

PhotonS: The Photonic Devices & Systems Group

Institute of Nanoscience & Nanotechnology
NCSR "Demokritos"
Athens, Greece



DEMOKRITOS

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- Our Mission & Vision
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- Expertise
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- Find out what you can work on with us!
- Infrastructure & Services Offer



01

Who we are

Meet the Team



Dr Nikos Papanikolaou
Director of Research
Physicist



Dr Ioannis Raptis
Director of Research
Physicist



Dr Eleni Makarona
Director of Research
Physicist



Dr Konstantinos Misiakos
Researcher Emeritus
Electrical Engineer



Collaborators

- Prof. N. Stefanou, Physics Dpt, NKUA Univ, Greece
- Dr P. Petrou & Dr S. Kakabakos, INRASTES, NCSR Demokritos, Greece
- Dr N. Kehagias, INN, NCSR Demokritos, Greece
- Prof. A. Budkowski & Prof. J. Rysz, Jagellonian University, Poland
- Dr G. Jobst, Jobst Technologies GmbH, Germany
- Dr Laila Al-Halabi-Frenzel, Abcalis GmnH, Germany
- Prof. Y. Georgiev, Helmholtz-Zentrum Dresden, Germany
- T. Kotseroglou, Zethea LLC, USA
- Dr J. Peters and Dr A. Elfenrik, Wageningen Univ, Netherlands
- Prof. M. Chatzichristidi, Chemistry Dpt., NKUA, Greece

Vision & Mission



Mission

Innovation in photonic devices and systems, addressing critical challenges in healthcare, environmental monitoring, biodiagnostics, and defense



Vision

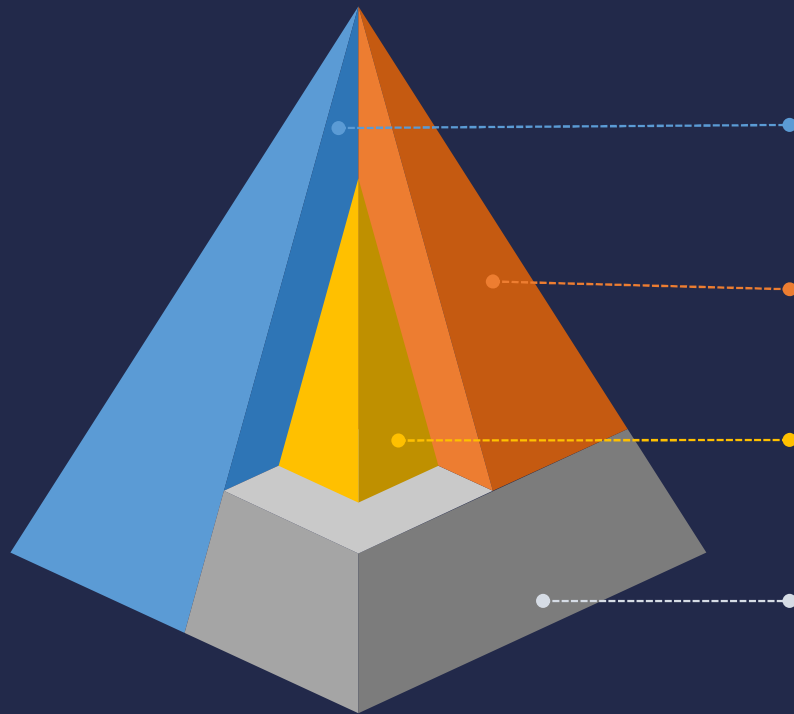
Push the boundaries of photonic research to create sustainable, cost-effective, and impactful solutions that bridge foundational science and real-world applications



Core Values

Excellence in research, interdisciplinary collaboration, practical innovation that addresses societal needs & nurturing the new generation of scientists

Core Competences



Application-driven Photonic Devices

Photonic Sensors, PICs, Metasurfaces, Photonic Components



Technological Know-how

Micro- and Nanofabrication and Process Optimization for Si-based PICs, photonic components, optics and optoelectronic devices



Design

PIC Simulations, Photonic Device, Design of Novel Materials and Structures for Optoelectronic Devices



Fundamental Studies

Theory, Development of methods for solving Maxwell's equations, Novel Principles of Operation

Our Modus Operandi

In-house One-stop-shop Development: Crafting Systems from Concept to Deployment



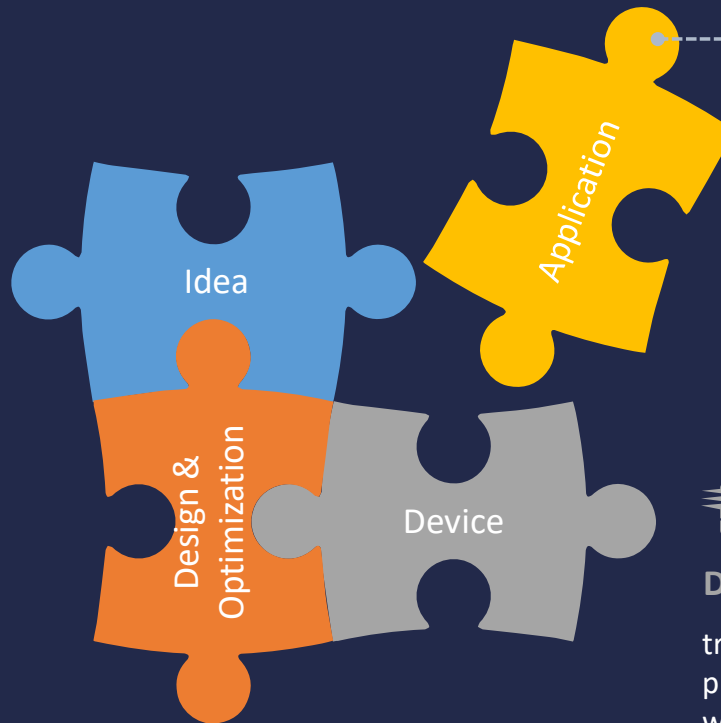
Idea Generation, Design, and Simulation

Leverage cutting-edge theories and simulations to conceptualize and design innovative optical sensor products



Fabrication and Material Optimization

Develop advanced processes in cleanroom micro- and nanofabrication facilities, alongside material innovations, to test ideas, designs and refine product performance



System Prototyping and Real-World Testing

Design and prototype systems targeting real-world applications, pushing the boundaries of photonics to propel next-generation technology

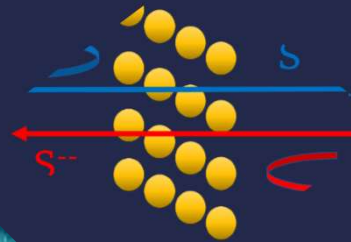


Device Prototyping and Development

transition from fundamental research to advanced product development, creating prototypes that pave the way for knowledge-driven, high-impact solutions

Fields of Application

Fundamental Concepts, Photonic Theory and Simulation



Medicine, Healthcare, Pharma,
Agriculture & Food Safety



Information & Communication
Technologies – Defense - Forensics



Environmental Motoring

Our Story in Numbers



+ 15 patents



**+ 30 students
and post-docs**



**+ 200 articles
+ 300 conference presentations**



+ 5M€ funding



02

Technology Portfolio – Selected Success Stories

Technology Portfolio

2.1

Fundamental Studies: developing novel concepts

2.2

Si-based Photonic Components and Sensor Systems

- ✓ 2.2.a Photonic Components by Design
- ✓ 2.2.b Multi-analyte Monolithic Interferometric (BB-MZI) Sensors of Ultimate Degree of Integration
- ✓ 2.2.c Immersible Microfluidics-free Photonic Sensors (Photostick Technology)
- ✓ 2.2.d MARS (Multi-Analyte Reflectance Spectroscopy) System

2.3

Metasurfaces & SERS Solutions

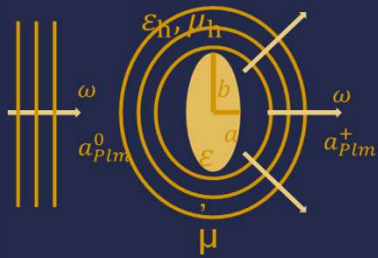
- ✓ 2.3.a Metasurfaces & Free-space Optics
- ✓ 2.3.b SERS and SEF



2.1

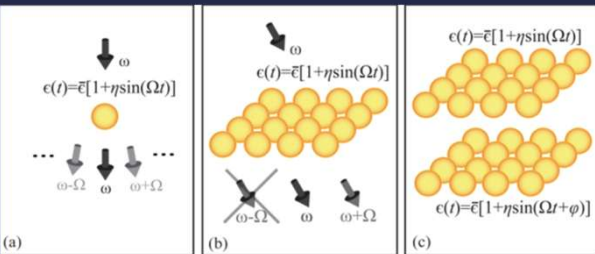
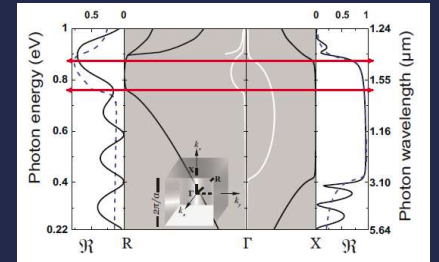
Fundamental Studies: developing novel concepts

2.1.a Photonics Theory and Concept Development



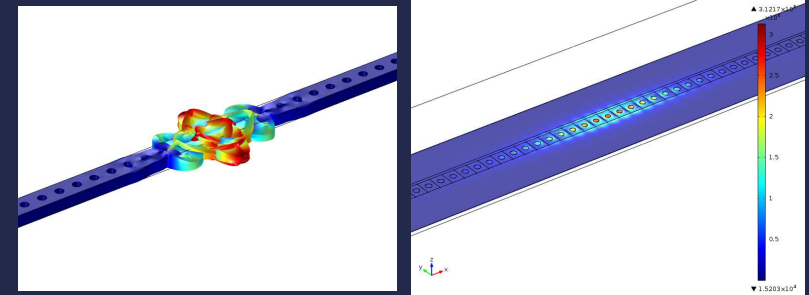
Multiple Scattering Methods for Metasurfaces

Time-varying Metasurfaces



Multiple Scattering Methods for Space-time Periodic Metasurfaces

Acousto-optic and Magneto-optic Interaction PhoXonics



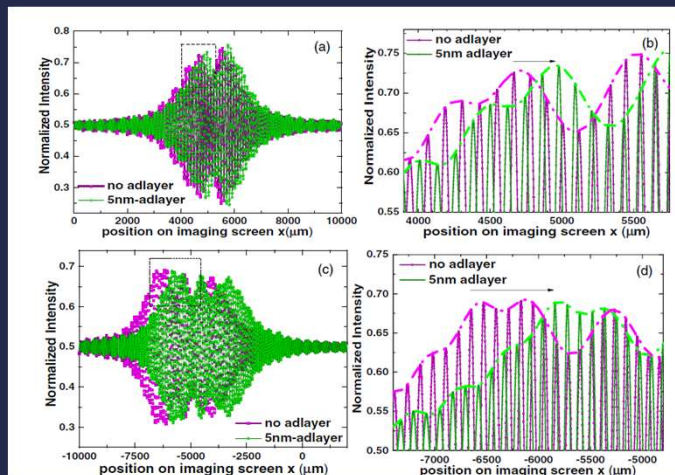
Plasmonics

Interaction of classical waves

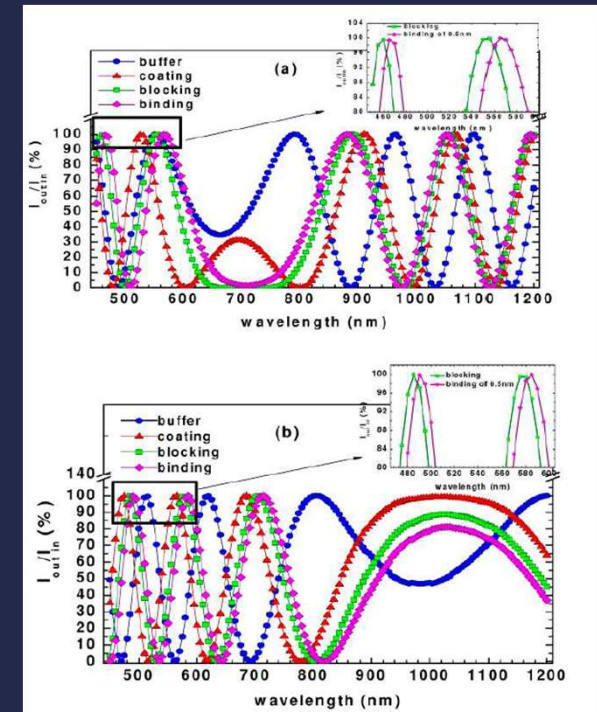
- *Light scattering by a periodically time-modulated object of arbitrary shape: the extended boundary condition method*, N Stefanou, I Stefanou, E Almpanis, N Papanikolaou, P Garg, C Rockstuhl, JOSA B 40 (11), 2842-2850 4 (2023)
- *Optical Transitions and Nonreciprocity in Spatio-Temporally Periodic Layers of Spherical Particles*, E Panagiotidis, E Almpanis, N Papanikolaou, N Stefanou, Adv. Opt. Mat. 11 (12), 2202812 (2023)
- *Inelastic light scattering from a dielectric sphere with a time-varying radius*, E Panagiotidis, E Almpanis, N Papanikolaou, N Stefanou, Phys. Rev. A 106 (1), 013524 (2022)
- *Nonspherical optomagnonic resonators for enhanced magnon-mediated optical transitions*, E Almpanis, N Papanikolaou, N Stefanou, Phys. Rev. B 104 (21), 214429 (2021)

2.1.b Photonics Theory and Concept Development

Broad-band Mach-Zehnder Interferometry



Polychromatic Young Interferometry

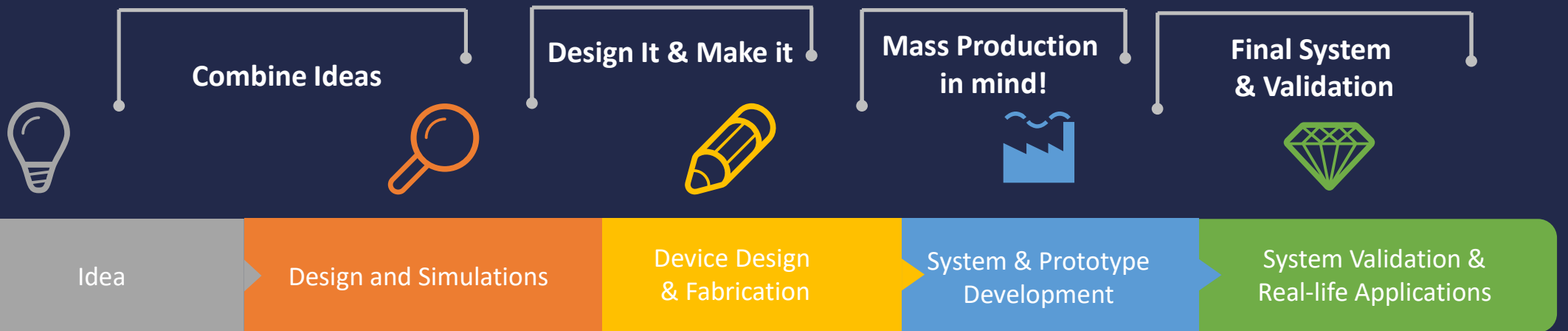


- *Integrated Optical Frequency-resolved Mach-Zehnder Interferometers for Label-free Affinity Sensing*, M. Kitsara, K. Misiakos, I. Raptis and E. Makarona, *Optics Express* **18** (8), pp. 8193-8206 (2010)
- *Broad-band Mach-Zehnder interferometers as high performance refractive index sensors: Theory and monolithic implementation*, K. Misiakos, I. Raptis, A. Salapatas, E. Makarona, A. Botsialas, M. Hoekman, R. Stoffer, and G. Jobst, *Optics Express* **22** (8), pp. 8856-8870 (2014)
- *Broadband Young interferometry for simultaneous dual polarization bioanalytics*, E. Makarona, A. Salapatas, I. Raptis, P. Petrou, S. Kakabakos, E. Stavra, A. Malainou and K. Misiakos, *Journal of the Optical Society of America B* **34** (8) 1691-1698 (2017)

2.2

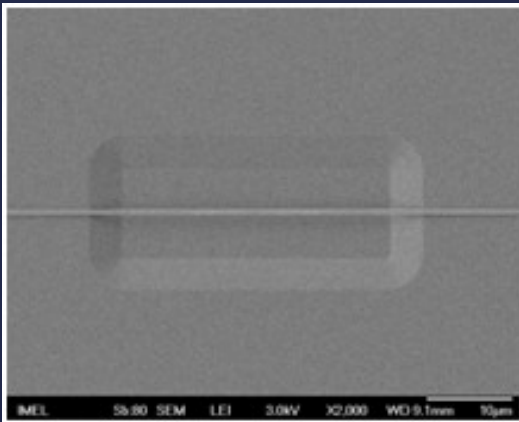
Si-based Photonic Components and Sensor Systems

Our Modus Operandi: All under One-roof

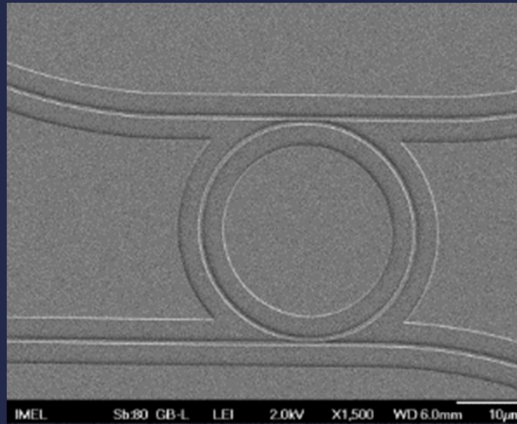


2.2.a Si-based PIC Components

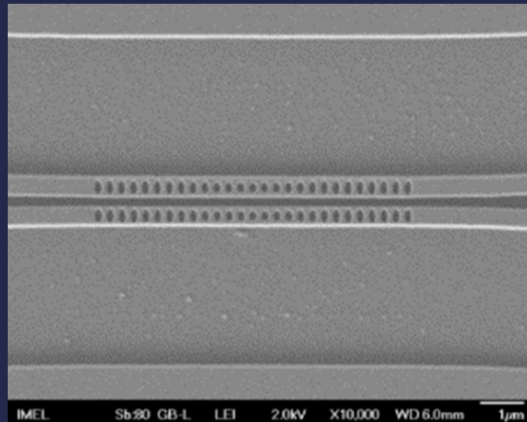
Low-loss Si_3N_4 Waveguides
for the VIS-NIR range



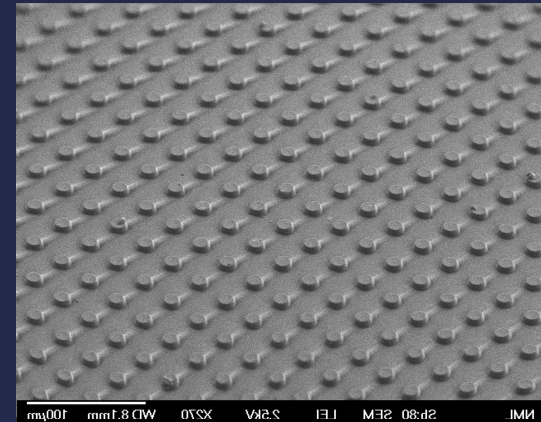
Microring Resonators



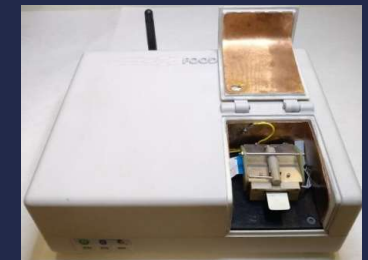
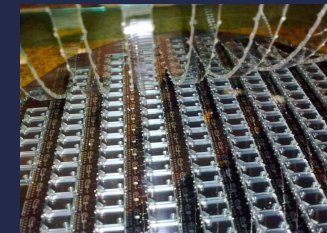
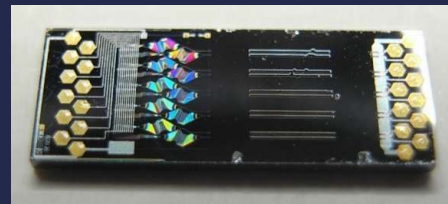
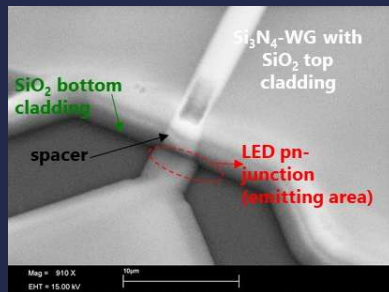
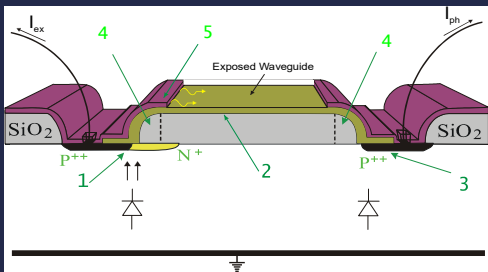
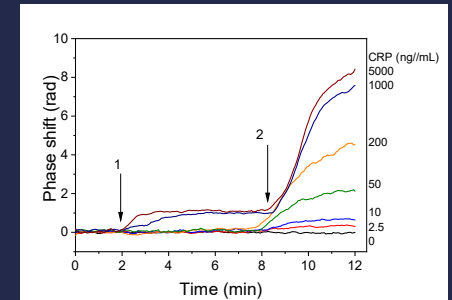
Photonic Crystals



Periodic Micro/Nanostructures
on Si and Flexible Substrates



2.2.b Multi-analyte Monolithic Interferometric (BB-MZI) Sensors of Ultimate Degree of Integration



All-silicon spectrally-resolved interferometric circuit for multiplexed diagnostics: a monolithic Lab-on-a-chip integrating all active and passive components, K.Misiakos, E.Makarona, M.Hoekman, R.Fyrogenis, K.Tukkiniemi, G.Jobst, P.S.Petrou, S.E.Kakabakos, A.Salapatas, D.Goustouridis, M.Harjanne, P.Heimala, I.Raptis *ACS Photonics* 6 1694(2019)

2.2.c Immersible Microfluidics-free Si Photonic Sensors (Photostick Technology)

Combine Ideas

Design It & Make it

Mass Production
in mind!

Final System
& Validation



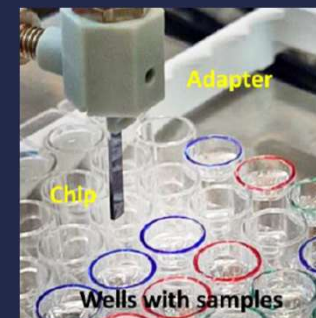
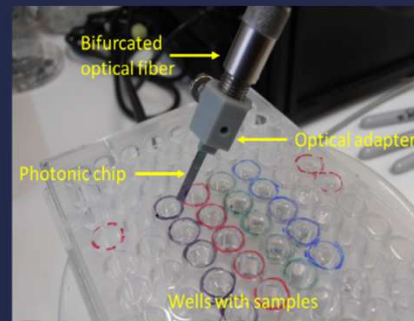
Concept 1:
Optomechanical
Coupler

Concept 2: Broad-band
Mach-Zehnder Interferometry

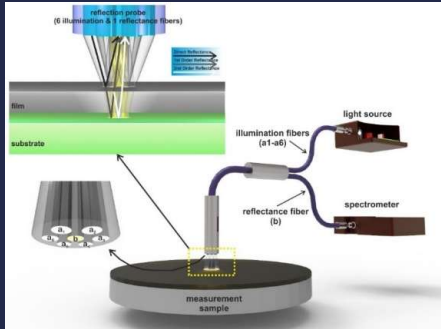
Device Design
& Fabrication

System & Prototype
Development

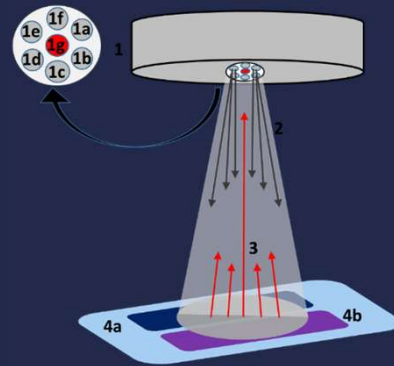
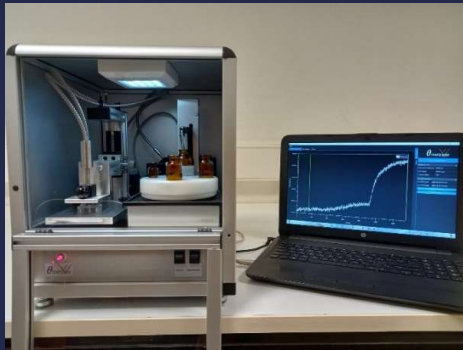
Low Ppower Cost-efficient
Reader &
Real-life Application



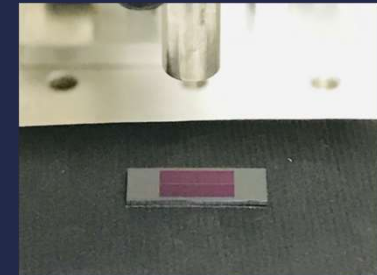
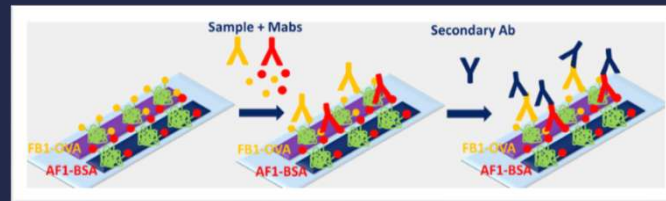
2.2.d WLRS and MARS Systems



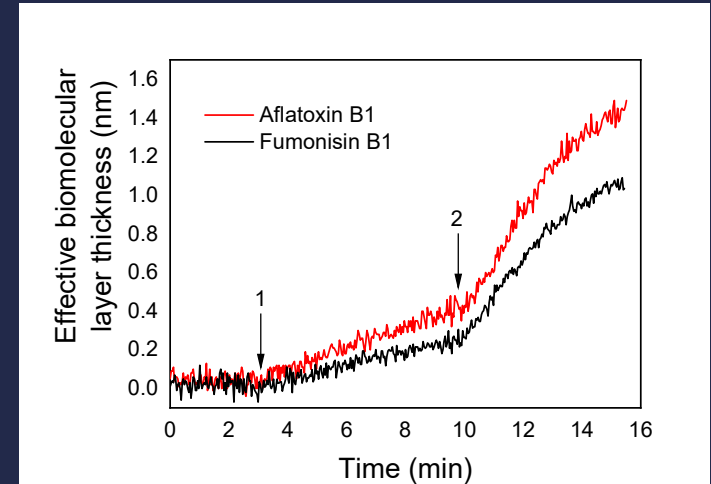
Reflectance Spectroscopy



Multi Analyte Reflectance Spectroscopy (MARS)



MARS chip



Multiplexed mycotoxins determination employing white light reflectance spectroscopy and silicon chips with silicon oxide areas of different thickness, V.Anastasiadis, G.Koukouvinos, P.S.Petrou, A.Economou, M.Harjanne, P.Heimala, D.Goustouridis, I.Raptis, S.E.Kakabakos Biosens. Bioelectron. **153 112035(2020)**

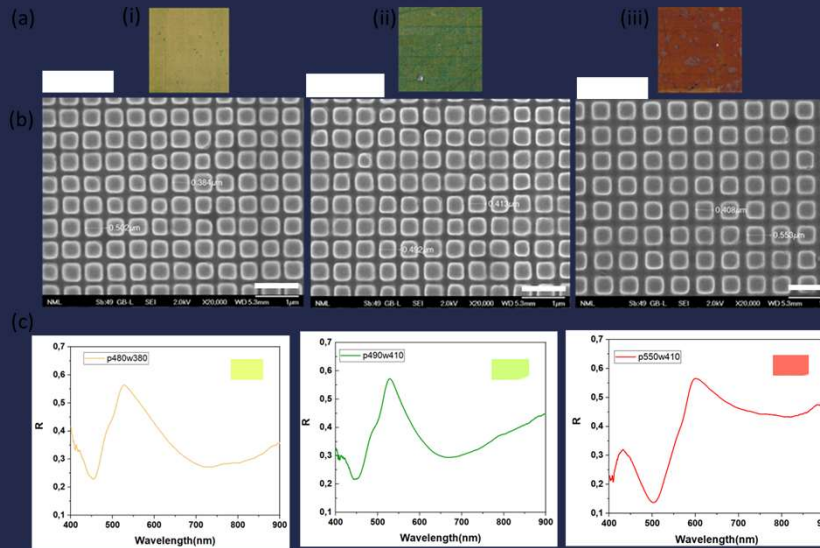
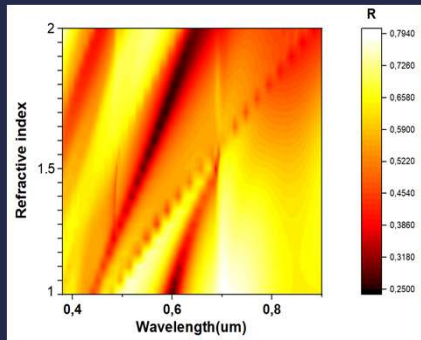


2.3

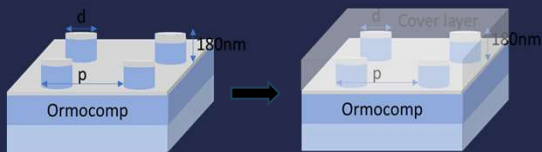
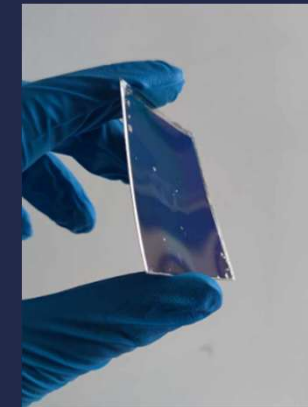
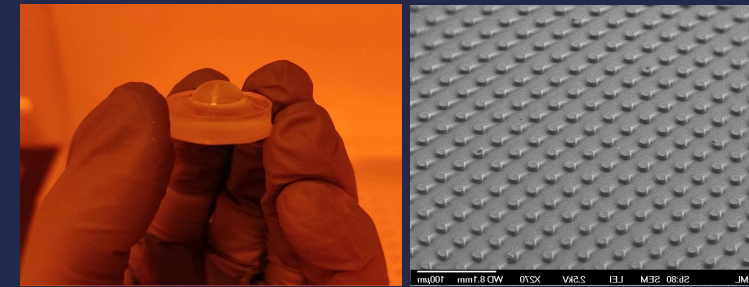
Metasurfaces and Free-space Optics

2.3.a Scalable fabrication of plasmonic color metasurfaces by UV-NIL

Theoretical parametric scan for varying RI



Free-form micro/nano structured surfaces

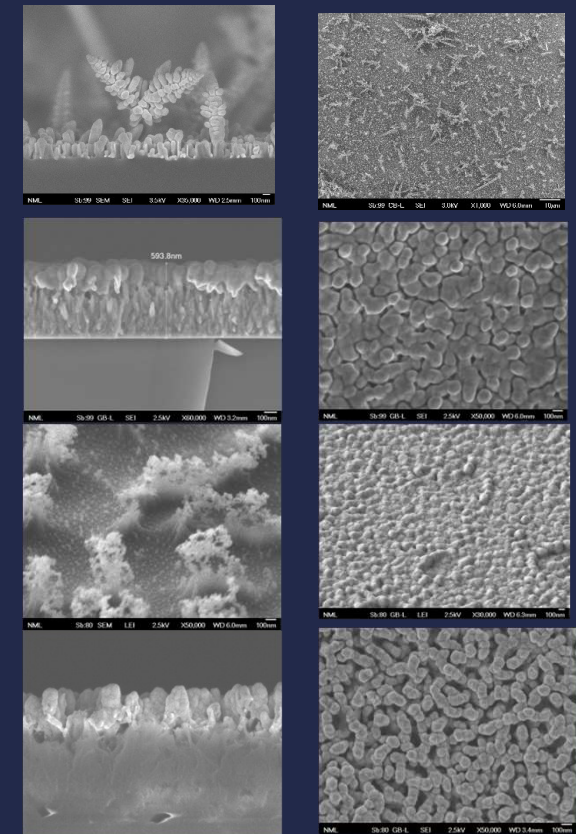


2.3.b SERS and PF Nanostructured Substrates

- Ag or Au deposition on nanotextured surfaces.
- High performance substrates for Detection of various elements with **Raman or Fluorescence spectroscopy**.
 - Enhancement Factor (EF)
 - Limit of Detection (LOD)
 - Reproducibility
- **Si based substrates**
 - Metal assisted Chemical Etching (MACE)
 - Copper Oxide
- **Plasma treated Polymer substrates (PMMA, olefins, PET)**
- **Aluminum and transition metal oxides**
 - Ag deposited Boehmite substrates

Substances tested/being tested

- Model Substances (R6G and CV) EF $\sim 5 \times 10^8$, LOD $\sim 10^{-10}$, Std $\approx 10\%$
- Elements of bioanalytical chemistry (Uric acid, Malondialdehyde)
- Oxidative stress markers Glutathione, Dismutase, Catalase
- Cancer markers (ovarian cancer) carbohydrate antigen 125 (CA125)
- human epididymis protein 4 (HE4), sirvinin BIRC5
- Explosives (Nitroglycerine, Picric Acid, Teteryl, RDX)





**Selected Success Stories
for Real-life Applications**

I. Single-analyte applications in food safety and disease biomarkers with systems of Si-based photonics biosensor chips

Analyte	Assay type	Assay duration	Sample	Sample dilution	LOD	Linear response range
Goat/Sheep milk adulteration with cow milk ¹	competitive	10 min	milk	50-fold	0.04% (v/v) (0.06 µg/mL k-casein)	0.1–1.0 % (v/v)
Feta cheese ²	competitive	9 min	cheese	50-fold	0.12% (w/w)	0.25-25% (w/w)
Mozzarella ²	competitive	9 min	cheese	50-fold	0.25% (w/w)	0.5-50% (w/w)
Ochratoxin A ³	competitive	50 min	beer	8-fold	2.0 ng/mL	4.0–100 ng/ml
C-Reactive protein ⁴	direct	5 min	serum	1000-fold	2.0 ng/mL	5.0-100 ng/mL
C-Reactive protein ⁵	sandwich	10 min	serum	1000-fold	1.0 ng/mL	2.0-200 ng/mL
Antibodies against SARS-CoV-2 ⁶	direct	15 min	serum	50-fold	20 ng/mL	50-10000 ng/mL

1) Angelopoulou M., et al., Assessment of goat milk adulteration with a label-free monolithically integrated optoelectronic biosensor. *Anal. Bioanal. Chem.* **407** (2015) 3995-4004

2) Angelopoulou M, et al., Rapid detection of mozzarella and feta cheese adulteration with cow milk through a silicon photonic immunosensor. *Analyst* **146** (2021) 529

3) Pagkali V., et al., Detection of ochratoxin A in beer samples with a label-free monolithically integrated optoelectronic biosensor. *J. Hazard. Mater.* **323** (2017) 75–83

4) Psarouli A., et al., Monolithically integrated broad-band Mach-Zehnder interferometers for highly sensitive label-free detection of biomolecules through dual polarization optics. *Sci. Rep.* **5** (2015) 17600

5) Misiakos K., et al., All-Silicon Spectrally Resolved Interferometric Circuit for Multiplexed Diagnostics: A Monolithic Lab-on-a-Chip Integrating All Active and Passive Components. *ACS Photonics* **6** (2019) 1694–1705

6) Angelopoulou M., et al., Directly immersible silicon photonic probes: Application to rapid SARS-CoV-2 serological testing, *Biosens. Bioelectron.* **215** (2022) 114570

II. Multi-analyte determinations for food contaminants with systems of Si-based photonics biosensor chips

Analyte	Assay type	Assay duration	Sample	Sample dilution	LOQ	Maximum allowable concentration
Bovine k-casein Soy protein Peanut protein Gluten ¹	competitive	6.5 min	Dairy industry rinsing water	no	0.1 ppm 2.5 ppm 0.5 ppm 0.25 ppm	< 5 ppm <10 ppm < 2 ppm < 20 ppm
Aflatoxin B1 Fumonisin B Deoxynivalenol ²	competitive	12 min	Beer	8-fold	1.6 ng/mL 11.2 ng/mL 40 ng/mL	0.1 µg/kg** 2 µg/kg 1 µg/kg of body weight
E. Coli S. Thyphimurium ³	competitive	10 min 15 min	Water Milk		300 cfu/mL 200 cfu/mL	1 cfu/25 g*

* Achieved after 8-hour pre-enrichment

** Total Daily Intake per Kg of body weight

1) Angelopoulou M., et al., Ultrafast multiplexed-allergen detection through advanced fluidic design and monolithic interferometric silicon chips. *Anal. Chem.* **90** (2018) 9559-9567

2) Pagkali V, et al., Simultaneous determination of aflatoxin B1, fumonisin B1 and deoxynivalenol in beer samples with a label-free monolithically integrated optoelectronic biosensor. *J. Hazard. Mater.* **359** (2018) 445–453

3) Angelopoulou M., et al., Simultaneous Detection of Salmonella typhimurium and Escherichia coli O157:H7 in Drinking Water and Milk with Mach–Zehnder Interferometers Monolithically Integrated on Silicon Chips. *Biosensors* **12** (2022) 507

III. Single-analyte applications in food safety, disease biomarkers and forensic samples with WLRS system

Analyte	Assay type	Assay duration	Sample	Sample dilution	LOD	Linear response range
AFM1 ¹	competitive	25 min	whole milk	no	6 pg/mL	12-2000 pg/mL
Salmonella typhimurium ²	competitive	15 min	milk	-	320 CFU/mL	600–5x10 ⁷ CFU/mL
Carbendazim ³	competitive	30 min	juices	no	20 ng/mL	50-20000 ng/mL
Complement component 3b ⁴	direct	10 min	plasma		1/6000 diluted plasma (20 ng/mL C3b)	1/3000-1/100 plasma dilution
Total-PSA ⁵	sandwich		serum	no	0.2 ng/mL	0.5-100 ng/mL
Free-PSA ⁵		65 min			0.15 ng/mL	0.5-20 ng/mL
CRP ⁶	sandwich	10 min	whole blood	50-fold	2 ng/mL	5-1000 ng/mL
PSA	sandwich	10 min	forensic samples	10-fold	0.5 ng/mL	1.0-500 ng/mL

1) Tsounidi D., et al., Rapid and sensitive label-free determination of aflatoxin M1 levels in milk through a White Light Reflectance Spectroscopy immunosensor. *Sens. Actuator B* **282** (2019) 104-111

2) Angelopoulou M., et al., Rapid Detection of Salmonella typhimurium in Drinking Water by a White Light Reflectance Spectroscopy Immunosensor. *Sensors* **21** (2021) 2683

3) Georgios Koukouvinos G., et al., Fast and Sensitive Determination of the Fungicide Carbendazim in Fruit Juices with an Immunosensor Based on White Light Reflectance Spectroscopy. *Biosensors* **11** (2021) 153

4) Petrou P.S., et al., Real-time label-free detection of complement activation products in human serum by white light reflectance spectroscopy. *Biosens. Bioelectron.* **24** (2009) 3359-3364

5) Koukouvinos G., et al., A label-free flow-through immunosensor for determination of total- and free-PSA in human serum samples based on white-light reflectance spectroscopy. *Sens. Actuator B* **209** (2015) 1041-1048

6) Koukouvinos G., et al., Rapid C-reactive protein determination in whole blood with a White Light Reflectance Spectroscopy label-free immunosensor for Point-of-Care applications. *Sens. Actuator B* **260** (2018) 282-288

7) Koukouvinos G., et al., White light reflectance spectroscopy biosensing system for fast quantitative prostate specific antigen determination in forensic samples. *Talanta* **175** (2017) 443-450

IV. Multi-analyte applications in food safety, disease biomarkers and forensic samples with WLRs system

Analyte	Assay type	Assay duration	Sample	Sample dilution	LOD	Linear response range
Chlorpyrifos Imazalil Thiabendazole ¹ (pesticides)	competitive	10 min	wine	10-fold	0.3 ng/mL 0.3 ng/mL 0.4 ng/mL	0.6-50 ng/mL 0.6 -50 ng/mL 0.8-20 ng/mL
Atrazine Paraquat ² (pesticides)	competitive	12 min	water	no	50 pg/mL 40 pg/mL	0.1 – 5.0 ng/mL 0.08 – 2.5 ng/mL
Aflatoxin B1 Fumonisin B ³	competitive	12 min	wheat maize	20-fold	0.05 ng/mL 1.0 ng/mL	0.1 – 5.0 ng/mL 2.0 – 50 ng/mL
CRP D-dimer ⁴	sandwich	45 min	plasma	50-fold	0.05 ng/mL 25 ng/mL	0.1 - 10 ng/mL 0.05–1.0 µg/mL
Procalcitonin IL-6 ⁵	sandwich	35 min	serum	no	2.0 ng/mL 0.01 ng/mL	4.0 – 100 ng/mL 0.02 – 10 ng/mL

1) Koukouvinos G., et al., Fast simultaneous detection of three pesticides by a White Light Reflectance Spectroscopy sensing platform. *Sens. Actuator B* **238** (2017) 1214-1223

2) Stavra, E., et al., Simultaneous determination of paraquat and atrazine in water samples with a White Light Reflectance Spectroscopy biosensor. *J. Hazard. Mater.* **359** (2018) 67-75

3) Anastasiadis V., et al., Multiplexed mycotoxins determination employing white light reflectance spectroscopy and silicon chips with silicon oxide areas of different thickness. *Biosens. & Bioelectron.* **153** (2020) 112035

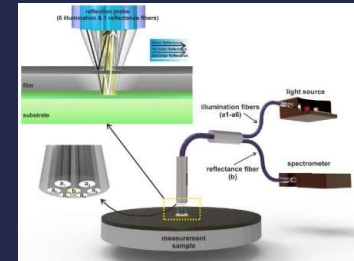
4) Koukouvinos G., et al., Simultaneous determination of CRP and D-dimer in human blood plasma samples with White Light Reflectance Spectroscopy. *Biosens. Bioelectron.* **84** (2016) 89-96

5) Tsounidi et al., Simultaneous determination of procalcitonin and interleukin-6 in human serum samples for sepsis diagnosis through a Point-of-Care biosensing device, Submitted for publication.

Real solutions for real-life Problems: Technology Transfer & Products

White Light Reflectance Spectroscopy (WLRS): Optical method for the accurate, fast and non-destructive characterization of transparent & semi-transparent coatings in the nm- μ m-mm thickness range

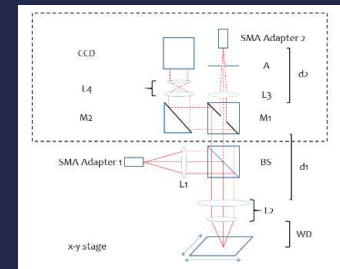
Company: ThetaMetrisis (est. 2008)



Microscope module for the accurate characterization of film thickness of patterned areas and of rough coatings, applicable in UV/VIS/NIR spectral regimes

Research project: SLICE

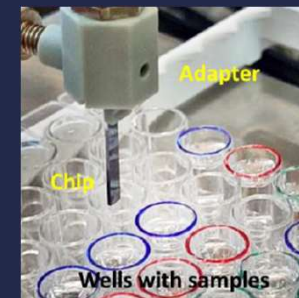
Company: ThetaMetrisis (est. 2008)



Immersible Microfluidics-free Photonic Sensor Platform for Biodetections and Reaction Kinetics

Research project: PYTHIA, FOODSNIFFER, FOODSENS

Company: PhotoStick Analytics (to be founded in 2025)





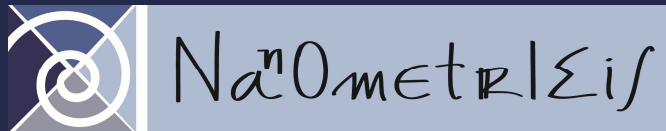
03

Collaboration Opportunities & Joint Ventures

Our Unique Offering and Positioning

- ✓ **Modus Operandi** (part of our identity): From Concept to Final System all under one roof.
- ✓ **Long-standing Experience** in the Design & Realization of Photonic Components, Devices and Systems complemented by the know-how to develop in-house the necessary Testing and Characterization Systems
- ✓ We focus on **specific applications** satisfying unmet **end-user needs**
- ✓ **Prototyping and Testing** from TRL0 → TRL6 at a single spot

Strong Collaboration with Spin-offs & vibrant SMEs to co-create new concepts & radical devices



You can work with us in any of the following ways:

- For Research and Development Projects, Scientific Collaborations and Networking: reach out directly to us!
- INNOVATION-EL (services on contract): innovation-el.net
- Services covered by the INFRACHIP Project (LIMITED TIME OFFER!) : infrachip.eu

For more information, reach out to:

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