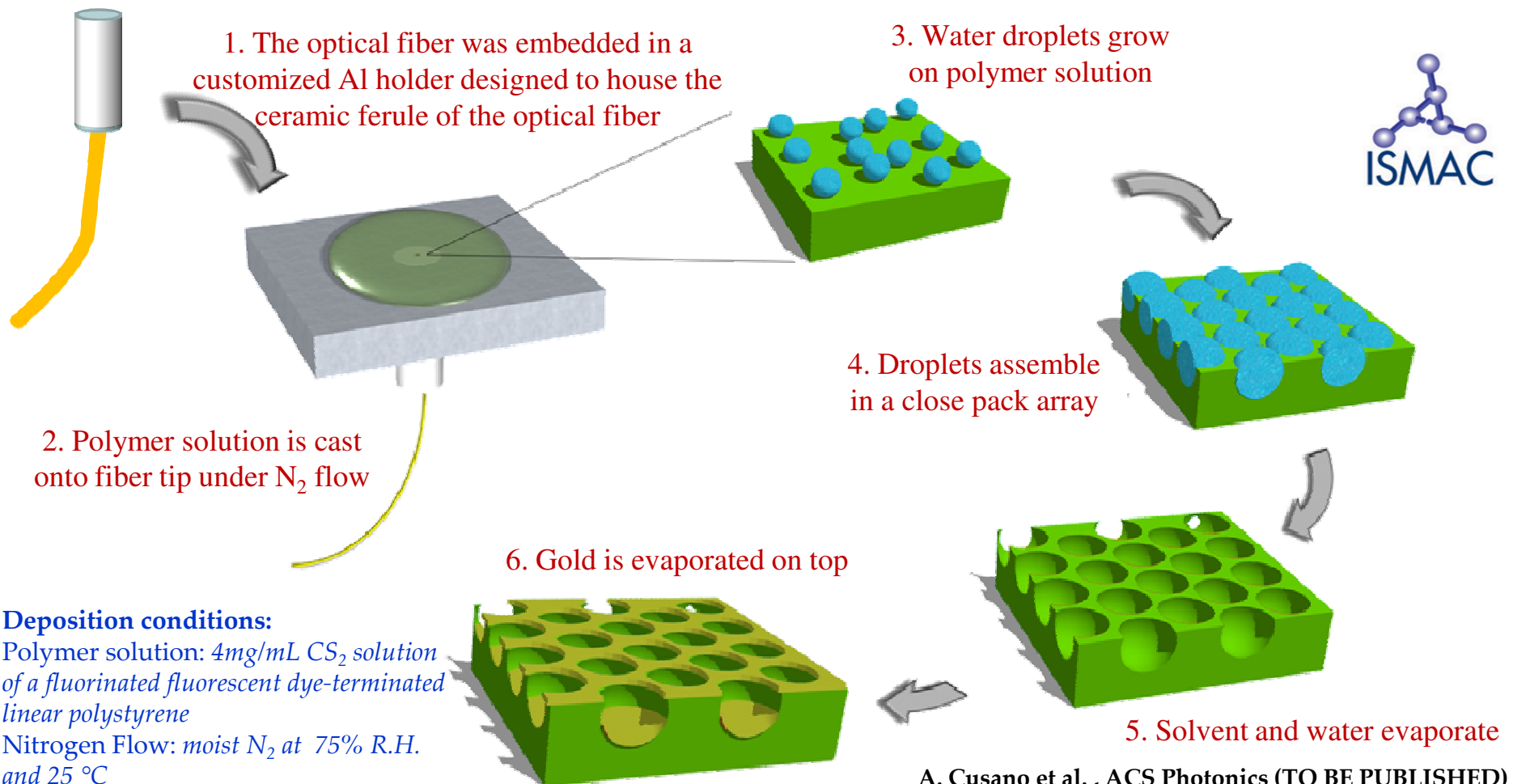
The Breath Figure Technique (Francois, Nature 1994, 369-387-9) relies on the precipitation of a polymer around condensed water droplets triggered by the fast evaporation of polymer solvent in a humid environment



Process control (i.e. by adjusting polymer concentration, kind of solvent, evaporation rate, relative humidity) enables the manipulation of some morphology features in the final film (i.e. degree of order, distribution and size of the cavities)

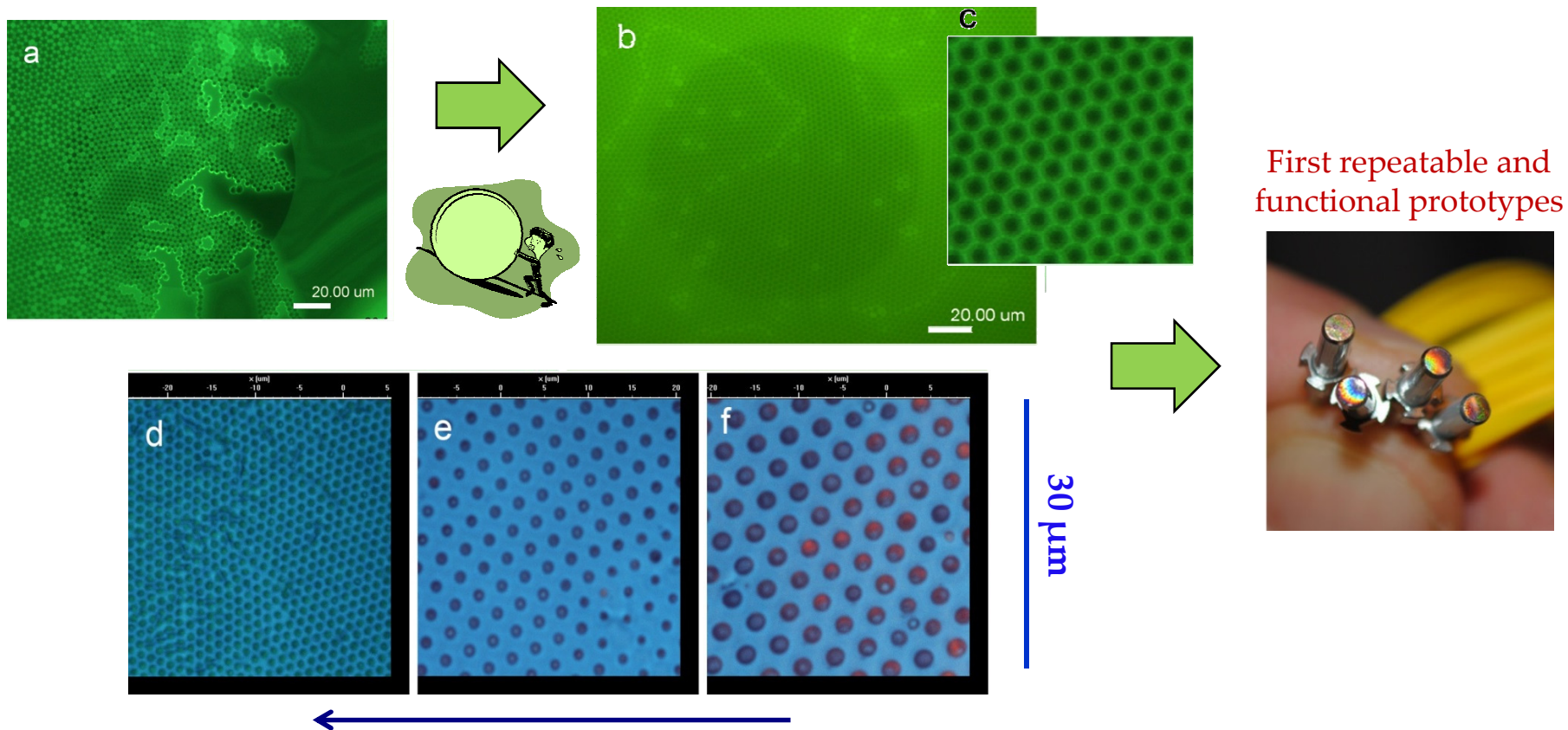
LAB ON FIBER BY THE BREATH FIGURES TECHNIQUE

We adapted the Breath Figures technique to operate on optical fiber substrates so as to realize self assembled metallo-dielectric photonic crystals onto the optical fiber end facet



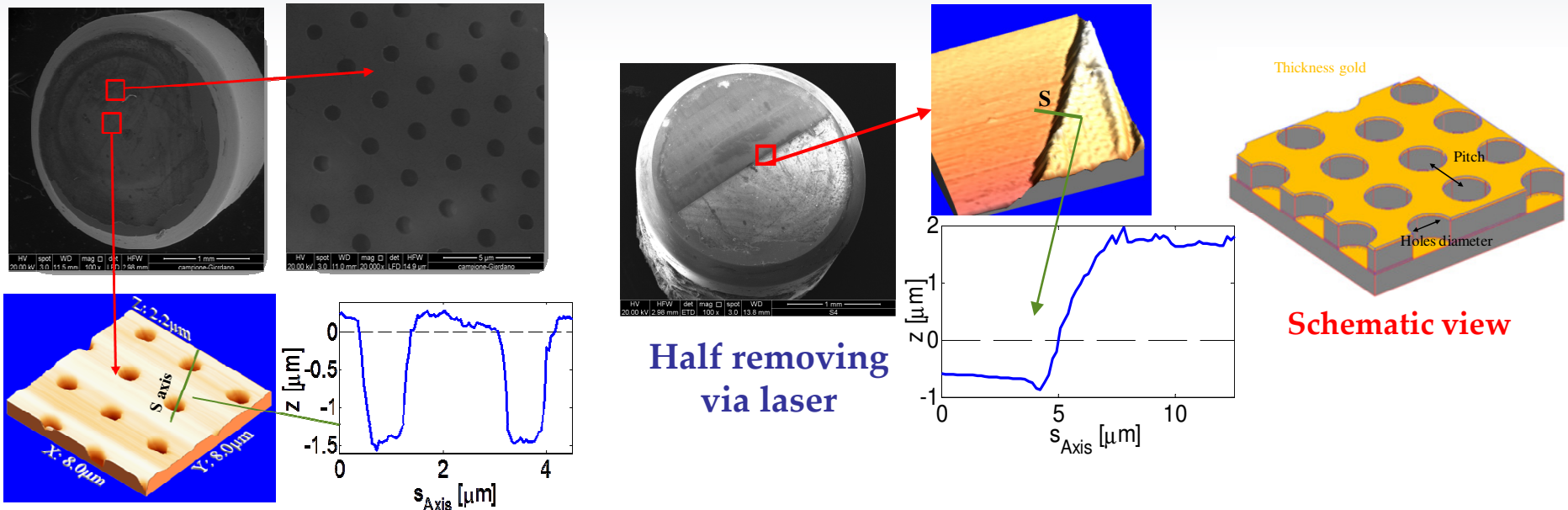
EXPERIMENTAL RESULTS: PROCESS ASSESSMENT

By the assessment of the fabrication process, we are now able to easily obtain well ordered and defect free patterns on the optical fiber tip



By changing the flow of humid nitrogen between 100 and 300 L/h, we obtained honeycomb arrays with cavities ranging from 2.5 to 1.0 μm

MORPHOLOGICAL CHARACTERIZATION



Half removing
via laser

Scanning Electron Microscopy (SEM) and Atomic
Force Microscopy (AFM) analysis
have been carried out to accurately study the
morphology of the created patterns

The optimized process ensures Order and
Regularity of the polymeric template

Flow rate 300L/h – gold thickness 33nm)

Average values (Relative standard deviation)

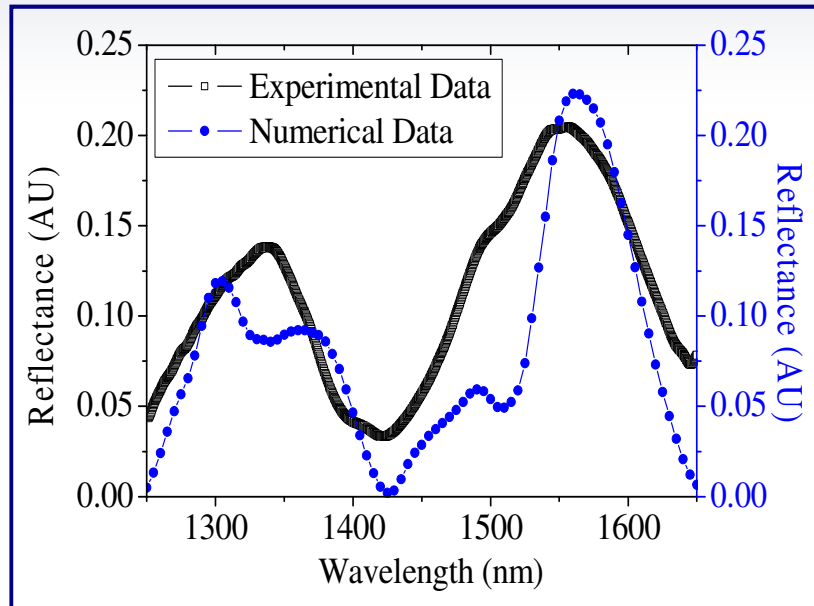
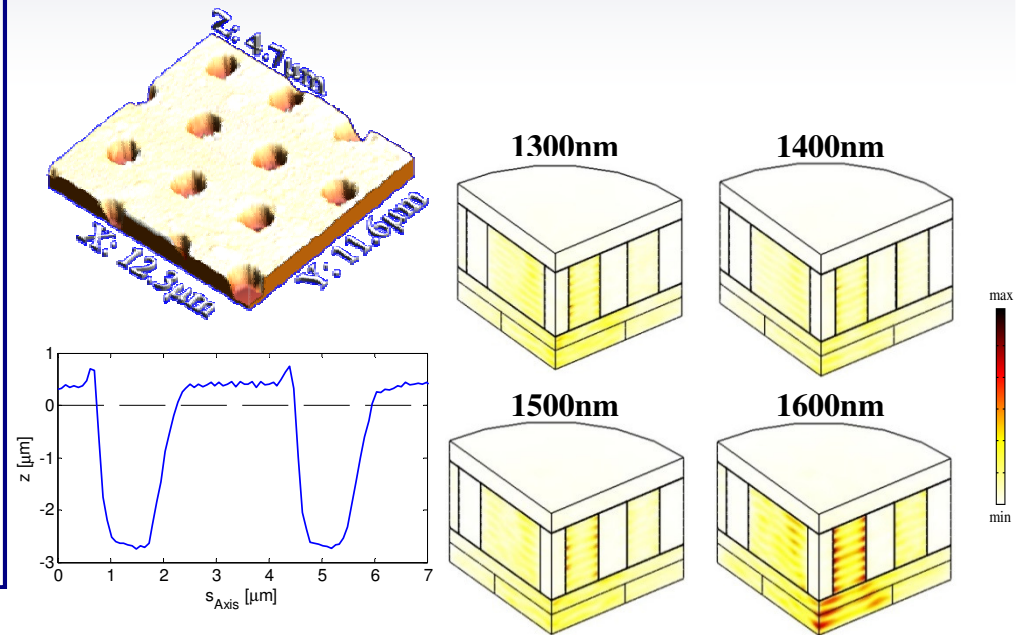
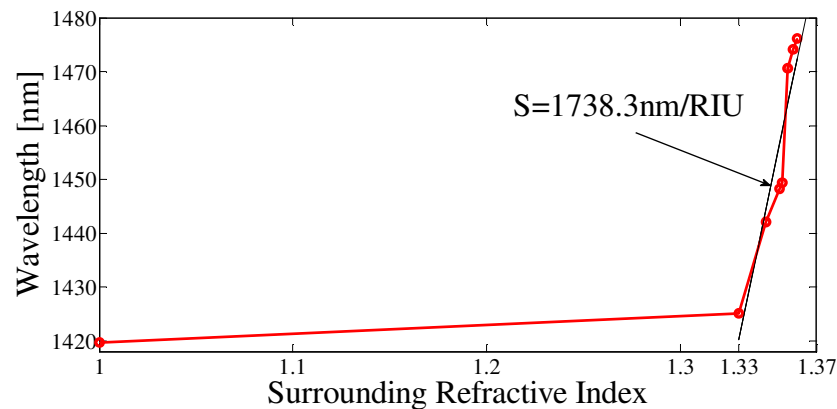
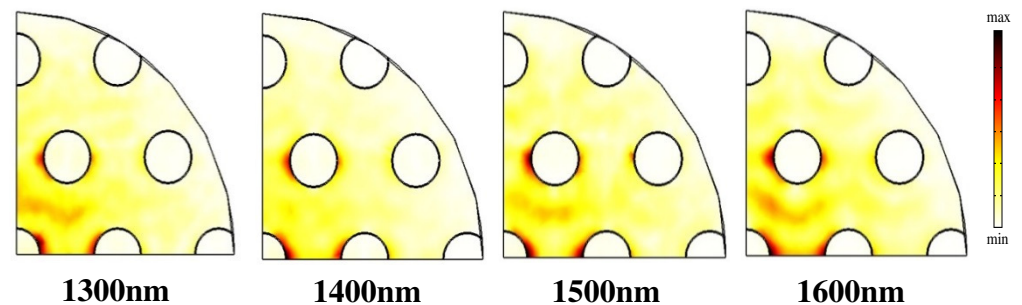
Holes Diameter = 0.95 μm (3.2%)

Pitch = 2.67 μm (1.3%)

Hole depth = 1.78 μm (3.5%)

Structure height = 2.5 μm (2.3%)

SENSING PERFORMANCES



LAB ON FIBER TECHNOLOGY: MORE THAN A VISION

A Lab ON FIBER

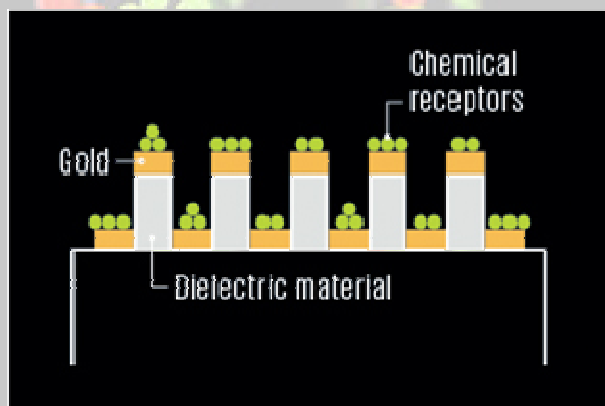
Tiny chemical sensors could use light to monitor the environment and hunt for disease

By
JACQUES
ALBERT

THINK BACK TO THE LAST TIME YOU GOT A BLOOD TEST.

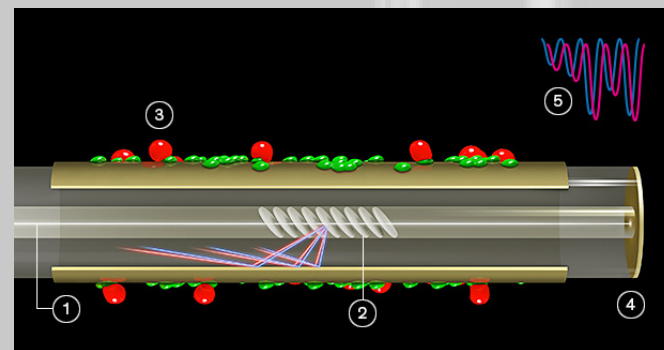
Maybe you had your cholesterol checked or got screened for infections, heart disease, stroke risk, thyroid troubles, or osteoporosis. Easy, right? A nurse simply drew your blood and shipped the vials to a lab. But behind the scenes, the process gets more complex. Today's laboratory technologies require rooms full of temperature-controlled chemicals, analytical machines worth hundreds of thousands of dollars, and trained technicians to run them. That's why it probably took days, maybe even a week or two, to get your results back. Now imagine the test results of thousands of people being

On the Tip



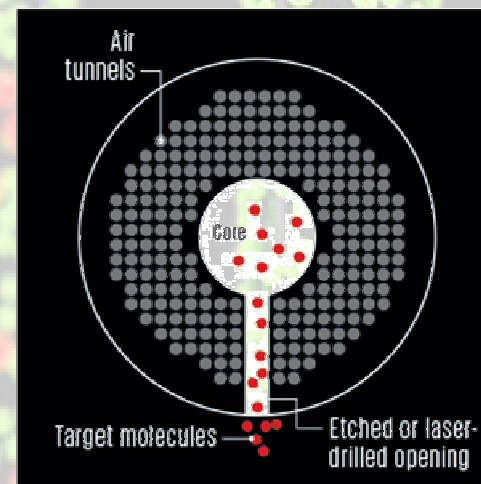
Andrea CUSANO et al., University of Sannio, Italy

Tilted Fiber Bragg gratings



Jacques ALBERT et al., Carleton University, Canada

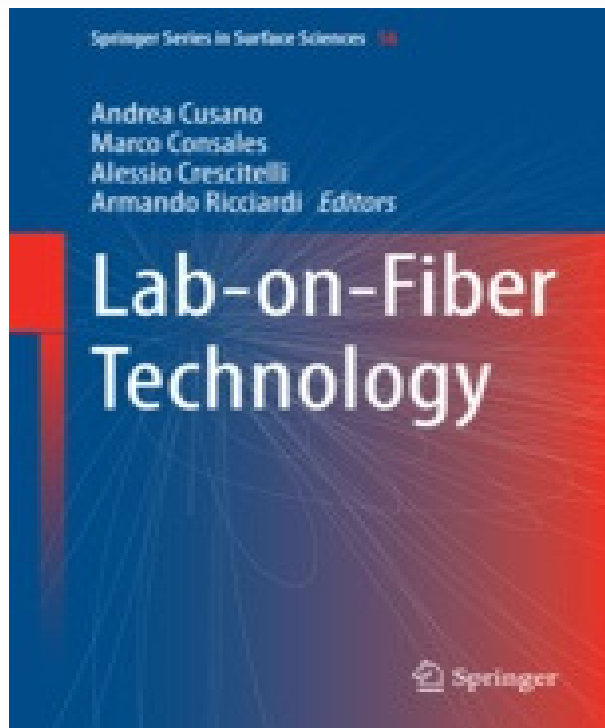
Microstructured optical fiber



Philip St. J. RUSSELL, Max Planck Institute for the Science of Light, Germany, Ole BANG, Technical University of Denmark et al.

Jacques Albert, IEEE Spectrum, April 2014

THE FIRST BOOK



- Written by the world's leading experts in this field
- First book on the lab-on-fiber technology
- Explains concepts, methods and applications of the lab-on-fiber technology

This book focuses on a research field that is rapidly emerging as one of the most promising ones for the global optics and photonics community: the "lab-on-fiber" technology.

Inspired by the well-established "lab on-a-chip" concept, this new technology essentially envisages novel and highly functionalized devices completely integrated into a single optical fiber for both communication and sensing applications.

Based on the R&D experience of some of the world's leading authorities in the fields of optics, photonics, nanotechnology, and material science, this book provides a broad and accurate description of the main developments and achievements in the lab-on-fiber technology roadmap, also highlighting the new perspectives and challenges to be faced.

This book is essential for scientists interested in the cutting-edge fiber optic technology, but also for graduate students.



Optoelectronic Division, Engineering Department
University of Sannio, Benevento (Italy)



THANKS FOR YOUR KIND ATTENTION



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