



Optoelectronic Division, Engineering Department

University of Sannio, Benevento, Italy

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UNIVERSITA degli STUDI del SANNIO

OMICS Group International through its Open Access Initiative is committed to make genuine and reliable contributions to the scientific community. OMICS Group hosts over 400 leading-edge peer reviewed Open Access Journals and organize over 300 International Conferences annually all over the world. OMICS Publishing Group journals have over 3 million readers and the fame and success of the same can be attributed to the strong editorial board which contains over 30000 eminent personalities that ensure a rapid, quality and quick review process.



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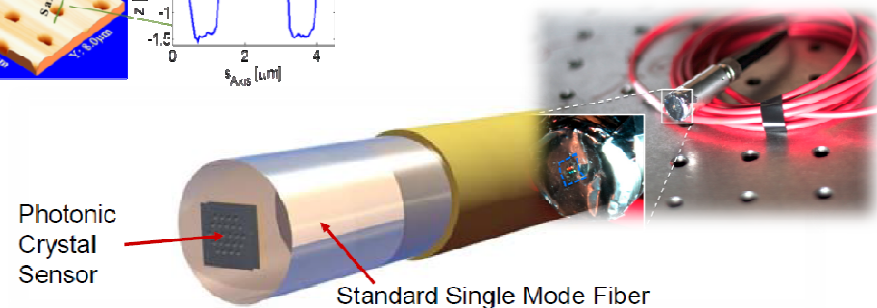
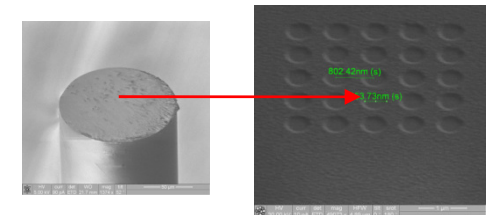
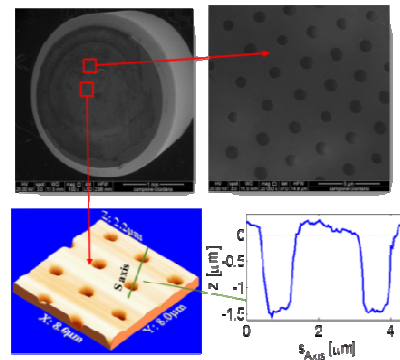
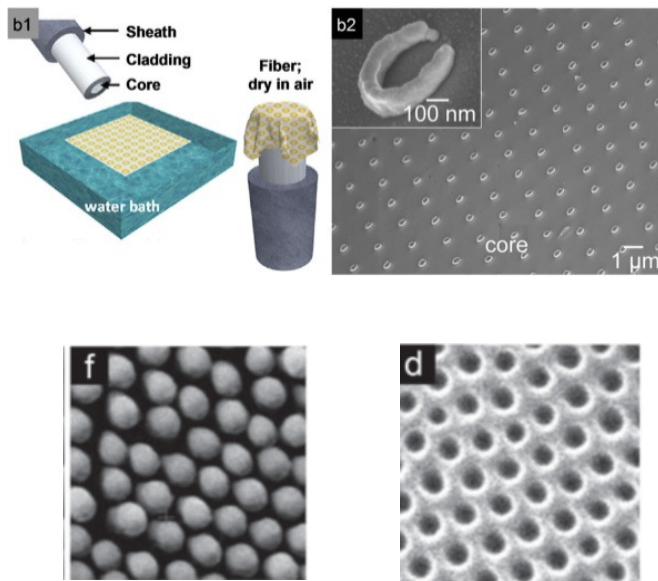
- ❑ OMICS Group signed an agreement with more than 1000 International Societies to make healthcare information Open Access. OMICS Group Conferences make the perfect platform for global networking as it brings together renowned speakers and scientists across the globe to a most exciting and memorable scientific event filled with much enlightening interactive sessions, world class exhibitions and poster presentations
- ❑ Omics group has organised 500 conferences, workshops and national symposium across the major cities including San Francisco, Omaha, Orlando, Raleigh, Santa Clara, Chicago, Philadelphia, United Kingdom, Baltimore, San Antonio, Dubai, Hyderabad, Bangaluru and Mumbai.

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



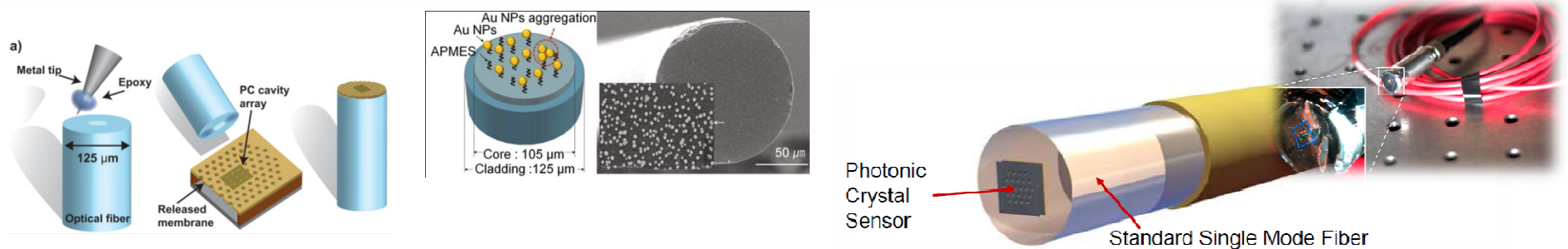


OUTLINE

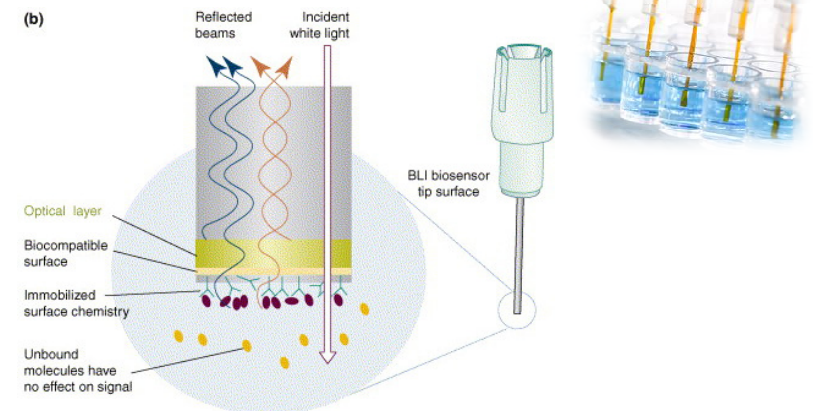
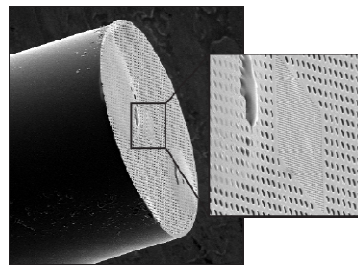
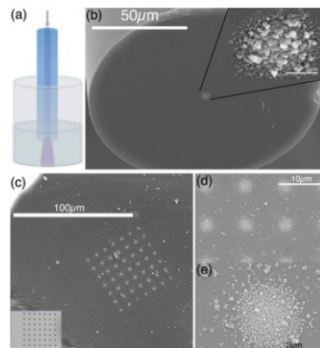
- LAB-ON-FIBER TECHNOLOGY*
- LAB ON FIBER AT UNIVERSITY OF SANNIO*
- FIBER OPTIC NANO-PROBES: PRINCIPLE OF OPERATION AND SENSING FEATURES*
- CONCLUSIONS*

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.

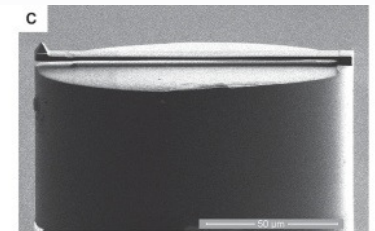
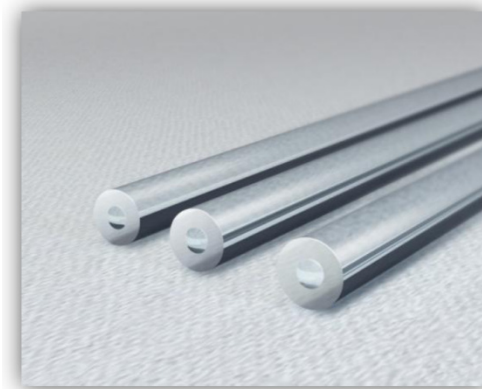
THE FIBER TIP: A UNIQUE LIGHT COUPLED PLATFORM FOR MICRO AND NANO TECHNOLOGIES

Unique and Unconventional Platform

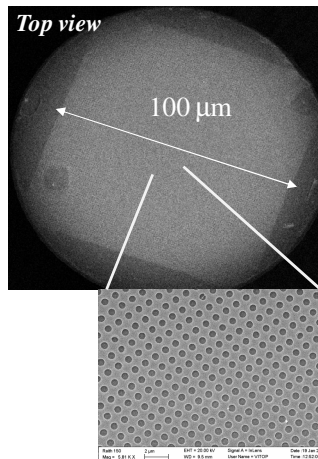
Microscopic Cross Section and large aspect ratio

Inherently Light Coupled

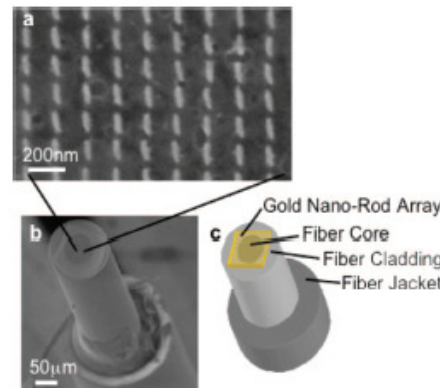
Biocompatible



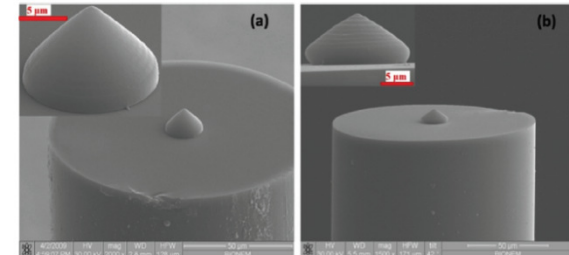
Opto-mechanical Systems
(AFM and near field probes,
Pressure and
Acoustic sensors)



Nanophotonics
(Nanodevices, diffractive filters, light
manipulation)

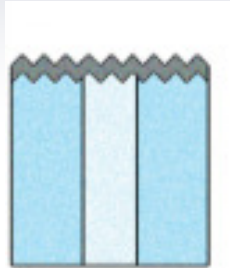


Biophotonics
(Sers, Plasmonics,
Optical tweezers, Nanosensors)

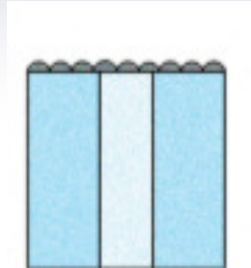


Micro-optics and Beam Shaping

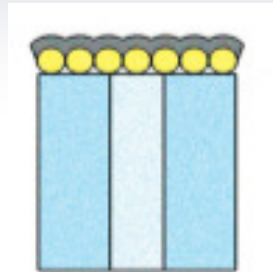
EARLIER DEVELOPMENTS DRIVEN BY SERS



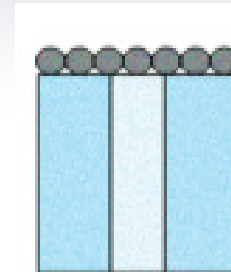
Roughening by mechanical abrasion
Mullen 1991



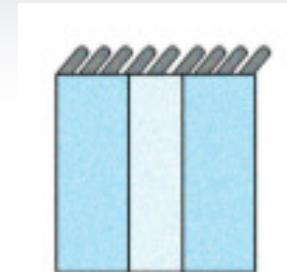
Island growth during thin film deposition
Viets and Hill, 1998



Self-assembly of colloidal templates
Vo Dinh, 1995

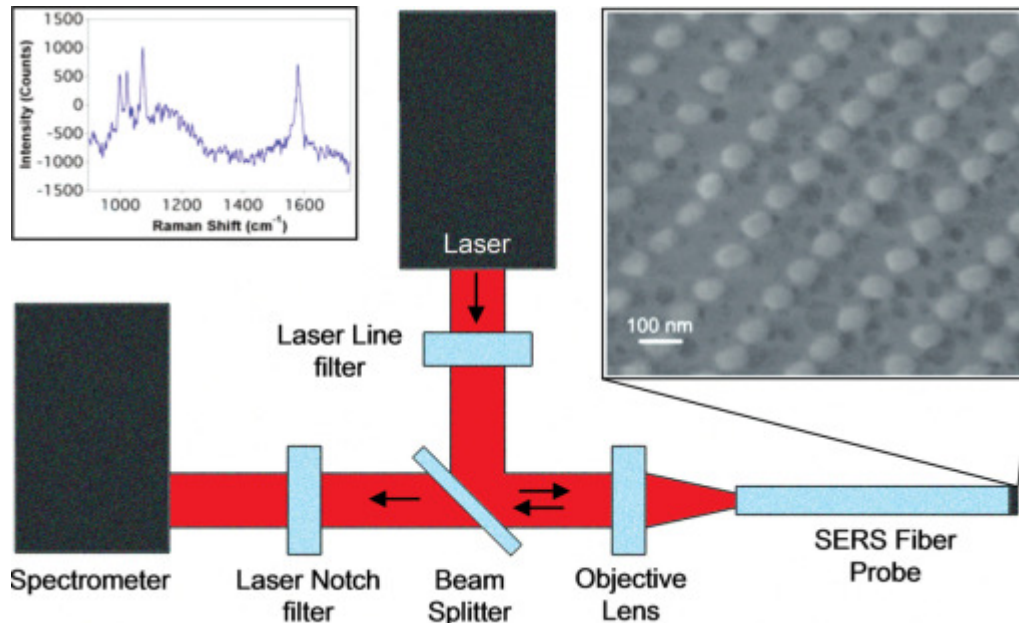


Coating with metal nanoparticles
Sadler, 2000



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

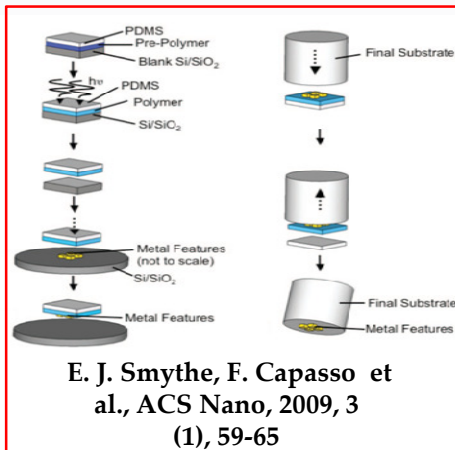
Main Issue

Stochastic deposition affects the order and regularity of the final nanostructure

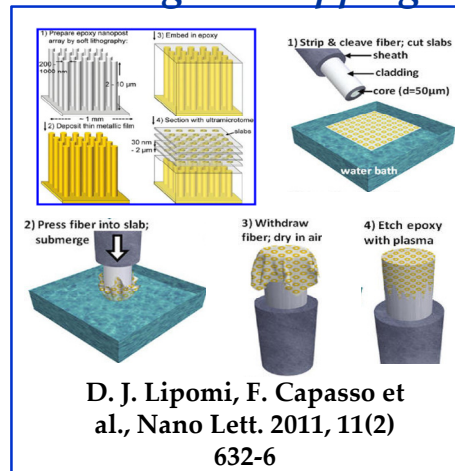
TOWARDS ENGINEERED NANOSTRUCTURES INTEGRATION

Nano-fabrication on planar substrates and transferring onto optical fibers

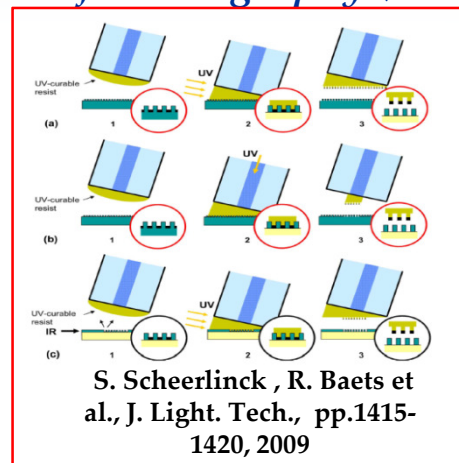
EBL and soft lithography



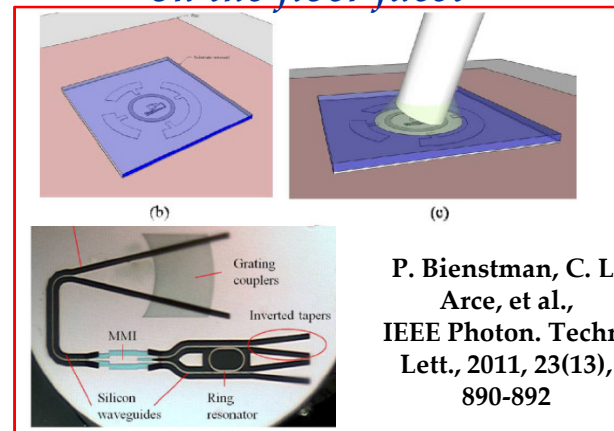
Soft lithography, nano-skiving and dipping



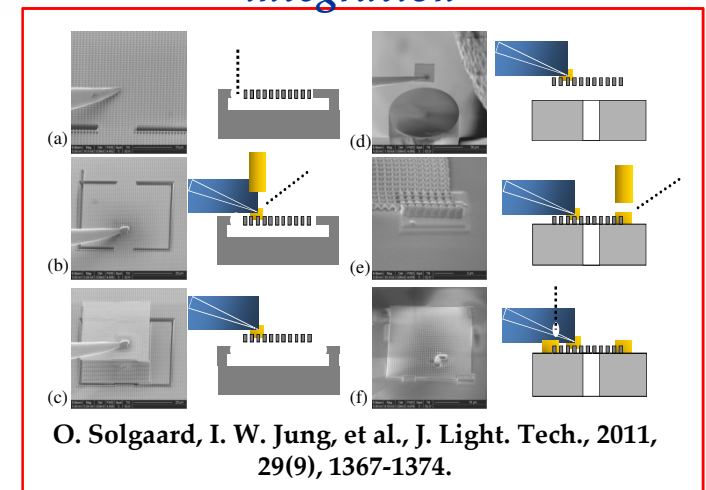
UV nano imprint and transfer lithography (NITL)



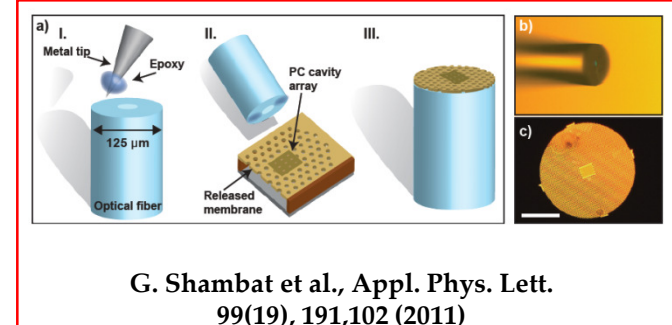
Soi microring resonator integrated on the fiber facet



Monolithic silicon photonic crystal integration

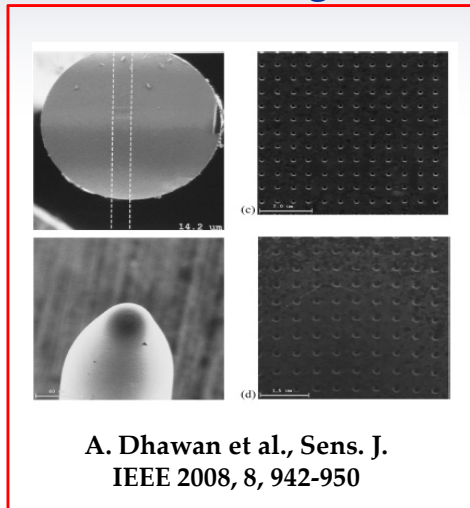


Photonic crystal cavity transfer



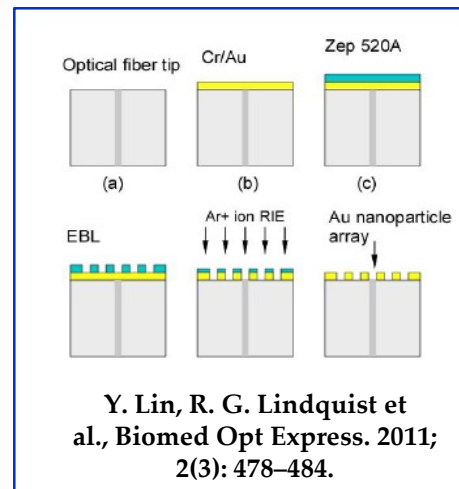
OVERCOMING THE TRANSFERRING APPROACH

FIB milling

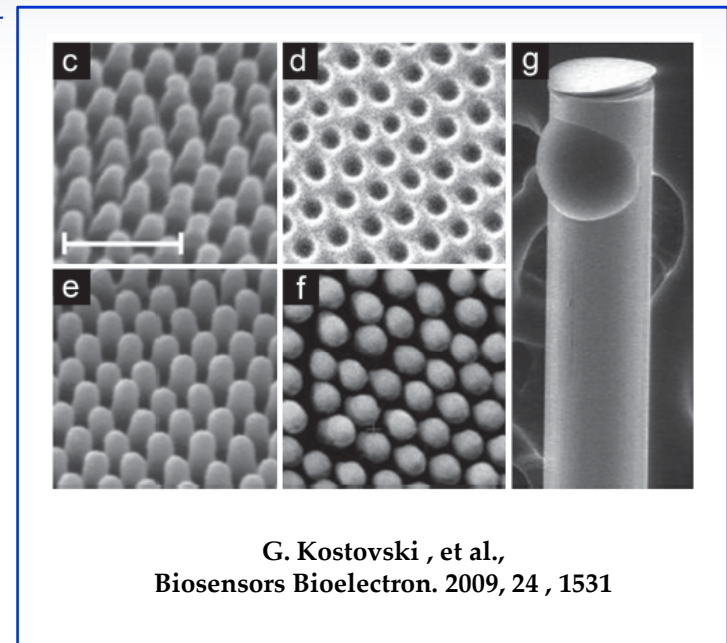


Direct-writing

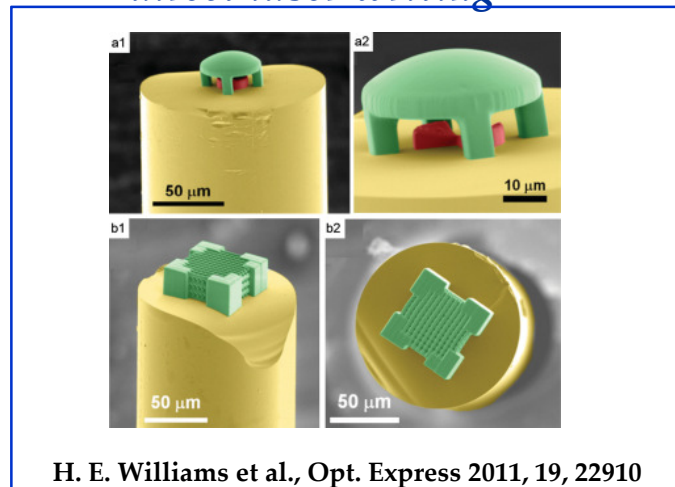
EBL and Reactive Ion Etching



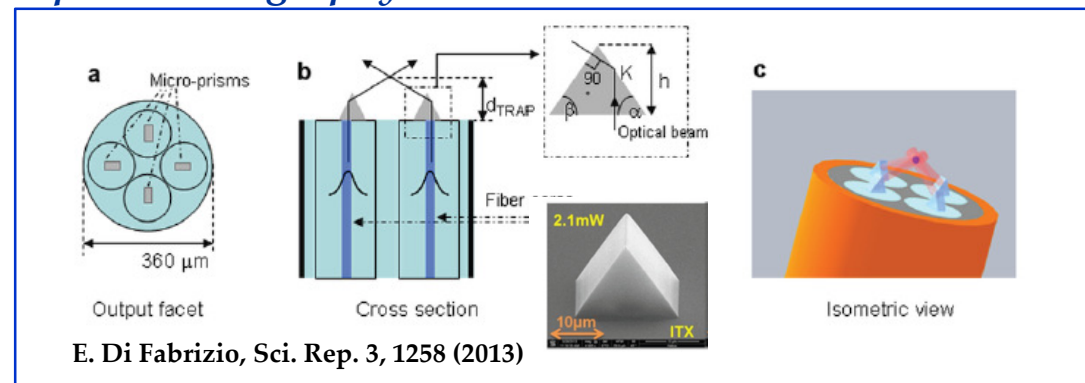
Nanoimprint lithography



Micro-optics using two-photon direct laser writing

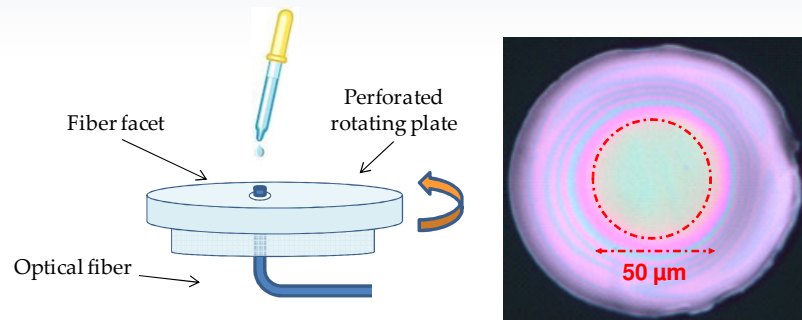


Optical tweezers using two photon lithography



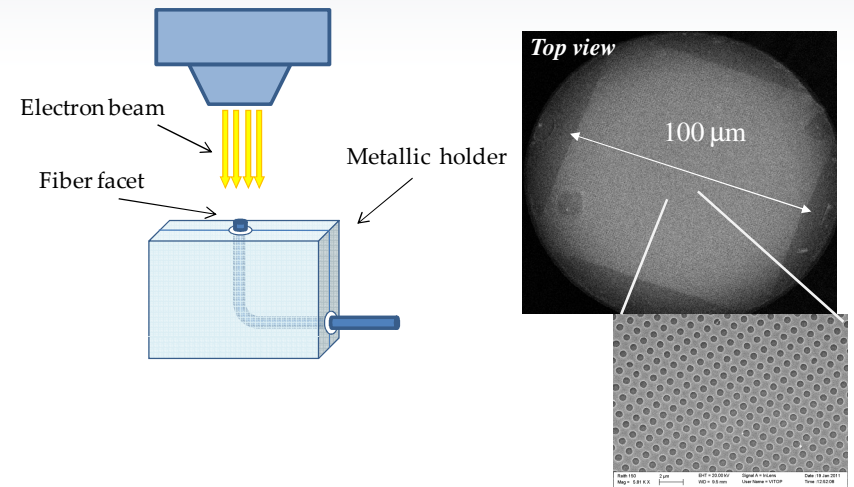
EBL DIRECT WRITING

1) Electron-resist spin coating

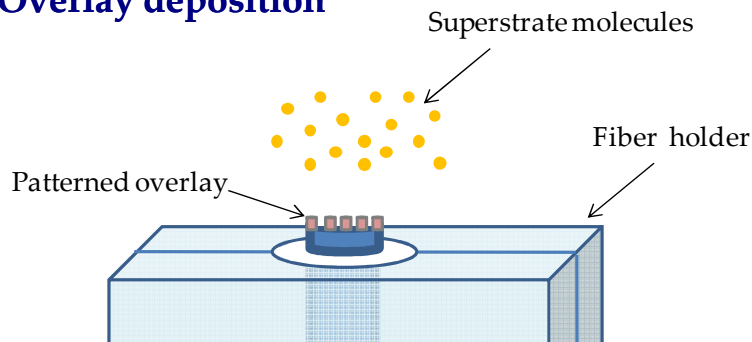


100-400nm thick (ZEP) overlay can be reproducibly obtained

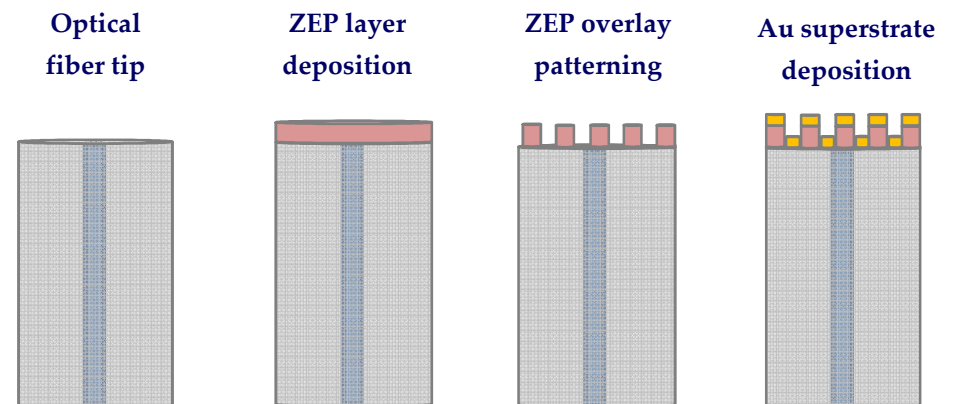
2) EBL patterning



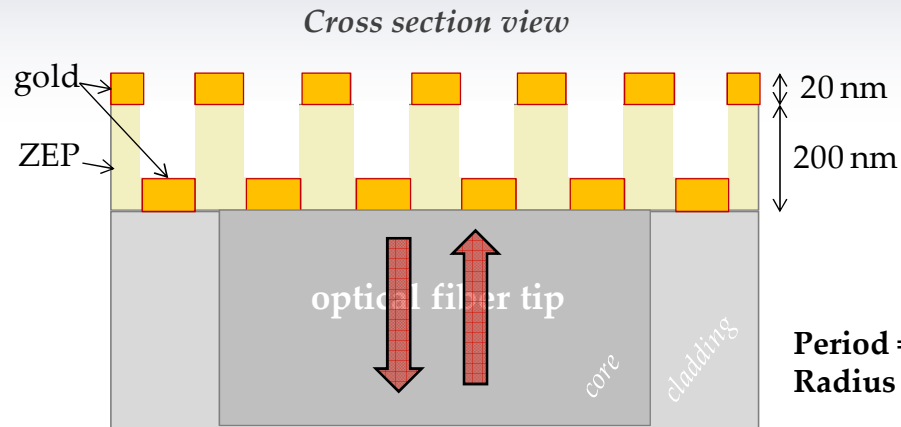
3) Overlay deposition



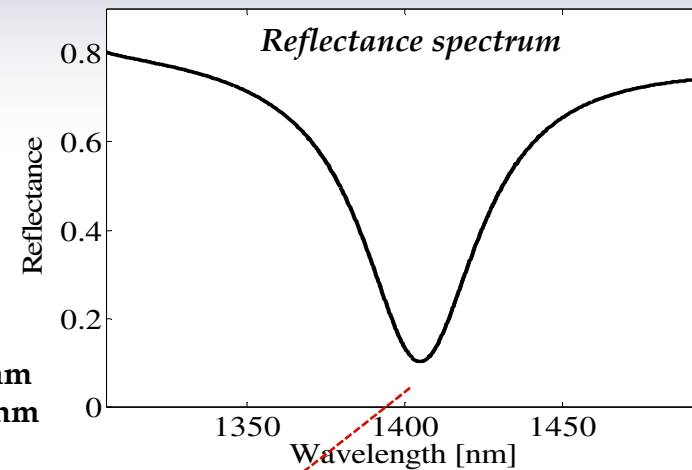
Different materials (metallic or dielectric) can be easily deposited



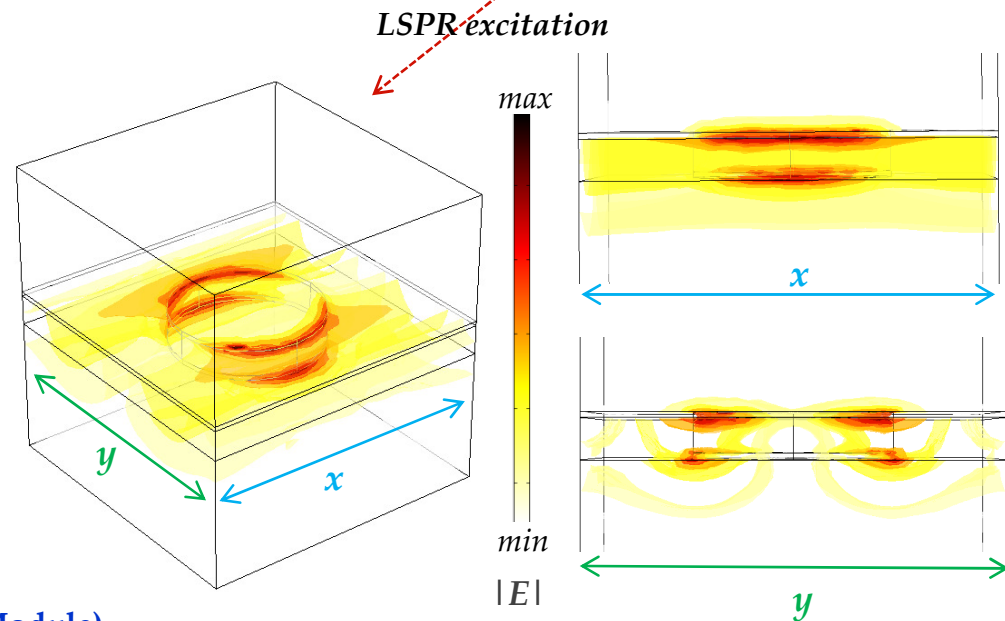
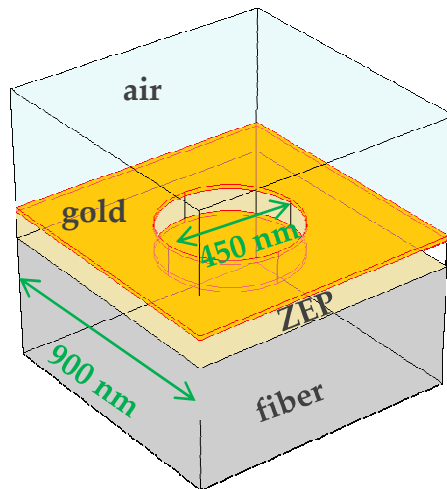
NANOPLASMONICS WITHIN OPTICAL FIBERS



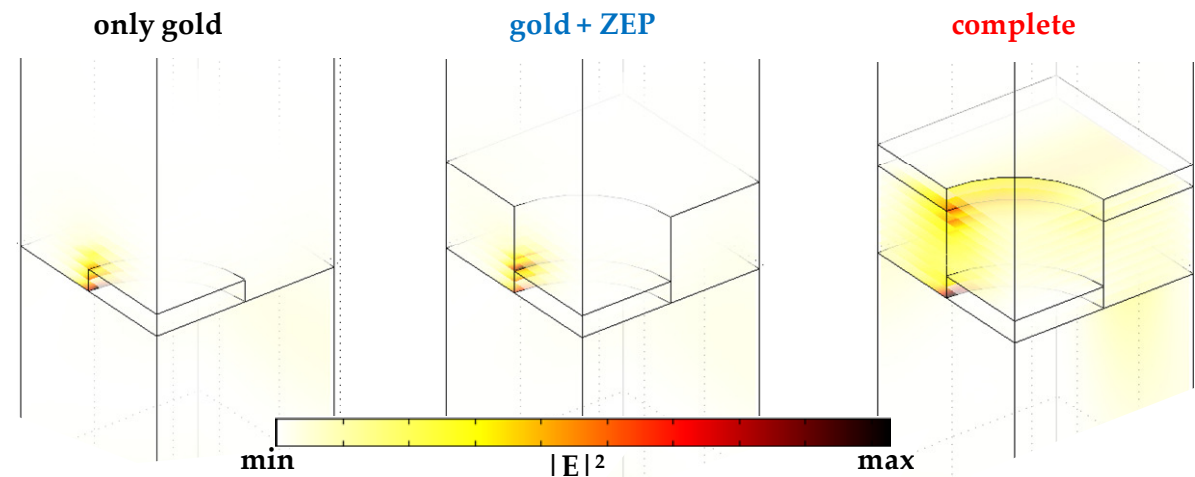
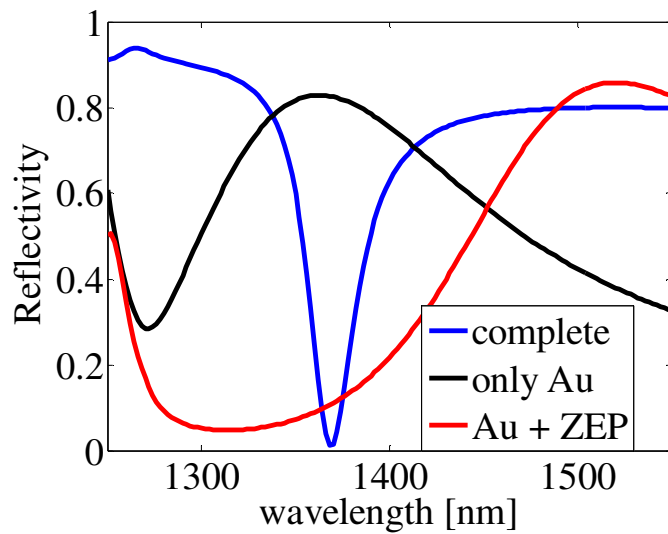
Period = 900 nm
Radius = 225 nm



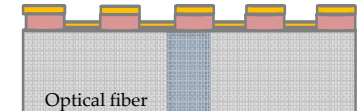
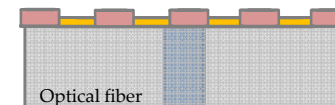
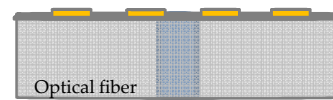
3D computational domain (unit cell)



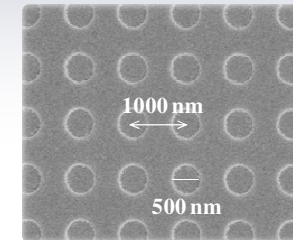
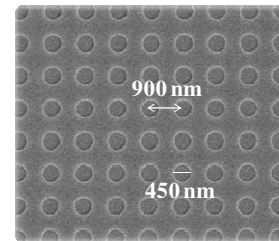
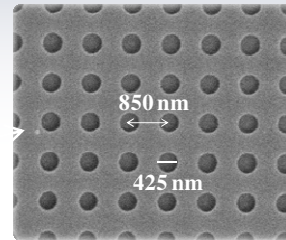
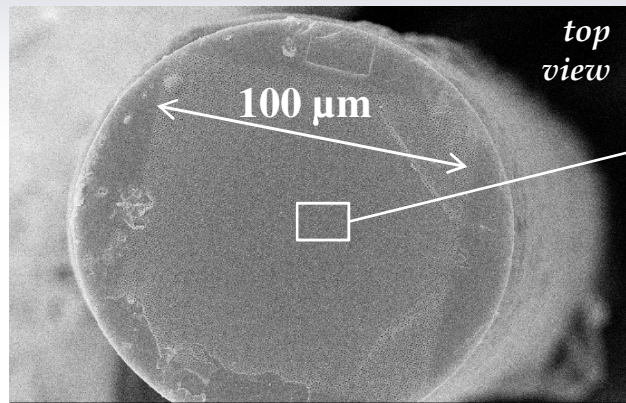
THE WHOLE IS BETTER THAN THE SINGLE PARTS



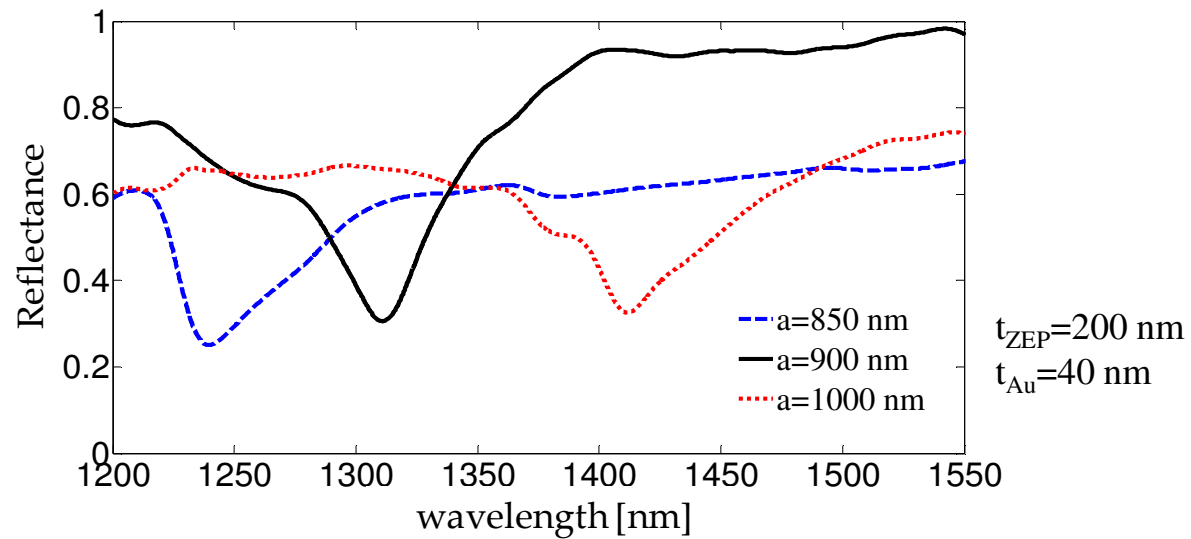
Enhancement of Field Intensity up to 7 times



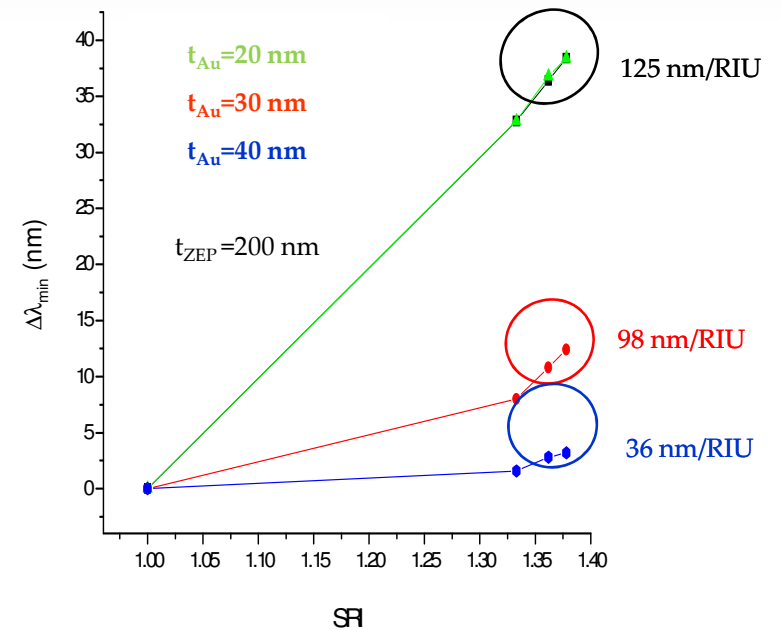
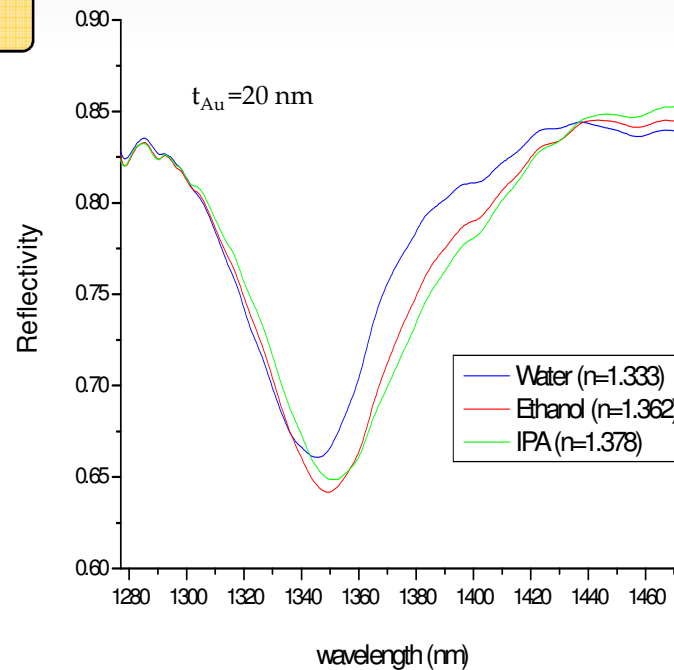
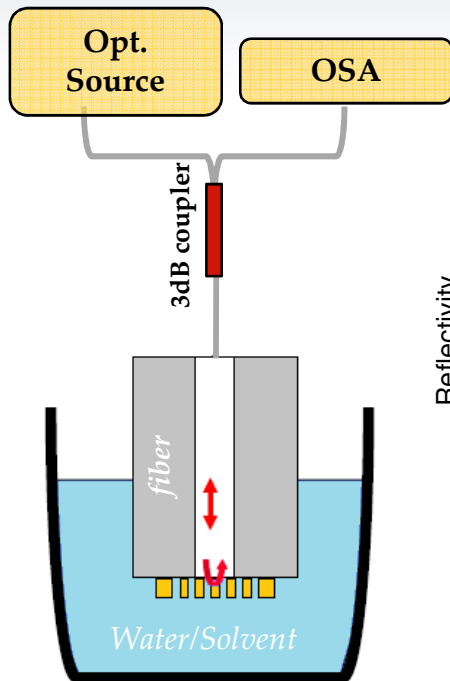
EXPERIMENTAL REALIZATION



Increasing period $a - r/a = 0.25$



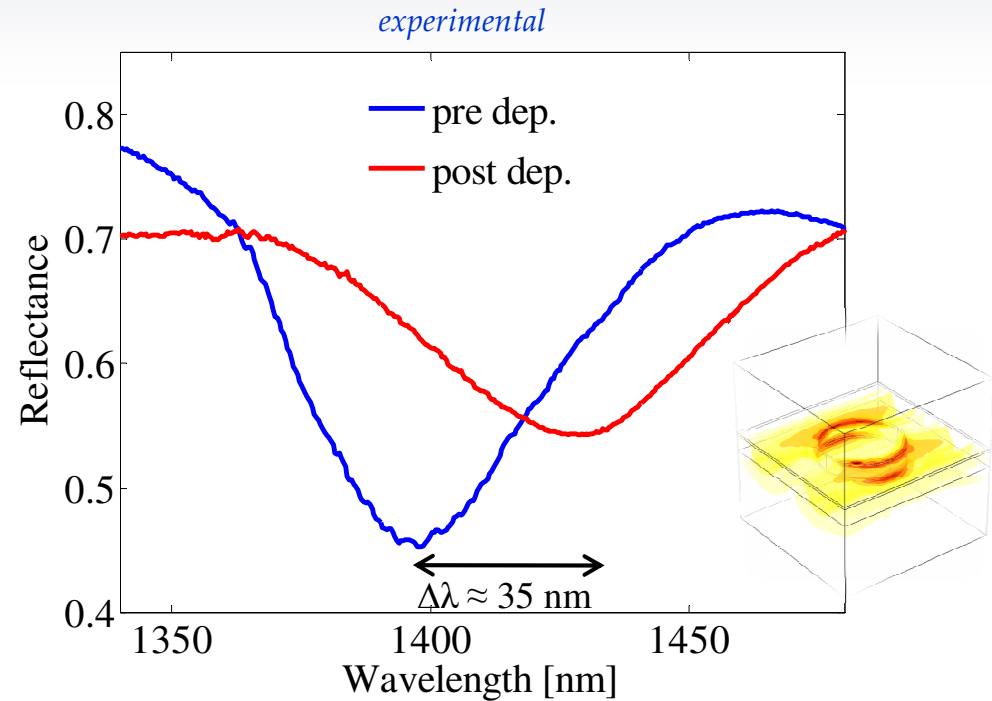
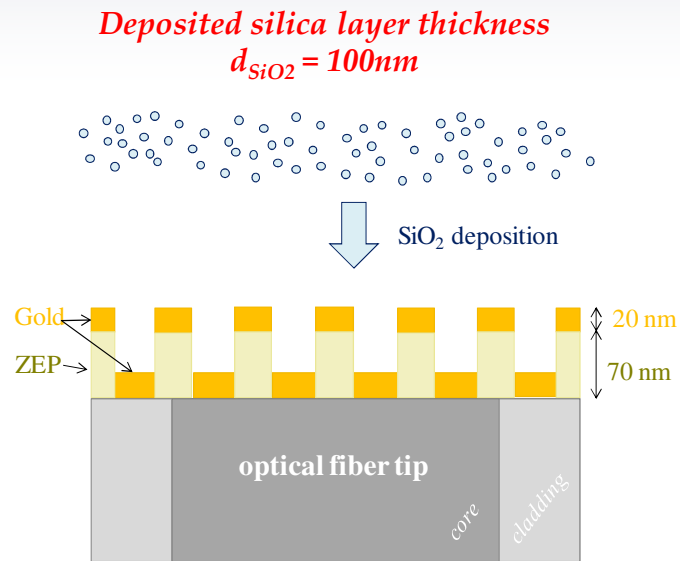
REFRACTIVE INDEX (BULK) SENSITIVITY



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

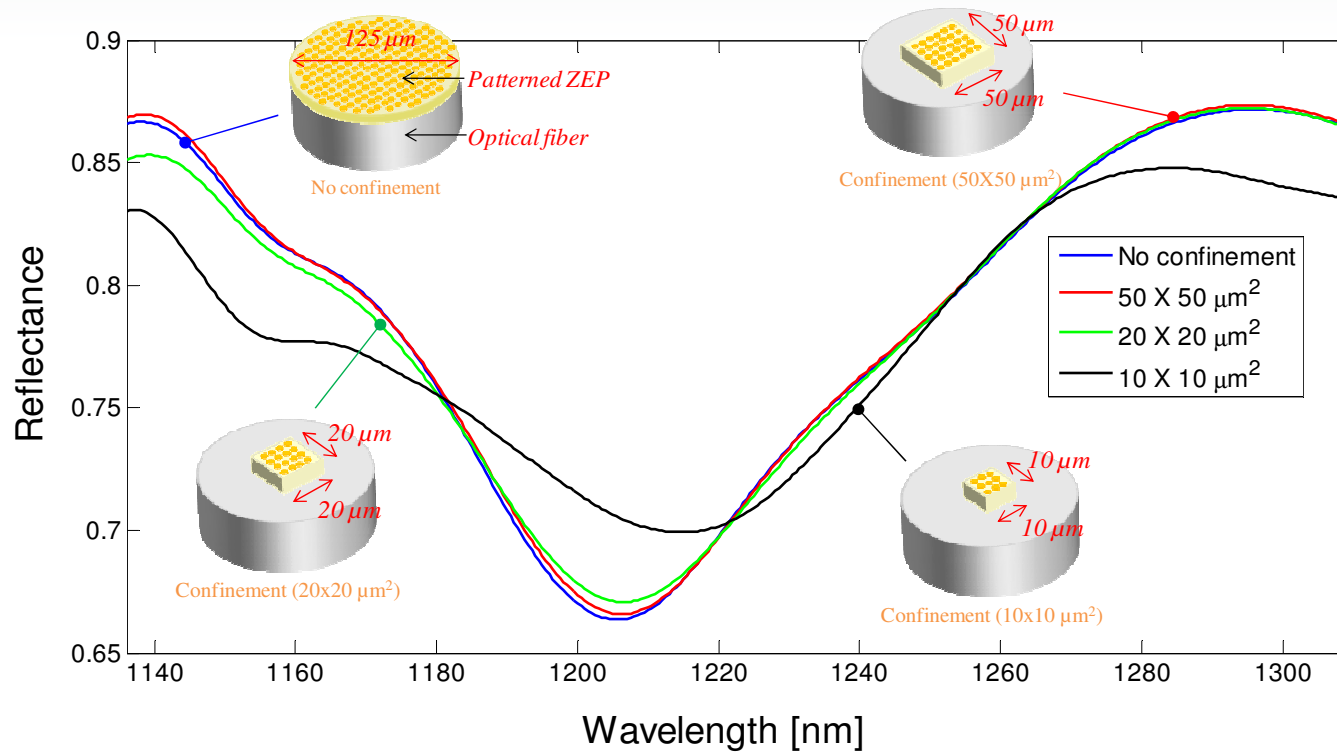


The surface sensitivities (in terms of resonance shift per nanometer of SiO₂ overlay) is 0.35

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.

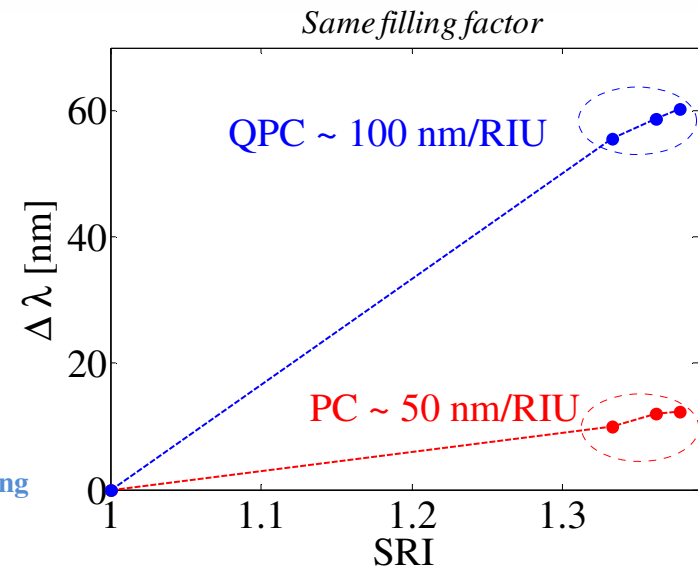
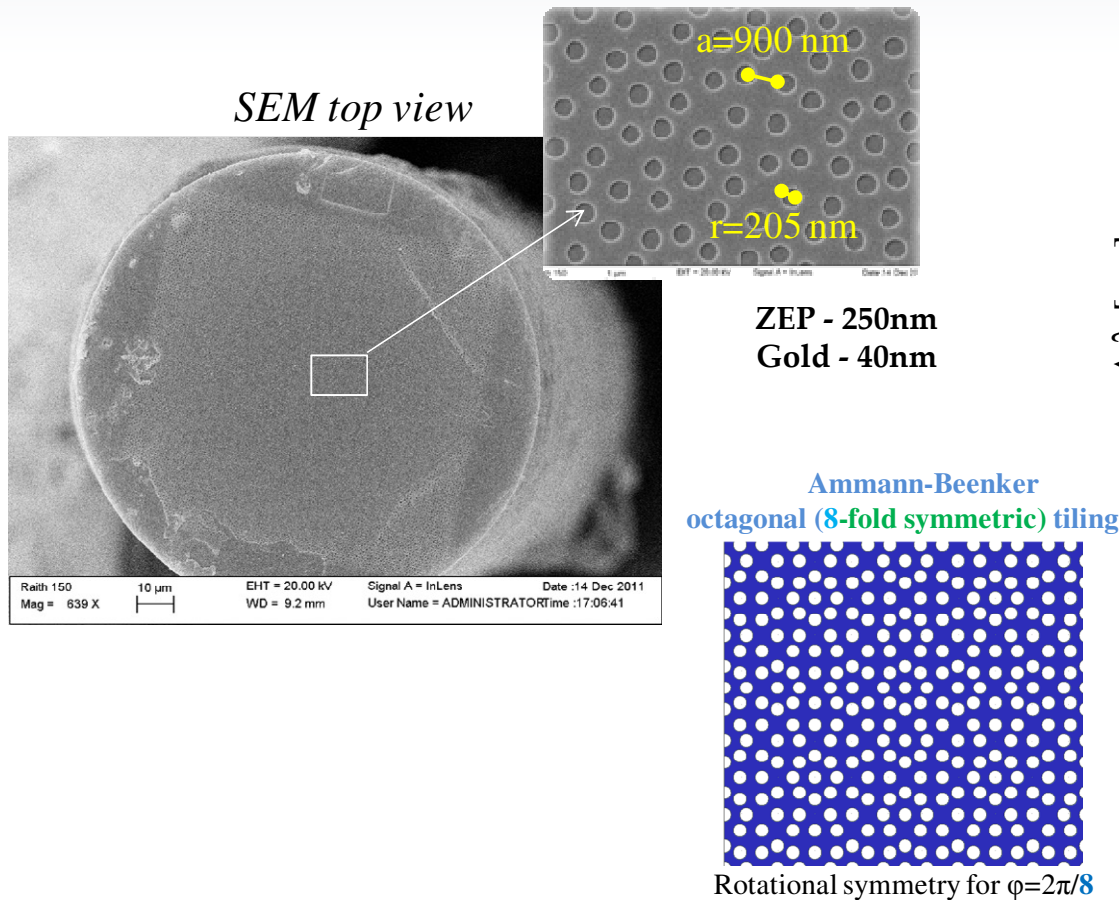
THE SENSING AREA

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



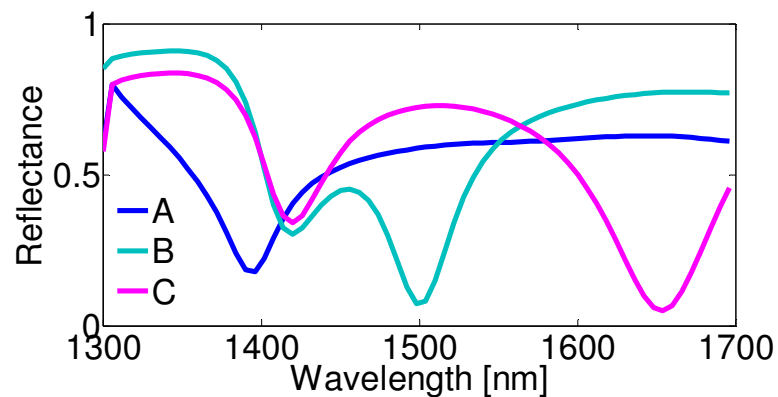
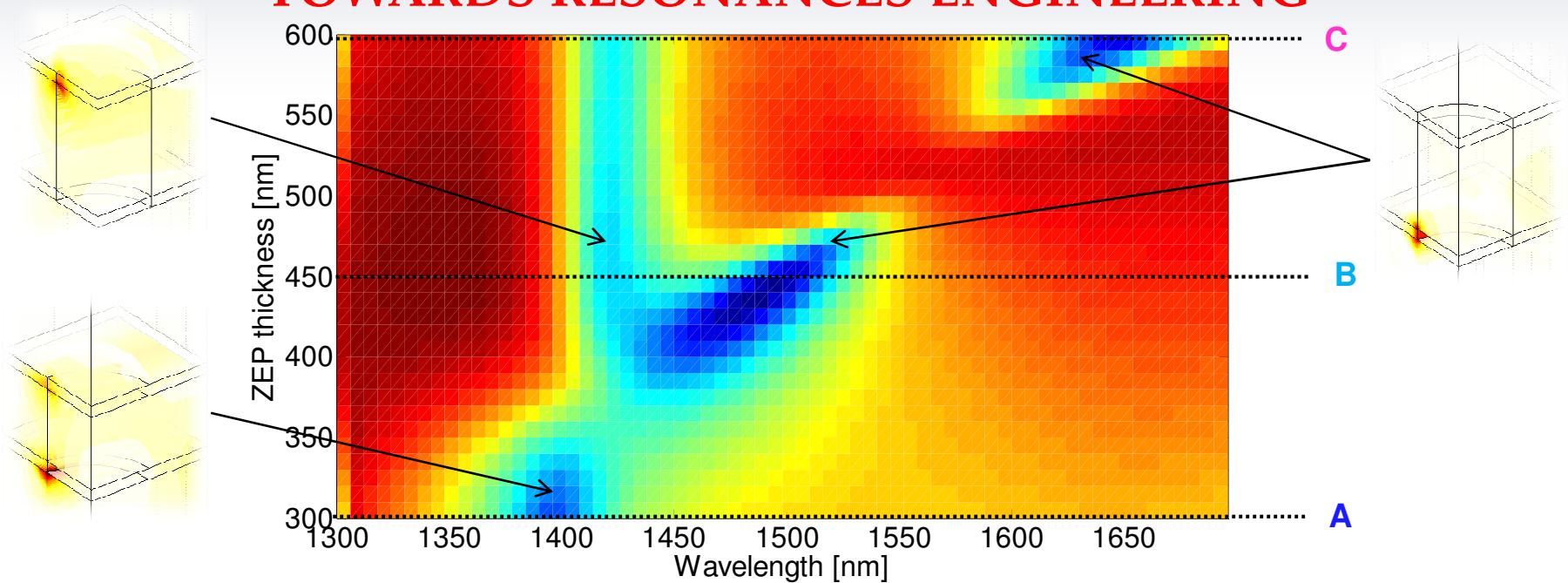
The sensing area can be reduced down to 20 × 20 μm^2 without affecting the spectral features (and thus the sensitivity)

RI SENSITIVITY ENHANCEMENTS WITH QUASICRYSTALS



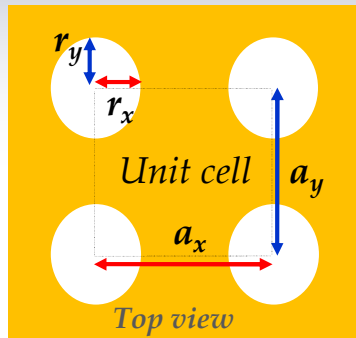
For a given filling factor and equivalent period, QC can outperform the periodic counterpart

DIELECTRIC THICKNESS TUNING : TOWARDS RESONANCES ENGINEERING



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

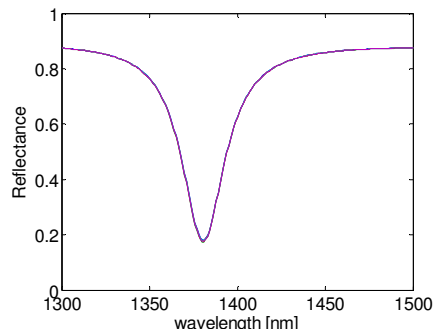
TOWARDS POLARIZATION SENSITIVE DEVICES



Symmetric

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

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

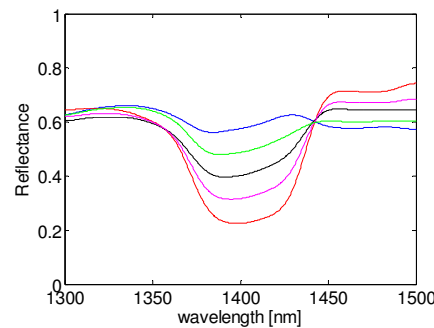
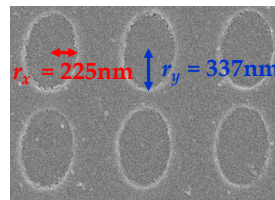
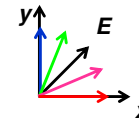
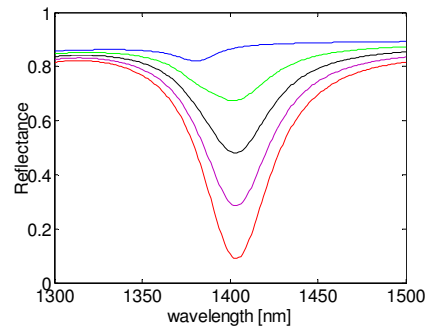


$$t_{ZEP} = 100 \text{ nm} \quad t_{Au} = 17 \text{ nm}$$

Hole ellipticity

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

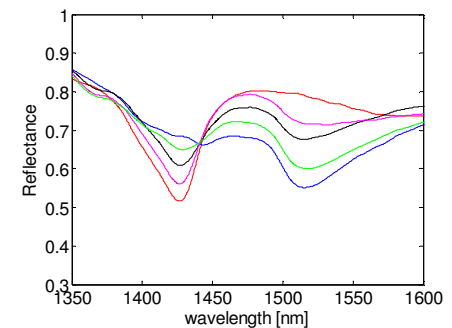
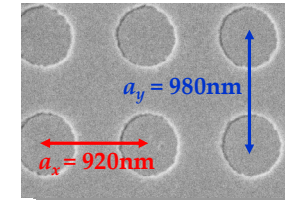
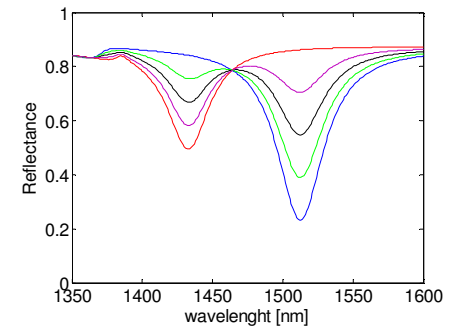
$$a_x = a_y = 900 \text{ nm}$$



Period Asymmetry

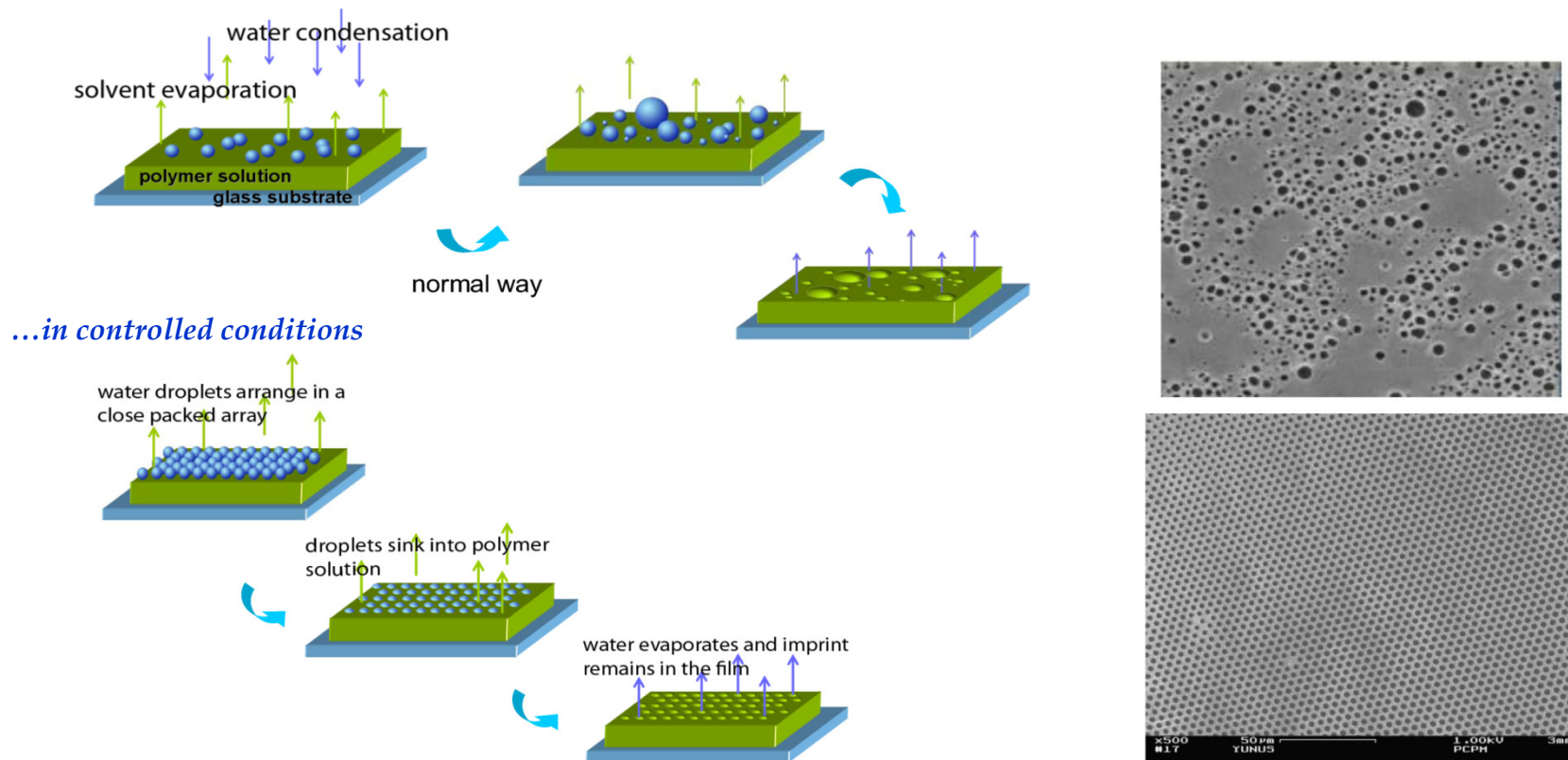
$$r_y = \eta r_x, \eta = 1, r_y = 250 \text{ nm}$$

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



BREATH FIGURE TECHNIQUE FOR RAPID AND COST EFFECTIVE PROTOTYPING

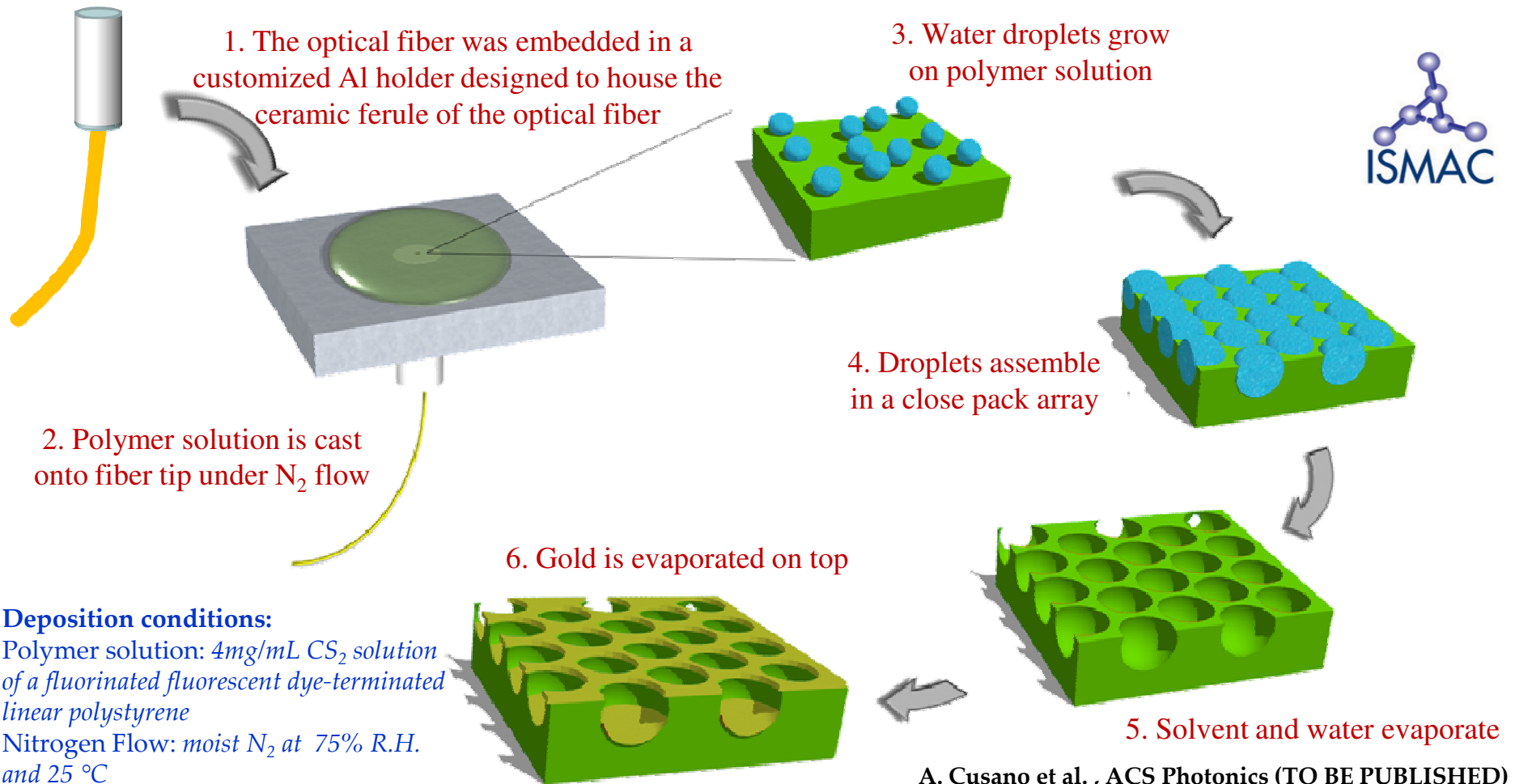
The Breath Figure Technique (Francois, Nature 1994, 369-387-9) relies on the precipitation of a polymer around condensed water droplets triggered by the fast evaporation of polymer solvent in a humid environment



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

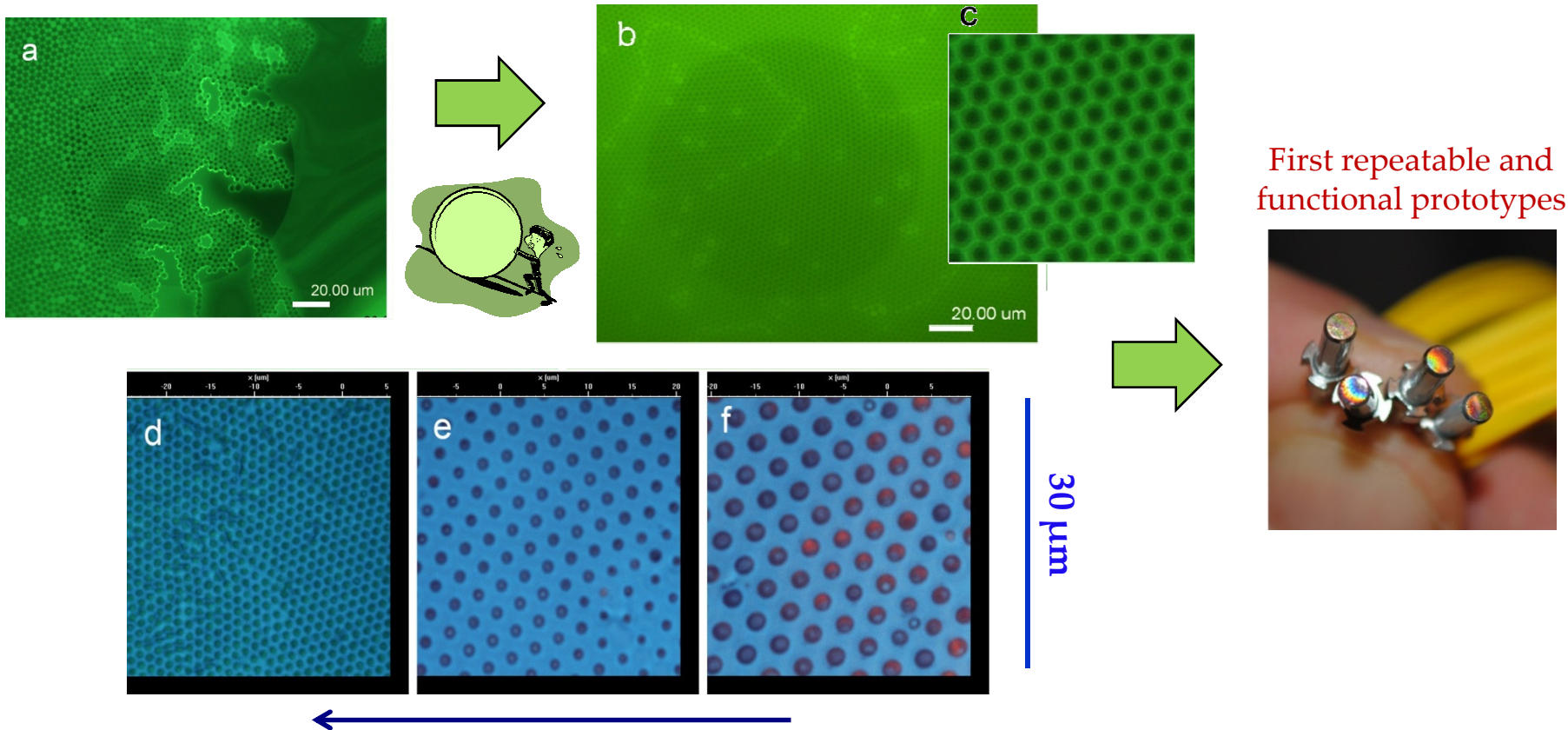
We adapted the Breath Figures technique to operate on optical fiber substrates so as to realize self assembled metallo-dielectric photonic crystals onto the optical fiber end facet



EXPERIMENTAL RESULTS: PROCESS ASSESSMENT

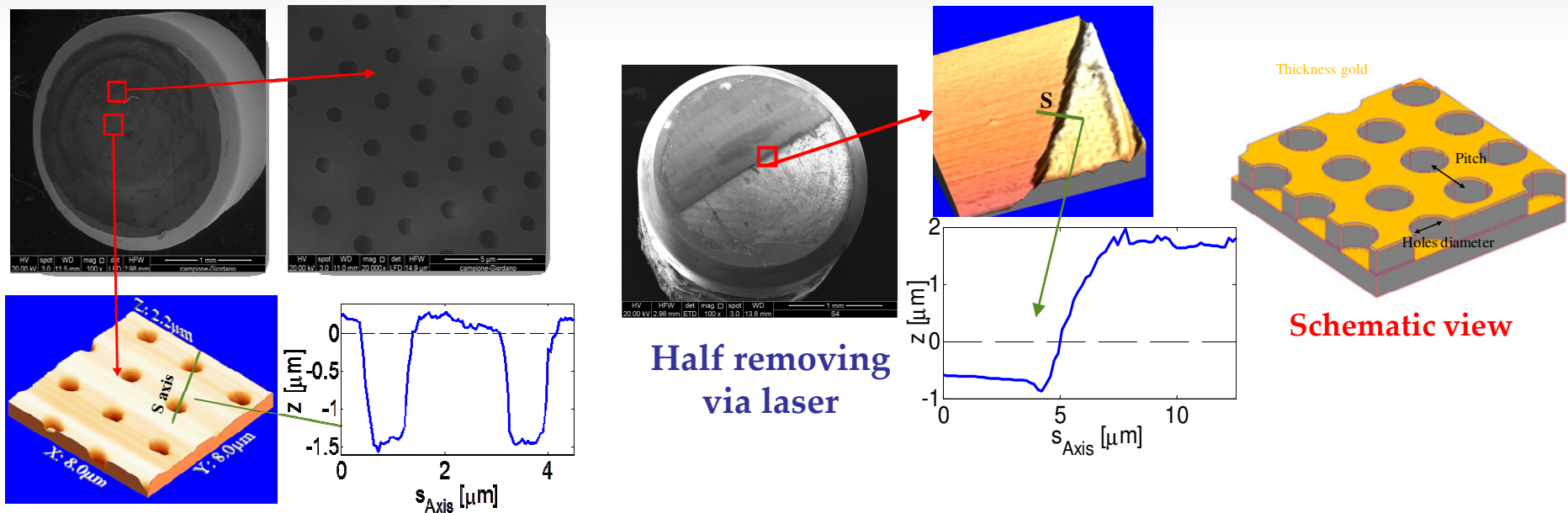


By the assessment of the fabrication process, we are now able to easily obtain well ordered and defect free patterns on the optical fiber tip



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



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%)

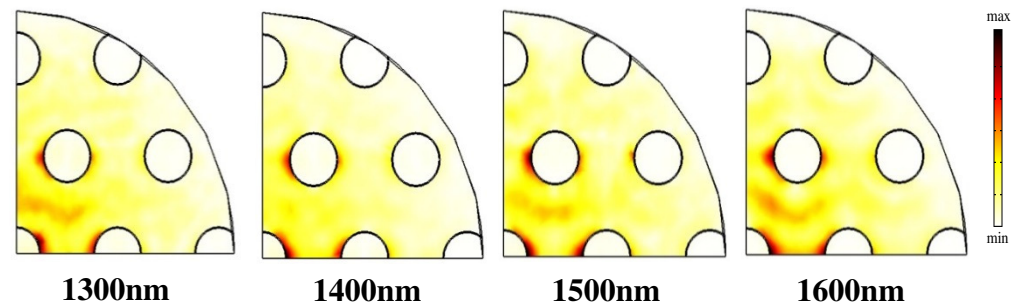
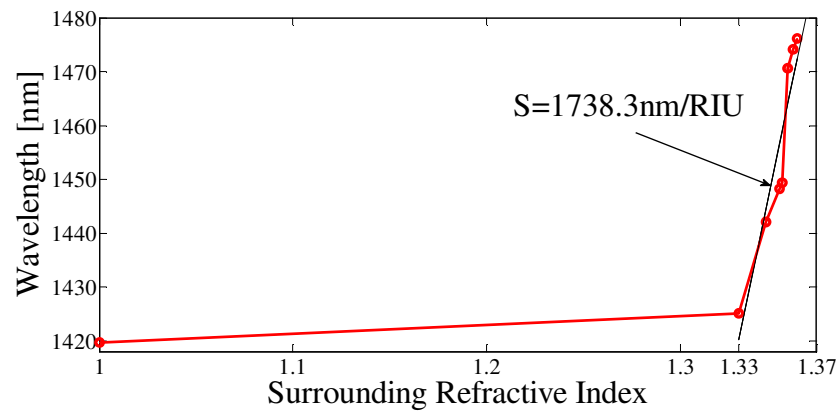
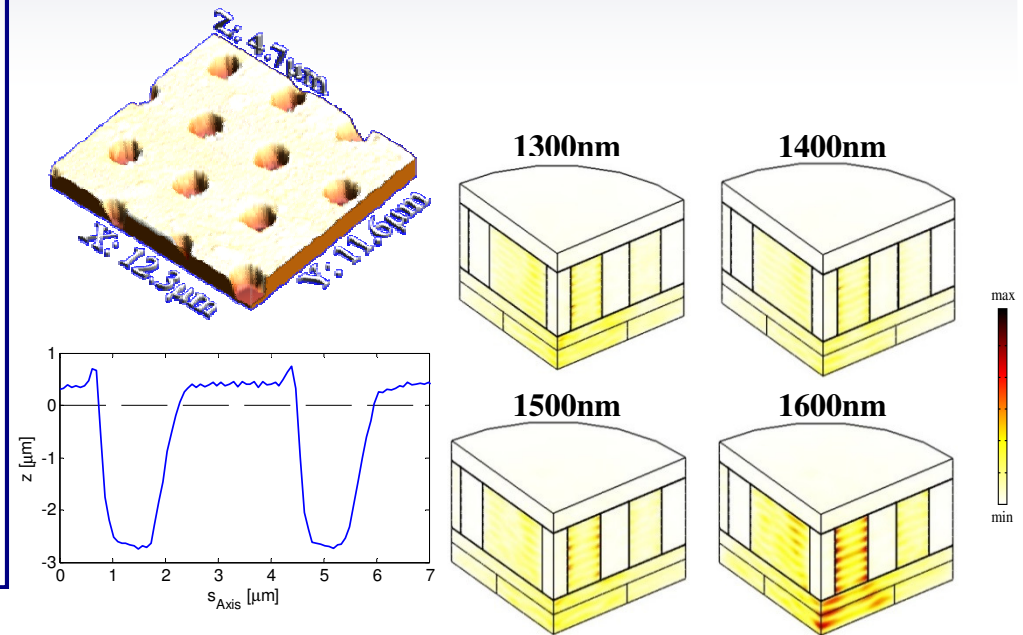
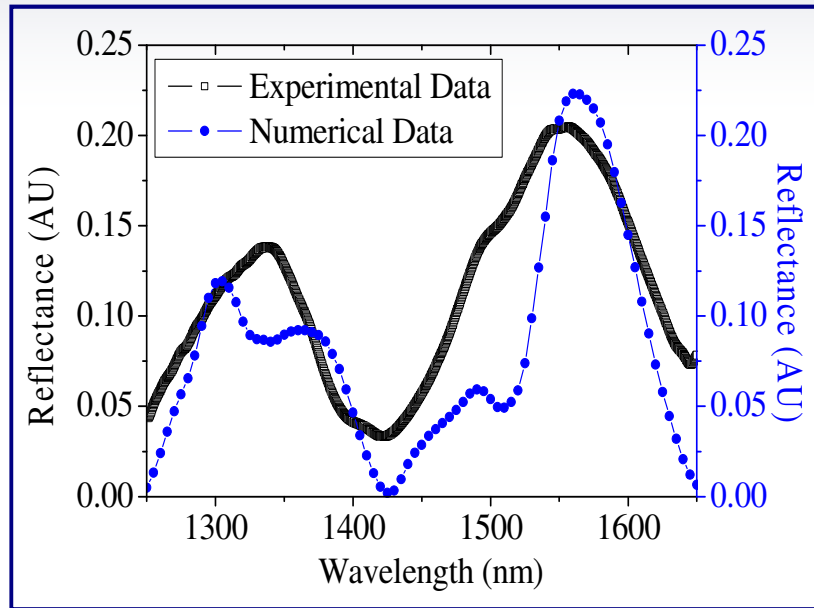
Hole depth = 1.78 μm (3.5%)

Structure height = 2.5 μm (2.3%)

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

SENSING PERFORMANCES



LAB ON FIBER TECHNOLOGY: MORE THAN A VISION

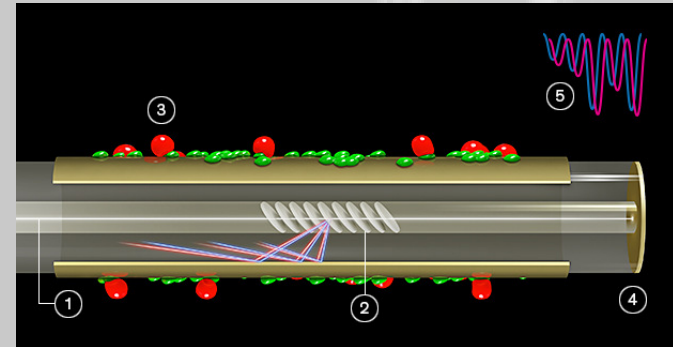
A Lab ON FIBER

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

By JACQUES ALBERT

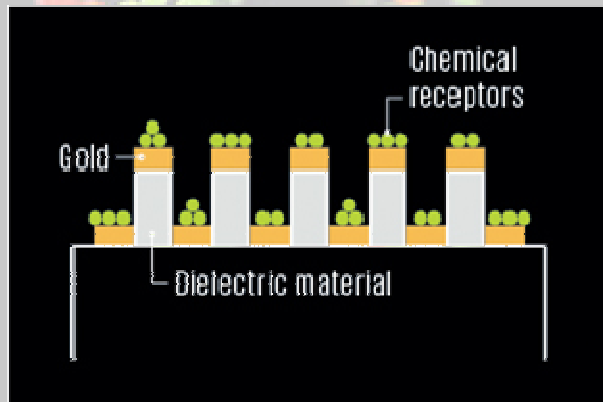
THINK BACK TO THE LAST TIME YOU GOT A BLOOD TEST. Maybe you had your cholesterol checked or got screened for infections, heart disease, stroke risk, thyroid troubles, or osteoporosis. Easy, right? A nurse simply drew your blood and shipped the vials to a lab. But behind the scenes, the process gets more 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

Tilted Fiber Bragg gratings



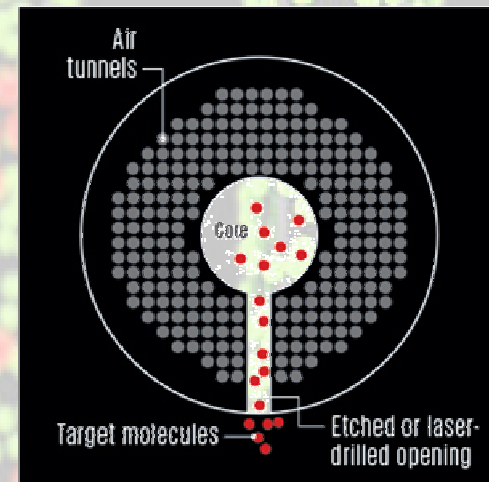
Jacques ALBERT et al., Carleton University, Canada

On the Tip



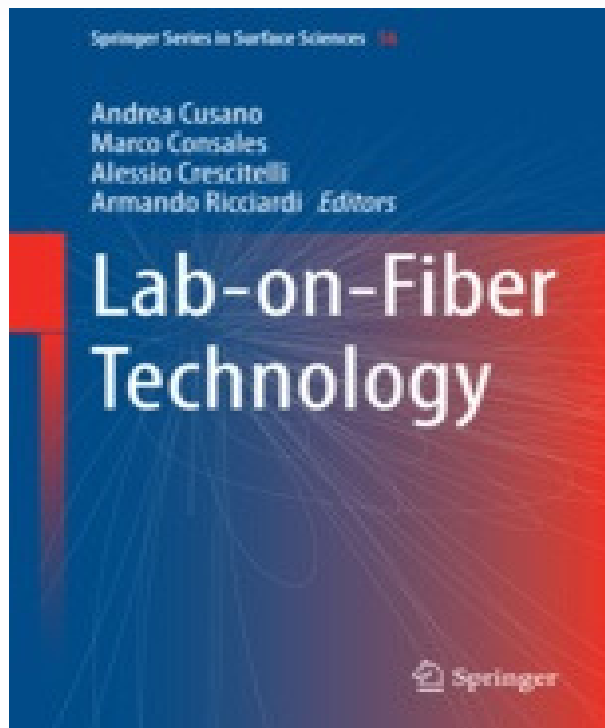
Andrea CUSANO et al., University of Sannio, Italy

Microstructured optical fiber



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

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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