PLASMONICA 2025

June 25-27, 2025 | Modena, Italy

PLASMONICA25

June 25-27, 2025

Complesso San Geminiano
Modena (IT)

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About

Plasmonica

Plasmonica is the annual national workshop organized by the working group *Plasmonics and Nano-Optics* of the Italian Society for Optics and Photonics (SIOF), the Italian branch of the European Optical Society (EOS). Since its first edition in 2013, *Plasmonica* has brought together an average of around 100 participants per year, offering a dynamic forum for researchers active in the fields of plasmonics, nano-optics, and nanophotonics, both in Italy and internationally.

This year's edition — the **11th Workshop on Plasmonics, Nano-Optics and their Applications** *Plasmonica* 2025 — will be held in Modena, Italy, from June 25 to 27, 2025, thanks to the synergy between the Istituto Nanoscienze (Cnr Nano), part of the Italian National Research Council (Cnr), and the University of Modena and Reggio Emilia (UNIMORE).

A distinctive feature of *Plasmonica* is its commitment to supporting early-stage researchers, by fostering their scientific development and providing a platform for them to present and discuss their work. This three-day event will feature cutting-edge research presentations, distinguished invited speakers, and valuable opportunities for networking and collaboration at the heart of the plasmonics and nano-optics community.

Credits

Workshop organizing committee	**Plasmonica steering committee**
Maria Bartolacelli, Cnr Nano, Modena, IT	Antonino Foti, Cnr Ipcf, Messina, IT
Alessandro Belardini, Univ. Sapienza, Roma, IT	Nicoletta Granchi, Univ. di Firenze & LENS, IT
Stefania Benedetti, Cnr Nano, Modena, IT	Chiara Novara, Politecnico di Torino, IT
Luca Bursi, Univ. di Modena e Reggio Emilia, IT	Emilija Petronijevic, Univ. Sapienza, Roma, IT
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Denis Garoli, Univ. di Modena e Reggio Emilia, IT	
Luisa Neri, Cnr Nano, Modena, IT	
Ilaria Rea, Cnr Isasi, Napoli, IT	

Workshop scientific committee	
Alessandro Alabastri, Rice University, Houston, US	Leonetta Baldassarre, Univ. Sapienza, Roma, IT
Paolo Biagioni, Politecnico di Milano, IT	Stefano Corni, Univ. di Padova, IT
Stefania D'Agostino, Cnr Nanotec, Lecce, IT	Emiliano Descrovi, Politecnico di Torino, IT
Carlo Forestiere, Univ. Federico II, Napoli, IT	Francesca Intonti, Univ. di Firenze, IT
Nicolò Maccaferri, Umeå University, SE	Riccardo Sapienza, Imperial College London, UK

Instructions for presenters

Contributed **talks** are allocated a 18 minute time slot (15' talk + 3' questions). Please bring your slides in a USB stick and upload them to the lecture hall's computer well in advance of your talk.

The recommended format for **posters** is A0 or A1 with portrait orientation (poster dimensions should not exceed 90×120 cm – width × height). Please hang your poster at the opening of the Conference. You may leave it displayed on the designated boards until the end of the event.

All participants are welcome to follow and engage with our **social media** accounts, with the handle **@Plasmonica** and **#Plasmonica2025** on LinkedIn – Plasmonica, X–Twitter – @Plasmonica, Bluesky – @plasmonica.bsky.social, and Instagram – @Plasmonica.

Venue

The Workshop will be hosted at the **San Geminiano complex**, a fully renovated 15th-century cloister situated in the historic center of Modena (Via San Geminiano 3). Once part of a Benedictine monastery, the venue now belongs to the University of Modena and Reggio Emilia and offers modern academic facilities within a historically significant setting.

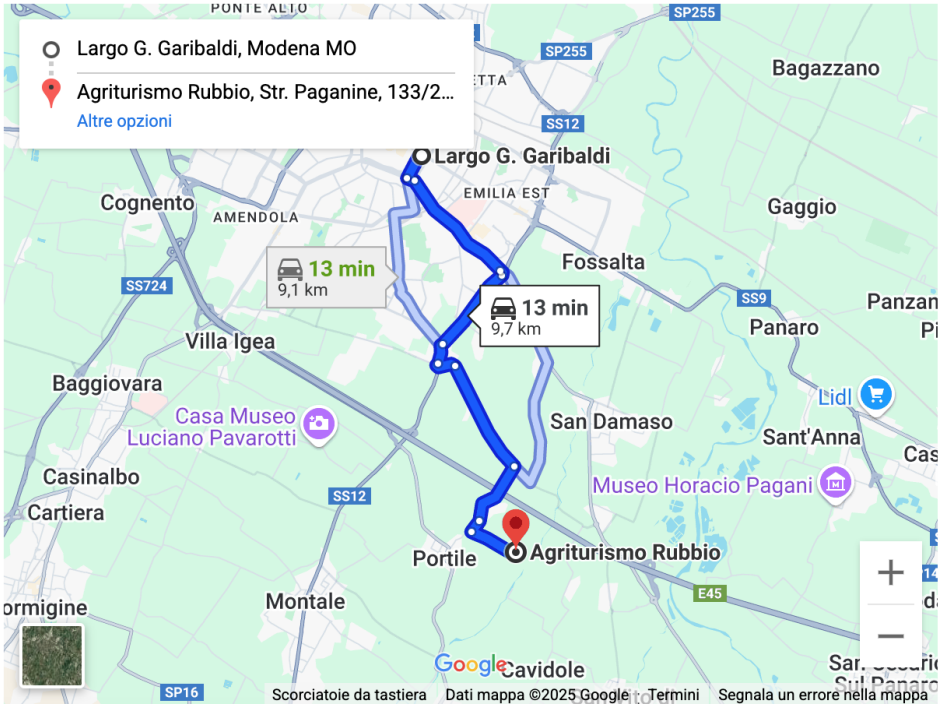
Scientific sessions will be held in the *Aula Convegni*, located on the first floor of the complex. Poster sessions and coffee breaks will take place in the portico of the cloister on the same floor.

The *eduroam* **Wi-Fi** network is available throughout the venue.

Social dinner

The social dinner will take place on **Thursday, 26 June at 20:30** at the **Agriturismo Rubbio** (Strada Paganine, 133/2, 41126 Portile MO), a traditional Modenese-style restaurant located in the countryside, approximately 20 minutes by car from the city center.

To facilitate transportation, a **shuttle bus service** will be provided for all participants. The bus will depart from **Largo Garibaldi** (7 mintues walk from the conference venue) **at 20:00** and will return there after dinner. Participants who wish to use this service are kindly invited to do so.



Timetable

Wednesday, June 25th

12:30–14:00	**Registration and light lunch**	
14:00–14:15	**Opening remarks**	
14:15–14:45 **[Invited]**	**Alejandro Manjavacas** Instituto de Química Física Blas Cabrera IQF-CSIC, ES	Collective lattice resonances in complex arrays of nanostructures
14:45–16:00	**Session I: Ultafast and active plasmonics. Chair: Carlo Forestiere**	
	Sveva Sodomaco Scuola Normale Superiore, Pisa, IT	Towards an integrated QM/classical framework for molecular nanoplasmonics
	Pablo Grobas Illobre Scuola Normale Superiore, Pisa, IT	Plasmon-mediated fluorescence enhancement of chromophores: An atomistically-detailed theoretical perspective
	Tersilla Virgili Cnr Ifn, Milano, IT	Ultrafast spectroscopy on a hybrid plasmonic-photonic platform
	Valeria Giliberti Center for Life Nano- and Neuro-Science, IIT, Roma, IT	Customized infrared nanospectroscopy technique for the study of electric-field-induced molecular dynamics
16:00–16:30	**Coffee break, Poster session, and Sponsors' exhibition**	
16:30–17:45	**Session II: Light-matter interaction and quantum plasmonics. Chair: Monica Bollani**	
	Hira Asif Akdeniz University, Antalya, TR	Stark control of plexcitonic states in incoherent quantum system
	Gabriele Calusi Università di Firenze, IT	Optical mode level repulsion in hyperuniform disordered systems
	Maria Villanueva-Blanco ISOM, Univ. Politécnica de Madrid, ES	Polaritonic hybrid modes in Cd(Zn)O thin films on SiC
	Alessandro Rogai Università di Pisa, IT	Yb^{3+}-doped $CsPbCl_3$ perovskite nanocrystals: Quantum cutting for optoelectronic applications
18:00–19:00	**Round table of *Plasmonica* (in Italian)**	

Thursday, June 26th – Morning

9:00–9:30 **[Invited]**	**Valentina Krachmalnicoff** Institut Langevin, ESPCI Paris, Univ. PSL, CNRS, FR	Sensing 3D electromagnetic landscapes at the nanometer scale with single emitters
9:30–10:30	**Session III: Thermoplasmonics and plasmon-excitonics. Chair: Leonetta Baldassarre**	
	Giorgio Zambito Università di Genova, IT	Hybrid 2D-plasmonic nanoemitters via grayscale thermal-scanning probe lithography
	Alessio Gabbani Università di Firenze, IT	Infrared thermoplasmonics with indium tin oxide nanocrystals
	Francesco Bisio Cnr Spin, Genova, IT	Plasmonic/excitonic hybrid systems for nanoscale thermometry
10:30–11:30	**Coffee break, Poster session, and Sponsors' exhibition**	
11:30–13:00	**Session IV: Hybrid and tunable metasurfaces. Chair: Francesco Pineider**	
	Henning Galinski ETH Zurich, CH	Hybrid resonant metasurfaces combining dielectric nanocup metasurfaces and plasmonic networks
	Yigong Luan Politecnico di Milano, IT	All-optical polarization encoding and modulation by nonlinear interferometry at the nanoscale
	Alberto Santonocito Università di Pisa, IT	Gires Tournois magnetically tunable metasurface for the dynamic control of light
	Yaping Hou Politecnico di Milano, IT	Electrically tunable polarization state of light using lithium niobate-based nanograting
	Ali Douaki Università di Modena e Reggio Emilia, IT	Plasmonic nanopores for nanopores gating
13:00–14:00	**Lunch break**	

Thursday, June 26th – Afternoon

14:00–16:15	**Session V: Metasurfaces for smart vision and imaging. Chair: Tommaso Ongarello**	
	Bert Hecht University of Würzburg, DE	Individually addressable nanoscale OLEDs
	Jonathan Barolak Università di Pavia, IT	Automated design of one-dimensional photonic crystals for all-optical image processing
	Pietro Baldin Politecnico di Milano & Smart Eyewear Lab, IT	Metasurfaces supporting guided mode resonances for holography and eye tracking in future smart eyewear devices
	Jacopo Stefano Pelli Cresi EssilorLuxottica, Milano, IT	In-plane scattering sustaining metasurface for eye-tracking applications
	Costantino De Angelis Università di Brescia, IT	Nonlinear-nonlocal flat optics for space-time image processing
	Andrea Vogliardi Università di Padova, IT	All-dielectric silicon metasurfaces for the generation and manipulation of structured light
	Giuseppe Emanuele Lio Cnr Nano, Pisa, IT	Reconfigurable beamforming metasurfaces for infrared beam steering
16:15–17:00	**Coffee break, Poster session, and Sponsors' exhibition**	
17:00–19:00	**Session VI: Devices and applications. Chair: Nicoletta Granchi**	
	Camilla Gonzini LENS, Università di Firenze, IT	Near-field spectroscopy of photonic crystal cavities with small footprint and high optimized Q-factor
	German Lanzavecchia Istituto Italiano di Tecnologia, Genova, IT	Tailored fabrication of 3D nanopores for advanced nanoscale techniques
	Simone Zanotto Cnr Nano, Pisa, IT	Tailoring thin film absorption and nonlinear transduction in thermomechanical bolometers
	Fritz Berkmann Brandenburg University of Technology, Cottbus, DE	Plasmonic-induced hot carrier generation for MIR detectors
	Ergun Simsek University of Maryland Baltimore County, USA	Excito-plasmonic phototransistors with improved thermal management
	Margherita Angelini ESSS & Ansys	ESSS & Ansys for the academic world: Empowering education, research and innovation
20:30–23:00	**Social dinner**	

Friday, June 27th

9:00–9:30 **[Invited]**	**Emiliano Cortés** Nanoinstitute Munich, Faculty of Physics, Univ. of Munich (LMU), DE	Plasmonics for energy and sustainability
9:30–10:30	**Session VII: Plasmonic biosensing. Chair: Chiara Novara**	
	Agostino Occhicone Università Sapienza, Roma, IT	Detection of anti-SARS CoV-2 antibodies in human serum by localized surface states on 1D photonic crystal biochips
	Valeria Nocerino Università di Napoli Federico II, IT	Engineering gold nanocluster in PEGDA hydrogel for SERS-based on-site dimethoate sensing on olives
	Veronica Zani Università di Padova, IT	Ultra-low frequency surface enhanced Raman scattering of CTAB: Unveiling its detection and exchange mechanism on gold nanorods
10:30–11:30	**Coffee break, Poster session, and Sponsors' exhibition**	
11:30–12:45	**Session VIII: Alternative plasmonic (meta)materials. Chair: Simone Zanotto**	
	Cristina Mancarella Politecnico di Milano, IT	Plasmonic multilayers metamaterials merging nitrides, oxynitrides and transparent conductors with broad and tunable properties
	Naveen Kumar Cnr Nano, Modena, IT	Role of amorphization in tuning the electronic and plasmonic structure of Al-doped zinc oxide
	Antonio Ferraro Istituto di Nanotecnologia Cnr Nanotec, Rende, IT	ENZ metamaterials as platform for different applications
	Gonzalo Álvarez-Pérez Istituto Italiano di Tecnologia, Arnesano, IT	Free-electron optical nonlinearities in heavily doped semiconductors: From fundamentals to integrated photonics
12:45–13:15	**Closing remarks**	

Poster sessions

No.	Presenter and poster title	
1	**Sidahmed Abayzeed** University of Nottingham, UK	Plasmonic bioelectric interfacing
2	**Hanan Ali** Università di Pavia, IT	Strong coupling regime of a quasi-bound state in a continuum in a plasmonic nanohole array with broken symmetry
3	**Francesca Alimonti** Cnr Nano, Modena, IT	Towards plasmon-enhanced photocatalytic efficiency using $Cu@Cu_2O$ core@shell nanoparticles
4	**Eva Almeida** University of Amsterdam, NL	High-efficiency metasurfaces for building-integrated PV
5	**Francesca Argentieri** Università di Trieste, IT	Enhancement of plasmonic dichroism by doping and protecting metal nanoclusters, a TDDFT study
6	**Parwaz Asif** University of Limoges, CNRS, XLIM, FR	Silver nanowire based plasmonic transparent electrodes for optoelectronic application
7	**Ali Azimi** Brandenburg University of Technology, Cottbus, DE	Numerical investigation of plasmon-induced field confinement in engineered nanoantenna arrays from long-wave infrared to THz regime
8	**Leonetta Baldassarre** Università Sapienza, Roma, IT	Antenna-enhanced Raman spectroscopy with a 1550 nm laser excitation
9	**Pietro Baldin** Politecnico di Milano & Smart Eyewear Lab, IT	Advanced theoretical models and simulation techniques for nonlocal metasurfaces
10	**Ghassem Baridi** Università di Modena e Reggio Emilia, IT	Simulation of plasmonic surface resonance of graphene for detecting physiological tissue
11	**Rafael Bellei de Carvalho** Politecnico di Milano, IT	Reducing stitching errors in large-area all-dielectric non-local metasurfaces using multi-pass electron-beam lithography
12	**Paolo Biagioni** Politecnico di Milano, IT	Quantitative estimation of the linear birefringence of a single-stranded DNA layer exploiting Bloch surface waves
13	**Monica Bollani** Cnr Ifn, Milano, IT	Fabrication of silicon-based dual linear polarizer exploiting quasi-bound states in the continuum
14	**Vittorio Bonino** EssilorLuxottica, Milano, IT	Optical computing with passive elements for smart eyewear

15	**Kaushik Brahmachari** University of Calcutta, IN	Influence of silicon material on the performance of bioplasmonic structure comprising of gold nanoparticle film
16	**Luca Bursi** Università di Modena e Reggio Emilia, IT	Defect complexes and charge compensation in Ta-doped anatase TiO_2 transparent conductor
17	**Stefano Campanaro** Università di Modena e Reggio Emilia, IT	Tunable volume plasmon polariton modes in hyperbolic metamaterials based on III-V semiconductors
18	**Filippo Coviello** EssilorLuxottica, Milano, IT	Evaluation of scattering efficiency in large scale simulated optical metasurfaces
19	**Mehmet Atif Durmus** University of Amsterdam, NL	Tunable nonlocal 2D excitonic metasurfaces
20	**Carlo Forestiere** Università Federico II, Napoli, IT	Quantum emitter interacting with a dispersive dielectric object: A model based on the modified Langevin noise formalism
21	**Antonino Foti** Cnr Ipcf, Messina, IT	Nano-imaging of 2D MoS_2 on gold nanostripes by tip-enhanced photo-luminescence
22	**Maria Gambelli** Università Sapienza & Cnr Ifn, Roma, IT	Group-IV SiGe material platform: From ultrastrong coupling toward the development of intersubband-based devices
23	**Shuvaraj Ghosh** Cnr Nano, Modena, IT	Amorphous ITO-ZnO mixed oxide-based transparent conducting films for plasmonics
24	**Maria Caterina Giordano** Università di Genova, IT	Flat-optics 2D TMD semiconductor heterostructures for large-area photoconversion applications
25	**Nicoletta Granchi** Università di Firenze & LENS, IT	Tailoring Fano lineshape in photonic local density of states by losses engineering
26	**Nicoletta Granchi** Università di Firenze & LENS, IT	Scalable nanophotonics: Revolutionizing optical components with advanced coatings & metasurfaces
27	**Claudia Pernilla Hallqvist** Politecnico di Milano, IT	Titanium oxynitride and vanadium dioxide thin films and multilayers for solar and IR light absorption
28	**Shahid Hameed** Government College University Faisalabad, PK	Anticancer and acute toxicity studies of cellulose–coated vanadium oxide nanomaterials
29	**Huatian Hu** Istituto Italiano di Tecnologia, Arnesano, IT	Calculating free-electron nonlinearities in nonclassical plasmonic heavily doped semiconductor systems

30	**Edoardo Mariani** University of Munich (LMU), DE	Plasmon-assisted lithium-ions capture in LiAl-LDHs
31	**Arif Nabizada** Università Sapienza, Roma, IT	Excitation of FF-SH surface plasmon polariton waves by femtosecond pulses at metal-nonlinear medium interfaces
32	**Valeria Nocerino** Università Federico II, Napoli, IT	The UniNano Nanotechnology Center for NanoPhotonics and Quantum Device Engineering
33	**Michele Ortolani** Università Sapienza, Roma, IT	Longitudinal bulk plasmons in heavily doped semiconductors for electrically reconfigurable linear and nonlinear optics
34	**Miranda Parisi** Università Roma Tre, Roma, IT	Functionalized chiral gold nanoparticles for sensing applications
35	**Samuele Pelatti** Cnr Nano, Modena, IT	A procedure to obtain niobium oxide films with variable stoichiometry
36	**Marcello Pozzi** ETH Zurich, CH	Self-assembled hybrid dielectric/plasmonic network metamaterials based on vanadium oxide and copper
37	**Enzo Rotunno** Cnr Nano, Modena, IT	SPEQTEM: A next-generation monochromated TEM for advanced plasmonic investigations
38	**Vaishnavi Sajeev** Politecnico di Milano, IT	Active THz surface plasmon modulation via tungsten oxide hole arrays
39	**Anastasiia Sapunova** Istituto Italiano di Tecnologia, Genova, IT	Study of magneto-plasmonic characteristics of nanopores for particle trapping
40	**Alberto Sivera** Politecnico di Milano, IT	High-index optical materials for all-dielectric non-local metasurfaces
41	**Claudia Skubisz** Università Sapienza, Roma, IT	Metasurface mapping by photoacoustic spectroscopy
42	**Eleonora Spurio** Cnr Nano, Modena, IT	Ultrafast charge transfer dynamics in plasmonic NPs-CeO_2 systems
43	**Shukun Weng** Istituto Italiano di Tecnologia, Genova, IT	Electrically tunable ion transportation of MoS_2/SiN nanochannel

Abstracts – Talks

Collective Lattice Resonances in Complex Arrays of Nanostructures

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Two-dimensional periodic arrays of metallic nanostructures can support collective optical modes known as lattice resonances. These excitations emerge at wavelengths determined by the periodicity of the array, leading to exceptionally strong and spectrally narrow optical responses. Owing to these remarkable properties, periodic arrays are widely used in applications such as ultrasensitive biosensing, nanoscale light emission, and color printing [1].

In this contribution, we will discuss recent theoretical advances in the study of lattice resonances. Specifically, we will examine how the interplay between the response of individual array constituents and their collective interactions determines the ultimate limits of near-field enhancement and the quality factor of a lattice resonance [2]. We will also explore the response of arrays with multi-particle unit cells through an analytical approach based on hybridization theory [3], which provides a simple and efficient framework for designing periodic arrays with tailored optical properties [4,5]. Additionally, we will investigate how the characteristics of the excitation source influence the optical response of the array [6-8]. We will analyze different array geometries that support lattice resonances with extraordinary properties, including perfect circular dichroism [9,10] and perfect absorption [10,11]. Finally, we will demonstrate that incorporating a highly radiative nanostructure into the unit cell of an array composed of nanostructures made of "poor" plasmonic materials can significantly enhance its absorbance, which paves the way for the use of periodic arrays in catalytic applications.

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[2] A. Manjavacas, L. Zundel, and S. Sanders. ACS Nano **13**, (2019).
[3] S. Baur, S. Sanders, and A. Manjavacas. ACS Nano **12**, (2018).
[4] A. Cuartero-González, et al, ACS Nano **14**, (2020).
[5] J. Alvarez-Serrano, et al., ACS Photonics **11**, (2024).
[6] L. Zundel, et al., ACS Photonics **9**, (2022).
[7] L. Zundel, et al., ACS Omega **7**, (2022).
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[9] L. Cerdán, L. Zundel, and A. Manjavacas. ACS Photonics **10**, (2023).
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Towards an integrated QM/classical framework for molecular nanoplasmonics

Sveva Sodomaco,[1,*] Piero Lafiosca,[1] Tommaso Giovannini,[2] and Chiara Cappelli[1,3]

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Plasmonic nanostructures exhibit intriguing optical properties that can be tuned by varying their shape, size, composition, and environment [1]. Plasmonic materials can hugely modify the electronic structure and spectral signals of molecular systems adsorbed on their surface, giving rise to the so-called surface-enhanced (SE) spectroscopies. Here, we present a fully atomistic multiscale framework to model the complex interactions between plasmonic substrates and target molecules under external radiation [2]. The method is based on a Quantum Mechanical (QM)/Classical partitioning of the system. In particular, the target molecule is treated at the (Time Dependent) Density Functional Theory (TD)DFT level, while the plasmonic environment is modeled classically, retaining its atomistic nature [2,3]. The classical approach is based on the frequency-dependent Fluctuating Charges (ωFQ) and Fluctuating Dipoles (ωFQFμ) models that feature a Drude-conduction mechanism, quantum tunneling, and interband transitions [4-6]. These models accurately capture the optical response of alkali metals [4], graphene-based materials [5], and noble metal nanostructures [6] of complex morphologies and compositions [7] while accounting for diverse chemical environments [8].

The hybrid QM/ωFQ(Fμ) framework enables the accurate computation of SE Raman scattering (SERS) [2] and SE infrared absorption (SEIRA) spectra [3], while considering key experimental parameters such as substrate morphology, composition, and molecular orientation. The versatility of the developed approaches is demonstrated by comparing the SE spectra of (bio)molecular systems, such as DNA nucleobases and amino acids, with experimental data.

Acknowledgments

This work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 818064).

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[2] P. Lafiosca, L. Nicoli, L. Bonatti, T. Giovannini, S. Corni, and C. Cappelli, J. Chem. Theory Comput. **19**, 3616 (2023).

[3] S. Sodomaco, P. Lafiosca, T. Giovannini, and C. Cappelli, *in preparation*

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Plasmon-mediated Fluorescence Enhancement of Chromophores: An Atomistically-Detailed Theoretical Perspective

Pablo Grobas Illobre,[1]* Piero Lafiosca,[1] Teresa Guidone,[1] Francesco Mazza,[1] Tommaso Giovannini,[2] Chiara Cappelli,[1,3]

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Plasmonic nanoparticles (NPs) play a pivotal role in the development of highly selective, fluorescence-based biosensors. The plasmon-mediated fluorescence signal of chromophores can be either quenched or enhanced as a function of several factors. Among others, accurate control of the chromophore-NP distance and orientation, as well as the NP's shape and size, is key for tuning the complex interactions governing the overall response. A theoretical investigation of the pairwise NP-chromophore interactions provides a physical understanding of the experimental outcomes and paves the path for the rational in-silico design of these types of biosensors [1-4]. In this context, a full quantum mechanical (QM) description of the NP–chromophore system offers the most accurate representation of the underlying physical phenomena governing the response. However, the number of degrees of freedom involved in such an evaluation limits the modeling to systems far smaller than those experimentally studied [5]. To overcome these limitations, we have developed the ωFluctuating Charges Fluctuating Dipole (ωFQFμ) model, a fully atomistic yet classical framework that integrates the Drude mechanism, electrostatics, quantum tunneling, and atomic polarizability to capture the optical response of plasmonic NPs [6,7]. This model accurately reproduces quantum-size effects, including plasmon shifts, non-local response, and electron density distributions, while remaining computationally efficient for systems containing thousands of atoms [8]. The fluorescence response of the chromophore is modeled by coupling ωFQFμ with a QM Hamiltonian within the framework of Time-Dependent Density Functional Theory (TDDFT) [9]. The resulting QM/ωFQFμ can accurately evaluate how atomistic nuances modify the plasmonic response of engineered NPs, and thus the fluorescence response of a molecule placed in their vicinity.

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Ultrafast Spectroscopy on a Hybrid Plasmonic-Photonic Platform

Tersilla Virgili,[1,*] Diego Florio,[1,2] Laura Pasquardini,[3,4] Mario Barozzi,[5] Monica Bollani,[1] Salvatore Stagira,[2] and Andrea Chiappini[6]

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Photonic crystals have attracted interest due to their unique photonic properties, such as enhanced near-field interactions and light confinement, that, along with the low fabrication cost requirements, have made them good candidates for applications in SERS, bio-sensing, and waveguiding. Here, we use femtosecond transient absorption spectroscopy, complemented by a theoretical model, to reveal the hybrid plasmonic-photonic nature of a system consisting of an opal photonic crystal covered with a thin gold layer from a photophysical perspective. The fabrication process involves the synthesis of a monodisperse colloidal solution of silica nanospheres using Stöber method, followed by self-assembling via vertical deposition on a quartz substrate to create an ordered opal structure. Subsequently, a thin gold layer is evaporated on the opal surface, producing a metal decoration with a peculiar morphology, made by gold nanocrescents connected by a thin film, as observed via high-resolution SEM.

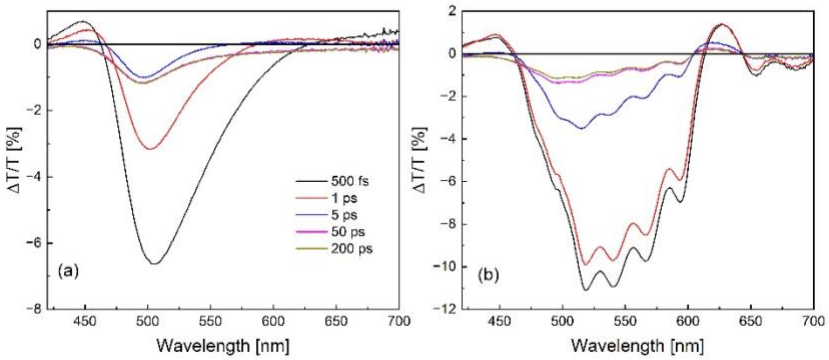

Figure 1: Pump-probe spectra at different probe delays on flat gold thin film (a) and on the Opal/Gold structure (b).

We compare the photophysical response of this sample with that of a flat gold film, obtained by an analogous gold evaporation on a flat quartz substrate. The results of the experiments reveal the presence of a positive band in the hybrid plasmonic-photonic platform at the opal photonic bandgap (PBG) spectral position (≈620 nm), which is absent in the flat gold film. We model our system noting that gold nanocrescents can support spectrally broad localized surface plasmon resonances (LSPRs) in the NIR region. The model accurately predicts the appearance of a positive band at the opal PBG spectral position, thus evidencing an interaction between the plasmonic and photonic characters in our hybrid system, manifested as an LSPR response amplification by the photonic crystal.

Finally, we covered the hybrid plasmonic-photonic platform with dehydrated *Bacillus cereus*, and we found a ≈10 nm red shift of the bleaching band suggesting the possibility to develop a system sensitive to bacteria [1].

[1] A. Chiappini et al. *Submitted*

Customized Infrared Nanospectroscopy Technique for the Study of Electric-Field-Induced Molecular Dynamics

Maria Eleonora Temperini[1], Raffaella Polito[1], Tommaso Venanzi[2], Leonetta Baldassarre[1], Huatian Hu[3], Cristian Ciracì[3], Marialilia Pea[4], Andrea Notargiacomo[4], Francesco Mattioli[4], Michele Ortolani[1], and Valeria Giliberti[2,*]

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Static electric fields play a considerable role in many nanoscale systems as diverse as molecular electronic devices, piezoelectric and ferroelectric nanomaterials, as well as biological cell membranes embedding proteins. In this context, conducting scanning probes have been widely exploited as nanoelectrodes, to apply a controlled electric field at the nanoscale. Although optical spectroscopies are, in principle, sensitive to diverse possible electric-field induced effects, such as molecule conformational changes and orientation, chemical modifications upon a given reaction, and the internal vibrational Stark effect (VSE) produced by the electrostatic environment of the molecules, rarely they have been performed in the near-field in the presence of an external electric field. Using a conducting scanning probe both as nanoelectrode and as near-field optical sensor would be an ideal strategy to perform *in-operando* spectroscopy to monitor the effects of static fields on nanosystems.

Here we demonstrate a customized IR nanospectroscopy platform enabling the simultaneous overlap of a static electric field and an enhanced IR probing field in the nanogap between a metallic atomic force microscope (AFM) tip and a metal-coated substrate used as sample support. Starting from an existing photothermal expansion IR nanospectroscopy (AFM-IR) platform (NanoIR2 by Bruker-Anasys), we have built an external electric circuit similar to that of conductive-AFM, so as to apply a controlled bias while simultaneously performing IR nanospectroscopy [1]. To validate the novel experimental configuration, we used thin films of polymer PMMA detecting the electric-field dependent changes in the C=O stretching band, interpreting the data in the framework of VSE to calibrate the absolute electric field value. We then moved to more complex systems, where orientation effects play an important role, such as transmembrane proteins. In this relevant case, we observed electric-field-induced changes of the protein backbone conformation and residue protonation state. The proposed technique also has the potential to measure DC currents and IR spectra simultaneously, insofar enabling the monitoring of the possible interplay between charge transport and other effects [2].

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Stark Control of Plexcitonic States in Incoherent Quantum Systems

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Active control of quantum states in incoherent quantum system is crucial for in situ programmable and multifunctional photonic integrated circuits (PICs) [1]. Quantum plasmonics provides an efficient pathway to achieve this control by leveraging the quantum properties of intense plasmon modes and the excitonic states of quantum emitters (QEs) [2, 3]. Here, we theoretically demonstrate the active tuning of plexcitonic modes in both (i) off-resonant and (ii) resonantly coupled plasmon-emitter systems through optical Stark effect (OSE) [4]. Using the Heisenberg-Langevin approach, we evaluate the dynamics of the intense plasmonic field generated by a bow-tie nanoantenna coupled to QE. In the off-resonant systems, the Stark field shifts the degeneracy of a three-level QE and coherently drives the off-resonant plexcitonic states closer to resonance, leading to a path interference effect and the formation of a transparency window, which we refer as Stark-induced transparency (SIT). Furthermore, even small perturbations in the Stark field yield significant changes in Rabi splitting, reaching values up to $\Omega \leq 350$ meV. These pronounced resonant shifts in the excitonic levels also enables the tunable photoluminescence (PL) in the visible regime, with on/off modulation of PL intensity. In resonantly coupled systems, the Stark field lifts the degeneracy by splitting the excited state of a two-level QE, inducing path interference in the hybrid plexcitonic modes. The Stark-induced splitting also shows the signature of Mollow triplets in the plexcitonic modes, with a maximum energy splitting up to 491 meV between the upper (UP) and lower (LP) plexcitons. We validate these plexcitonic shifts through PL spectra and evaluate the optical response of the system for varying Stark field strengths [Fig.1(d)]. With increasing field strength, the splitting between UP and LP polaritonic states increases, while the PL intensity gradually decreases, indicating a transition of spontaneous photon emission from high (on) to low (off) as a function of probe field.

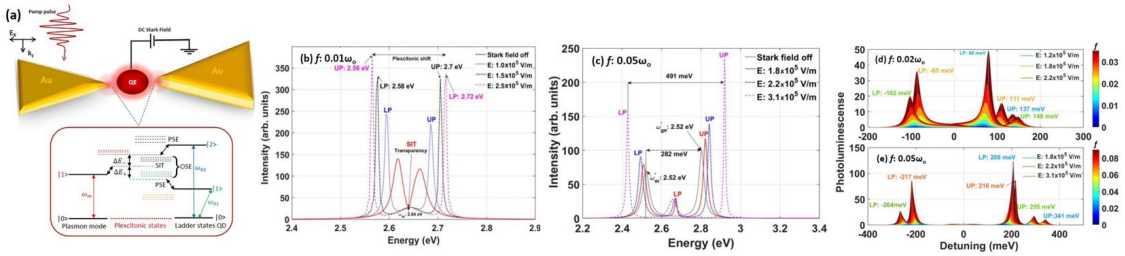

Figure 1: (a) Hybrid quantum plasmonic system of Au bow-tie nanoantenna and voltage-tunable QE. (b) Stark-induced SIT in the off-resonant coupled system. (c) Stark-induced Rabi splitting in resonantly coupled plexcitonic states. (d) PL spectra of Stark tuned plexcitons as a function of detuning for different strengths of Stark field in the weak ($f : 0.02\omega_o$) and (e) strong coupling ($f : 0.05\omega_o$)

Our proposed method of Stark tuning of plexcitonic modes provides a pathway for coherent control of quantum devices, offering a means to not only mitigate decoherence in quantum systems but actively tune the spontaneous photon emission in the visible regime.

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Optical Mode Level Repulsion in Hyperuniform disordered systems

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Recently, disordered dielectric materials with structural correlations, which are halfway between random structures and perfectly ordered photonic crystals, have generated an ever-growing interest. Hyperuniform Disordered (HuD) photonic materials exhibit a high spectral and spatial density of resonant modes, characterized by extremely different spatial extensions depending on the light transport regime which can vary from diffusive to Anderson-like localization [1]. These regimes belong to modes of different spectral ranges, highlighted in the spectrum of Fig. 1a. The presence of deterministically tailored localized and diffusive transport within the same photonic platform has raised novel and exciting questions. Here, we investigate the properties of modes in different transport regimes within luminescent HuD materials, focusing on the Level Repulsion phenomenon [2, 3]. This effect causes spatially overlapping modes to exhibit a frequency level distribution with a near-zero probability of closely spaced frequencies. In contrast, when level repulsion is absent, modes are uncorrelated and may have close or degenerate frequencies. Detecting such phenomenon in a HuD photonic architecture, where both kind of regimes can be found, would definitively set a hallmark of Anderson localization in these systems. Here, we take advantage of the subwavelength spatial resolution offered by Scanning Near-field Optical Microscopy (SNOM) to present the first experimental evidence of level repulsion between optical modes in a tailored diffusive regime. To extract from the experimental spectra the level repulsion hallmark we performed a statistical analysis based on the autocorrelation technique [2]. Fig.1 reports the results of a SNOM measurement performed on the sample which consists in a dielectric slab patterned with the HuD geometry (Fig.1b); the SNOM PL maps in (1c) and (1d) are examples of typical Anderson localized modes and delocalized ones, respectively. We evaluate the autocorrelation function in the spectral windows of localized (green curve, Fig.1e) and delocalized modes (purple curve, Fig.1e). The presence of a pronounced shoulder at short spectral distances in the purple curve is a clear indication of level repulsion between delocalized modes, differently, from what is observed between localized modes. In conclusion, we experimentally demonstrated that in a HuD system there is a strong correlation between the mode spatial extension and their energetic level distribution. The findings introduced here are essential to the exploration of the energy level structure in complex disordered photonic materials.

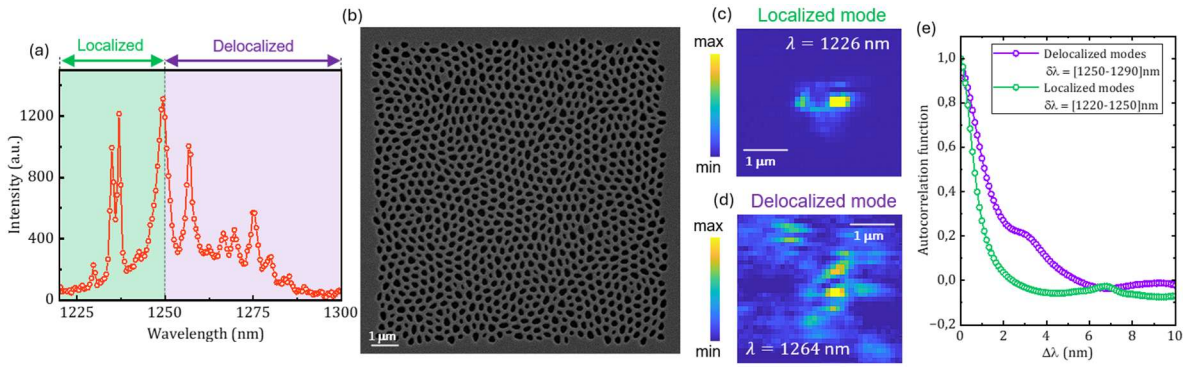

Figure 1: (a) SNOM typical spectrum. (b) SEM image of HuD sample. (c) SNOM PL map of a localized mode at 1226 nm. (d) SNOM PL map of a delocalized mode at 1264 nm. (d) Autocorrelation function of localized (green curve) and delocalized modes (purple curve). The shoulder in the purple curve indicates level repulsion.

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Polaritonic hybrid modes in Cd(Zn)O thin films on SiC

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Cd(Zn)O has risen as a promising material for the development of new plasmonic devices in the mid-IR due to its high plasma frequency and low losses [1], but it has traditionally been grown on passive substrates like sapphire and glass [2]. This study addresses this issue by demonstrating the presence of surface plasmon polaritons (SPP) in Cd(Zn)O thin films deposited on a 4H-SiC substrate. Silicon carbide (SiC) is a polar, wide-bandgap semiconductor, widely used in metal-oxide-semiconductor field-effect transistors (MOSFETs) whose electrical characteristics can be manipulated by doping. In addition, SiC is a highly polar material [3] whose surface phonon polaritons (SPhP) can hybridize with the SPPs from CdZnO, providing additional control of the polariton characteristics.

Cd(Zn)O layers of varying thickness were deposited on 4H-SiC substrates by metal organic chemical vapor deposition (MOCVD). Cd(Zn)O layer thicknesses ranged from 20 to 460 nm and three different Zn contents were used (0, 10, and 20%). The sample reflectance was measured using a Fourier Transform Infrared (FTIR) spectrometer in attenuated total reflection (ATR) in the Otto configuration. The dispersion curves of these structures were modeled by the transfer matrix method (TMM). The parameters for the dispersion curves as well as the thicknesses of the samples were deduced from fits to conventional reflectance spectra.

Figure 1 shows the calculated reflectance and the experimental SPP resonance frequencies for three different Cd(Zn)O thin film thicknesses. As seen in previous studies on sapphire substrate [4], the dispersion curves show two separate polaritonic branches, the high energy symmetric mode, and the low energy antisymmetric mode. While the upper mode is essentially plasmonic in nature, the lower one results from the hybridization between the SPPs from CdZnO and SPhPs from SiC, resulting in low losses and a long propagation length.

The results of this work demonstrate the viability to grow Cd(Zn)O thin films on SiC substrates while maintaining favorable plasmonic properties, such as low losses, tunable plasma frequency, and long propagation length, comparable to those found on sapphire substrates.

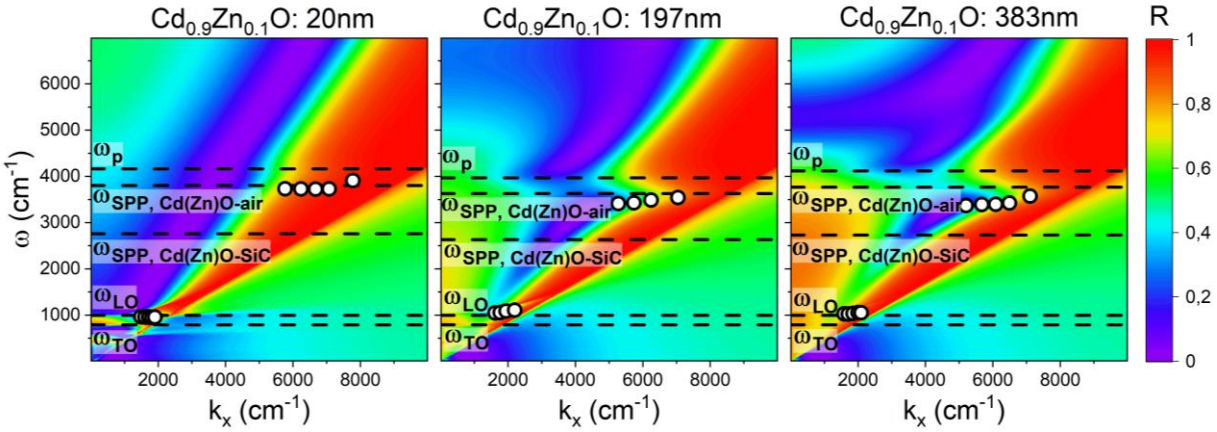

Figure 1: Simulated reflectance contour plots and experimentally determined SPP frequencies (white circles) for Cd(Zn)O/SiC structures for different layer thicknesses. The Zn content was 10% for all three samples.

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Yb^{3+}-Doped $Cspbcl_3$ Perovskite Nanocrystals: Quantum Cutting For Optoelectronic Applications

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Perovskite nanocrystals are emerging as a promising alternative material for optoelectronics and photovoltaic solar cells [1]. In particular, the incorporation of rare-earth ion Yb^{3+} in lead halide perovskites boost the PLQY close to 200% thank to quantum cutting (QC) [2]. In QC the absorption of one photon at shorter wavelength is followed by the emission of two photons at higher wavelengths which arises from the forbidden f–f transition of rare-earth ions. Rather than common energy transfer mechanisms, the doping with ytterbium ions generates a vacancy in the lead lattice to compensate for the extra charge, leading to the formation of shallow trap states that mediate quantum cutting. This phenomenon has been proposed to increase the performance of standard Si solar cells since it rises the number of photons that can be converted in electricity (PLQY upon 200%) when perovskite is coupled to another photovoltaic material [2]. In this work, lead halide perovskites doped with trivalent rare-earth ions, specifically Yb^{3+}:$CsPbCl_3$, were synthesized and characterized using XRD, TEM, ICP, as well as absorption and photoluminescence (PL) spectroscopies under variable excitation power density [3]. The doped and undoped $CsPbCl_3$ NCs exhibit distinct emission characteristics since in the former the forbidden f–f transition of Yb^{3+} ion (980 nm) is present alongside the host one. The PL spectra, recorded at increasing power densities, were analysed to qualitatively investigate the emission behaviour. Both signals show a linear increase with excitation power, although the 980 nm peak eventually reaches saturation. Further studies are ongoing to correlate these findings with the still debated theory for quantum cutting in Yb-doped perovskites and hopefully gain additional insight into the underlying mechanism.

Italian MUR is acknowledged through PRIN 2022 PNRR project P20229723Z (CUP: B53D23025560001).

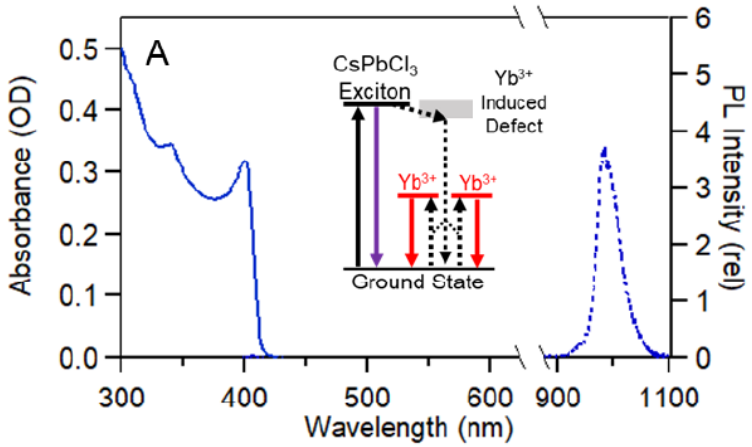

Figure 1: Room-temperature absorption (solid) and photoluminescence (dashed) spectra of 1.4% Yb^{3+}:$CsPbCl_3$ NCs suspended in hexane. Inset: Schematic energy-level diagram depicting Yb^{3+} sensitization by quantum cutting [2].

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Sensing 3D electromagnetic landscapes at the nanometer scale with single emitters

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Pushing light-matter interaction at the extreme with nanostructured materials and being able to measure the strength of such interaction at the nanoscale is one of the major challenges of nanophotonics. To this aim, fabrication and characterization techniques of nanostructured materials have undergone an explosion of progress in the last decades. More recently, the performances achieved with Single Molecule Localization Microscopy in terms of ability to observe biological phenomena at the nanometer scale, have become of great interest also for the study of light–matter interaction in nanostructured materials, showing that the interaction between biophysics and nanophotonics can push forward the current technical limits and allow the study of new phenomena [1]. Since fluorescence lifetime, and its inverse, the decay rate, is directly linked to the local density of states (LDOS) of the electromagnetic environment, simultaneously measuring the lifetime and the position of single emitters is a powerful tool to map light-matter interaction in nanostructured materials.

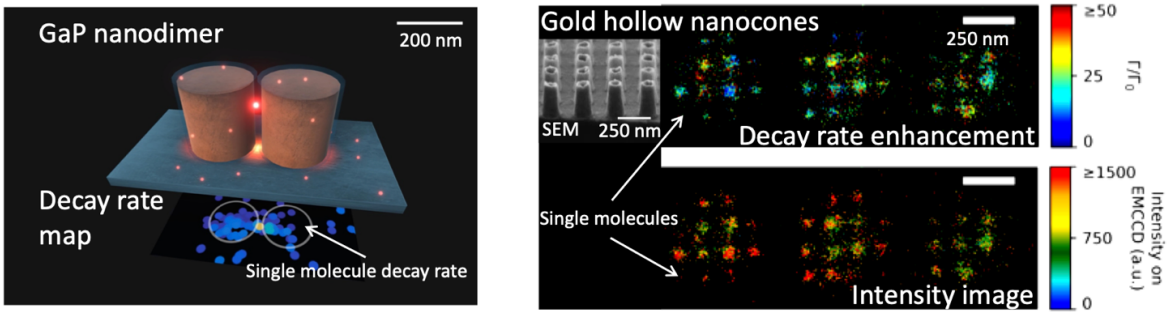

Figure 1. Left: Super-resolved decay rate (inverse of the lifetime) map of single molecules labeling a GaP nanoantenna [2]. Right: Super-resolved single-molecule decay rate enhancement and intensity images in the near-field of an array of gold truncated hollow nanocones (shown in the SEM image) [3].

We report on recent results obtained at Institut Langevin with smFLIM (single molecule Fluorescence Lifetime Imaging Microscopy), a novel technique that enables LDOS mapping at the single molecule level on nanometer scale as shown in fig.1 [2, 3]. smFLIM consists in multiplexed and super-resolved fluorescence lifetime imaging with single molecules with a field of view of ~10 μm^2, a localization precision of ~15 nm [4, 5], and a temporal range spanning from ps to ms [2-5]. The sample is labeled with a dense layer of stochastically photoactivatable single molecules that are illuminated in wide field. The fluorescence of each emitting single molecule is detected simultaneously on an EMCCD camera used to localize the emitting molecule and a linear array of single-photon avalanche diodes (SPADs) for time-resolved measurements [5]. In this talk we will report on the application of this technique to image the LDOS of dielectric and metallic nanostructures, with extensions going from a few hundred nanometers to several microns. As shown in fig.1, we were able to image the radiative decay rate of single molecules coupled to GaP nanoantennas (collaboration with R. Sapienza, Imperial College London) [2], and the decay rate of three-dimensional periodic arrays of hollow gold truncated nanocones [3] which produce large intensity hotspots and Purcell enhancements of the order of hundreds.

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Hybrid 2D-plasmonic nanoemitters via grayscale thermal-Scanning Probe Lithography

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Two-dimensional (2D) Transition Metal Dichalcogenides (TMD) layers, featuring strong light-matter interaction effects, recently emerged due to their exceptional optoelectronic properties as both absorbers and quantum emitters, and to the possibility to tailor their photonic response via strain engineering. However, key issues such as the relatively low optical absorption of atomic layers and their poor quantum efficiency still limit their integration in competitive photonic devices[1].

To overcome these limitations the ability to reshape 2D TMDs at the nanoscale represents a crucial step toward the fabrication of TMD-based flat-optics metasurfaces featuring enhanced photon harvesting and/or photon emission[2,3].

In this work, we demonstrate the deterministic reshaping of fragile 2D TMDs layers via non-invasive thermal Scanning Probe Lithography (t-SPL) approaches[4]. The engineering of either 2D nanostructures or hybrid 2D-plasmonic nanoemitters have been achieved to locally tailor the strain and/or the photon emission properties of 2D TMD semiconductor layers.

We develop high-resolution 3D nanopatterns characterized by out-of-plane tilted nanofacets via grayscale t-SPL and exploit such templates for the conformal transfer of 2D MoS_2 layers tailoring their optoelectronic response at the local scale via strain engineering (Fig. 1a)[5]. Similar grayscale t-SPL templates have been exploited for the maskless confinement of tilted noble metal nanoantenna arrays supporting Localized Surface Plasmon (LSP) resonances that can be tuned over a broadband Visible and Near-Infrared spectrum. The following conformal transfer of 2D MoS_2 monolayers onto the nanoantennas allow to achieve hybrid 2D-plamonic nanoemitter arrays characterized by deterministic morphology and out-of-plane tilt (Fig. 1b). Under this condition the photoluminescence emission of the hybrid nanosystems has been investigated, observing a polarization-sensitive enhancement of the signal when the LSP is tuned in resonance with the 2D TMD exciton polaritons. These preliminary results deserve further study of the strong exciton-plasmon coupling in hybrid 2D-plasmonic nanoemitters, suggesting applications in many fields ranging from photonics and energy conversion, to sensing and quantum technologies.

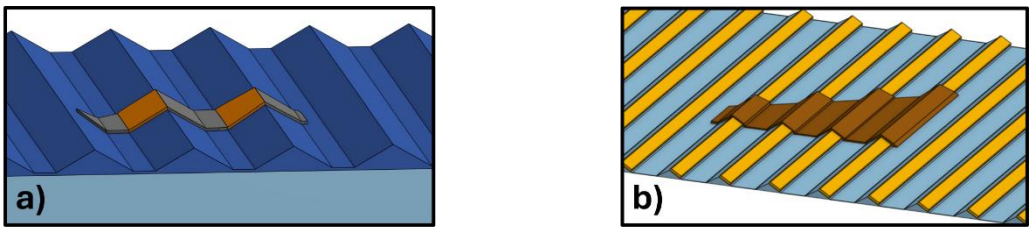

Figure 1: a) Locally strained 2D TMD layers. b) Hybrid 2D-plasmonic nanoantennas

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Infrared Thermoplasmonics with Indium Tin Oxide Nanocrystals

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Thermoplasmonics exploits light absorbed by plasmonic nanocrystals (NCs) to generate heat, which is readily exploitable for nanomedicine, catalysis, thermal imaging or light harvesting[1]. Recently, plasmonic materials alternative to noble metals (gold and silver) are emerging, and transparent conductive oxides, such as Indium Tin Oxide (ITO), represent a promising choice for applications requiring near infrared (NIR) light[2], such as photo-thermal treatment of tumours. While for noble metals the engineering of the NC shape or core@shell architectures are typically mandatory to shift the plasmonic resonance in the NIR spectral range, requiring challenging synthetic approaches,[3] 10 nm ITO nanospheres display a sharp NIR plasmonic peak due to the low carrier concentration, without requiring complex morphologies.

Here, 10 nm ITO NCs were synthesized by bottom-up colloidal chemistry synthesis. A sharp NIR plasmonic peak at ~1800 nm is observed in ITO NCs, due to the free electrons introduced by the incorporation of aliovalent tin cations, while exhibiting complete transparency in the visible range due to its wide band gap (Figure 1a).[4] These two features, rarely occurring simultaneously in typical plasmonic materials, are here exploited for different applications. First, we realized ink-jet printed anticounterfeiting tags that are invisible by naked eyes but can be imaged in less than 1 s with a thermal camera upon NIR irradiation (Figure 1b)[5]. Secondly, we designed a self-healing nanocomposite incorporating ITO NCs in a thermo-responsive polyketone matrix, achieving an extremely fast kinetics with low ITO content (< 1 wt %), allowing to repair a damage in 3 s compared to more than 100 s of the bare polymer (Figure 1c).[6]

Finally, we transferred ITO NCs in water phase through a surface ligand exchange process, and we performed preliminary in-vitro photo-thermal experiments on melanoma cancerous cells in the third biologically transparent windows (1500-1900 nm), which has been scarcely explored in the literature of thermoplasmonics. We designed a hybrid nanomaterial loading ITO NCs onto cellulose nanocrystals, here functionalized with a glucose selector (over-expressed in several cancerous cells) to improve the cellular uptake. Our preliminary results demonstrated that the photo-thermal effect is efficient in significantly reducing the cell viability after NIR irradiation.

All together, these results demonstrate the huge potential of ITO NCs for NIR thermoplasmonics.

Italian MUR is acknowledged through PRIN 2022 PNRR project P20229723Z (CUP: B53D23025560001).

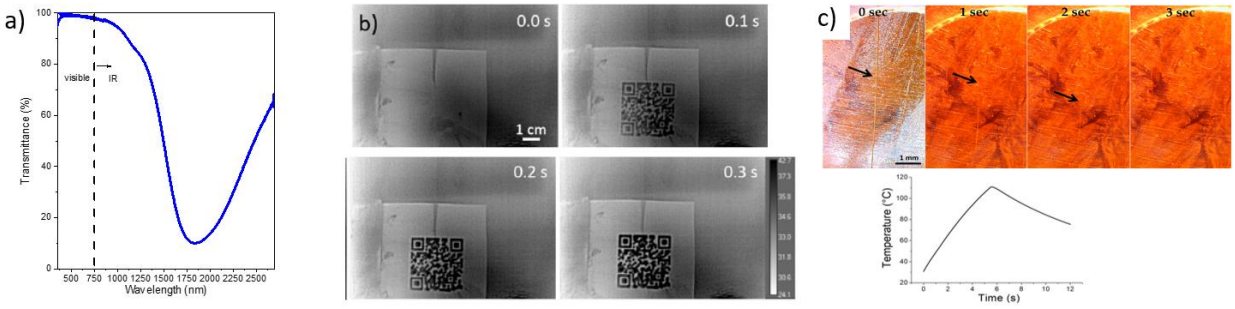

Figure 1: a) Transmittance spectrum of ITO NCs dispersions; b) ink-jet printed anticounterfeiting tag imaged with a thermal camera during IR illumination; c) IR-activated self-healing of ITO-polyketone nanocomposite

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Plasmonic/Excitonic hybrid systems for nanoscale thermometry

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Heat transmission at the nanoscale presents a fascinating arena for scientific inquiry and technological innovation. At this diminutive scale, materials behave uniquely, often defying classical thermodynamic principles and demanding novel approaches to understand and manipulate heat transfer. To understand these phenomena, it is of paramount importance to develop systems and strategies to create heat on a nanometric scale, and to measure the ensuing temperature distribution with atomic-scale accuracy. In this contribution, we report the fabrication and validation of a nanosystem designed to generate heat on the few-nm lateral scale and measure the achieved temperature variation with atomic-scale precision. The system exploits the thermoplasmonics effect in Au nanoparticles for heat generation, and the temperature-dependent optical response of monolayer TMDC to measure the temperature less than 1 nm away from the particle surface [1].

The device consists of an array of plasmonic nanodisks (NDs) with localized surface plasmon resonance (LSPR) at λ=780 nm, on which we transferred a WS_2 monolayer flake encapsulated in h-BN monolayers. The system could be excited by two co-focused laser beams, one exciting the photoluminescence (PL) from WS_2, while the latter was tuned with the LSPR of the Au NDs. Comparing the PL spectra with/without the LSPR excitation, a clear redshift could be observed, corresponding to a temperature rise of the WS_2 induced by the thermoplasmonics heating of the Au NDs. The hybrid plasmonic/excitonic system represents therefore a viable approach to measure the local temperature variation in nanosystems.

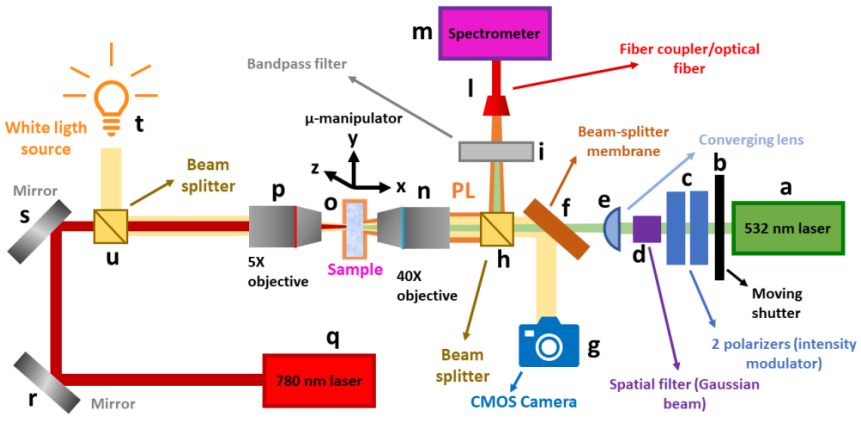

Figure 1: Schematic representation of the experimental setup for nanoscale thermometry.

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Hybrid resonant metasurfaces combining dielectric nanocup metasurfaces and plasmonic networks

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Hybrid metasurfaces combine the advantages of plasmonic and all-dielectric metasurfaces. However, state-of-the-art dielectric metasurfaces commonly consist of geometric primitives, such as cylinders or nanofins, and their integration into hybrid systems is fundamentally limited as confinement of light occurs only in their interior.

In this talk, we discuss a simple fabrication scheme that unlocks a new degree of freedom in the optical design space, as it enables the design of complex metasurfaces that break the out-of-plane symmetry [1]. The fabrication scheme is very general as it relies on geometric shadowing effects and directed growth during physical vapor deposition under grazing angles. The versatility of this approach is highlighted on the specific example of nanocup metasurfaces made of amorphous silicon. Within the framework of structural color, the extraordinary modal properties of these resonant sub-wavelength structures including confinement of light in air, hybrid lattice resonances, and optical non-reciprocity are outlined.

By advancing the idea of hybrid metasurfaces to systems that comprise coupled ordered and disordered elements (Figure 1), local hybridization of these modes is achieved. While the ordered dielectric nanocup metasurface leverages the non-uniform growth conditions to create asymmetrical, out-of-plane nanostructures, the disordered nanophotonic element is a plasmonic network fabricated by self-assembly [2–4]. Achieved strong coupling between the dielectric and broad-band plasmonic eigenmodes [2] provides an important advancement for realizing optical components based on complex media. These components pave the way for new forms of information encoding, eco-friendly colors, light-assisted catalysis [4], and site-specific sensing.

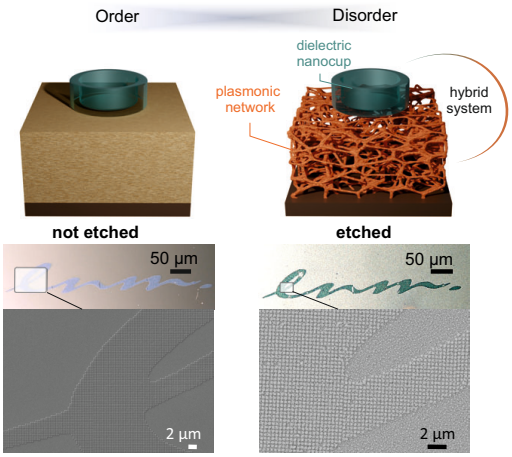

Figure 1: **Configurable order-disorder transformation in hybrid metasurface.** Schematic illustration of the transformation from an ordered to a combined ordered-disordered state. Optical micrographs illustrating the color change through chemical dealloying, i.e., the introduction of disorder in the form of a disordered plasmonic network metamaterial.

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All-optical polarization encoding and modulation by nonlinear interferometry at the nanoscale

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All-optical control using metasurfaces has emerged as a frontier in photonics, offering unprecedented capabilities for light manipulation at the nanoscale. Recent advances have extended these capabilities to nonlinear regimes, where wave-mixing processes can be effectively employed to perform all-optical modulation. For example, the intensity of upconverted light among the diffraction orders of a metasurface can be modulated via nonlinear interferometry, which is suited to free space all-optical routing.[1] In this work, we exploit the modulation of the polarization state using a nonlinear metasurface with a simple geometry, consisting of a periodic array of $Al_{0.18}Ga_{0.82}As$ nanocylinders.[2] This is achieved by employing a phase modulation between two frequency-degenerate nonlinear processes of opposite parity, namely Third-Harmonic Generation (THG) and Sum-Frequency Generation (SFG). We demonstrate an arrangement where the mirror symmetry is broken in detection by monitoring individual off-axis diffraction orders. This asymmetric detection enables the simultaneous encoding of two orthogonal polarization states of the upconverted light in two specular diffraction orders, using linearly polarized pumps at normal incidence (see Figure 1). Additionally, we gain the ability to continuously tune the output polarization state, from linear to circular, by adjusting the relative phase between the two pumps.[3]

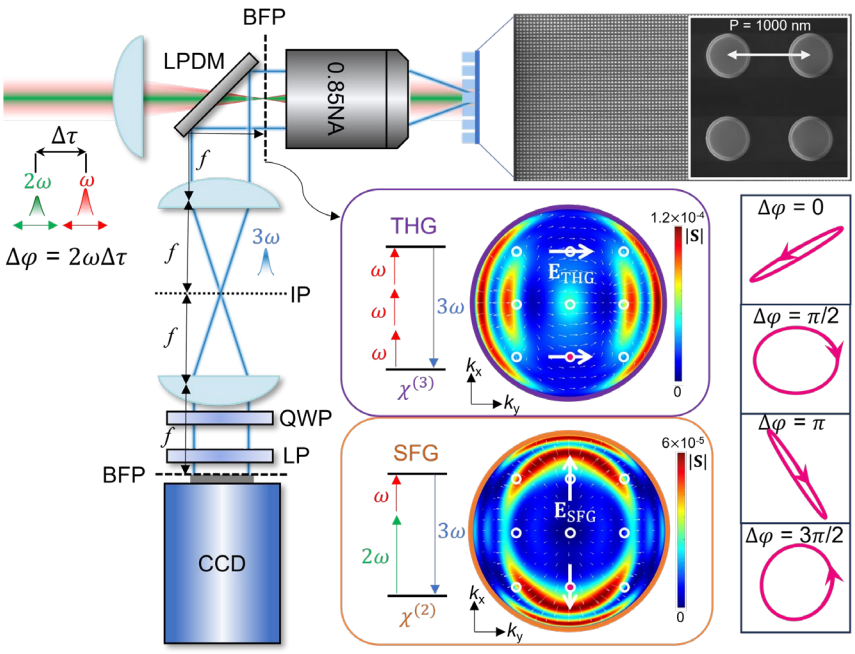

Figure 1: Scheme of the experimental setup and the concept of modulating the polarization state of upconverted light via nonlinear interferometry.

Experimentally, we recorded delay traces longer than the pulse duration to identify the diffraction orders where SFG and THG fields are orthogonal. The THG and SFG powers at zero-delay were then equalized to obtain circular polarization states rather than just elliptical. Eventually, we demonstrated the continuous polarization modulation from linear to circular states, reaching a DOCP of 83%. In perspective, the capability to encode with high modulation speed on-demand polarization states into different channels, which can be continuously adjusted from linear to circular, discloses a potential for applications in chiral sensing. Specifically, the balanced detection of the two specular orders would provide a differential signal to sense the adhesion of chiral molecules to the sample. Moreover, the ability to control in parallel the polarization states of distinct diffraction orders can extend the potential of this approach even to quantum computing and advanced imaging techniques, further broadening its impact.

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Gires Tournois Magnetically Tunable Metasurface for the Dynamic Control of Light

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Metasurfaces exhibit exceptional capabilities for controlling the propagation of electromagnetic waves. While static metasurfaces have been extensively studied, fully realizing their potential in optical applications requires the development of tunable metasurfaces that can dynamically adjust their optical properties [1]. A promising approach to achieve this goal is the control by means of external magnetic field, enabling non-contact, rapid, and reversible modulation of the optical response without mechanical moving parts. Notably, the technology for generating intense and rapidly modulated magnetic fields on the sub-micron scale is already available, such as in magnetic hard disk drives, where writing heads generate field strengths up to 1 T with GHz bandwidth on spatial scales around 100 nm [2]. To realize magnetic tunability, we focused on designing and fabricating Gires-Tournois (GT) [3] metasurfaces integrated with ferromagnetic materials. These reflective metasurfaces consist of a multilayer structure: a dielectric spacer separating a uniform reflective layer on bottom and discrete nanodisks on top (acting as semi-reflective elements) defines cavity modes, that are modulated by magneto-plasmonic [4] interaction of the meta-atoms with the impinging optical wave. The design and material properties of the meta-atoms, in combination with the dielectric spacer and any embedded ferromagnetic layers, allow for tuning the reflectance spectrum under external magnetic fields and circularly polarized light. This design offers highly reconfigurable optical properties, making GT metasurfaces, when integrated with ferromagnetic materials, a powerful solution for dynamic light modulation. The interaction between the localized surface plasmon resonance (LSPR) of the ferromagnetic meta-atoms and the GT cavity modes, in conjunction with the Bragg resonance condition, leads to complex optical behavior, enabling precise control and modulation of reflectance and phase delay at specific wavelengths when subjected to an external magnetic field.

The ability to control light in real-time through magnetic fields makes GT metasurfaces good candidates for applications such as dynamic intensity modulators (see Figure 1), adaptive optical switches, beam shapers, and more.

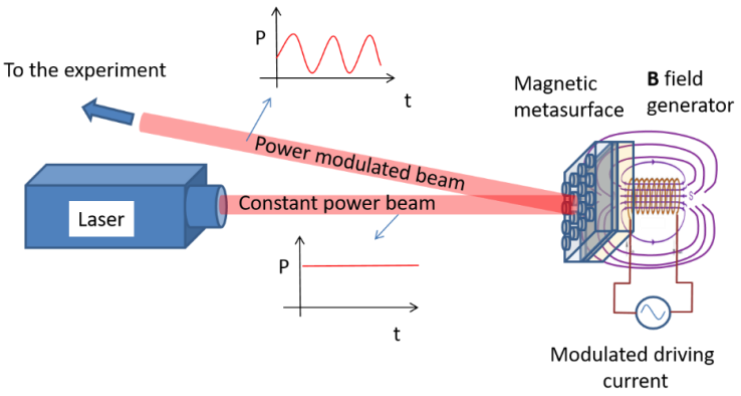

Figure 1: Schematic representation of GT metasurface working as an intensity modulator.

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Electrically tunable polarization state of light using lithium niobate-based nanograting

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Polarization is a fundamental characteristic of light waves, describing the oscillation direction of the electromagnetic vector during propagation, and is widely used in optical communications, imaging and sensing. However, traditional polarization modulation devices are usually bulky, complex in designed and limited in functionality, making it difficult to cater to the high integration and performance requirements of modern optical systems. The research on dynamic metasurfaces, which comprises the flexible tuning of the polarization state by external stimuli, has become a hotspot with the current advances in nanotechnology [1]. The modulation capabilities of dynamic metasurfaces significantly expands the application potential of optical systems, especially in the field of electro-optics (EO).

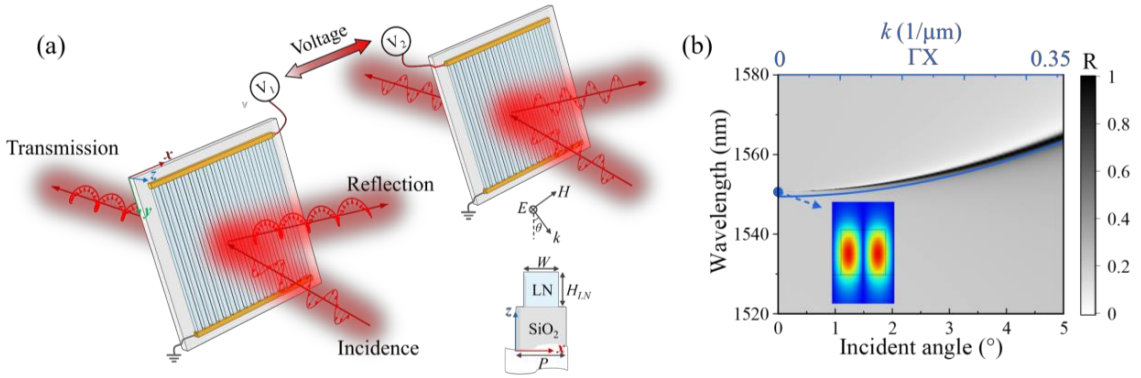

Figure 1: (a) Schematic of the LN-based nanograting. The polarization of reflected and transmitted lights can be dynamically modulated by applying an external voltage V. (b) The angle-dependent reflectivity mapping of LN arrays. The blue line represents the band structure related to the BIC mode.

Our work focuses on EO tuning of metasurfaces, aiming at efficient and dynamic tuning of light polarization states. As schematically shown in figure 1, a lithium niobate-based nanograting is proposed to dynamically tune the polarization state [2]. By judiciously designing the nanograting, a quasi-bound state in the continuum (qBIC) is excited under oblique plane wave incidence. The excited mode with a high quality-factor and enhanced local electric field can be generated with a low external voltage via the EO effect. Consequently, both the polarization states of reflected and transmitted lights can be dynamically tuned from a right circular to a linear polarization state simultaneously in the near-infrared range.

In conclusion, our work explores polarization modulation techniques based on dynamic metasurfaces. We have realized EO polarization modulation of near-infrared light at low voltage using lithium niobate nanograting and qBIC effects. This work demonstrates the enormous potential of metasurfaces in photonic device integration, providing innovative solutions for high-speed optoelectronic devices and photonic functional devices.

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Plasmonic nanopores for nanopores gating

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We present an innovative method for optically gating solid-state nanopores through plasmonic heating, offering significant applications in single molecules sensing [1]. By integrating temperature-responsive polymers such as poly(N-isopropylacrylamide) (PNIPAM) inside nanopores, we achieved thermal gating as the temperature goes above the lower critical solution temperature of PNIAM. This approach combines plasmonic structure with PNIPAM within the nanopore architecture, enabling optical control of individual or multiple nanopores with micrometer spatial resolution and rapid gating speed of a few milliseconds through thermo-plasmonic effects. We attain rapid temperature changes of 40 kelvin per millisecond, confirmed by ionic conductivity measurement and COMSOL, allowing selective activation of nanopores in an array. This approach paves the way for smart nanofluidic devices with multifunctional applications such as multiplex sensing, targeted drug delivery, and fluidic mixing.

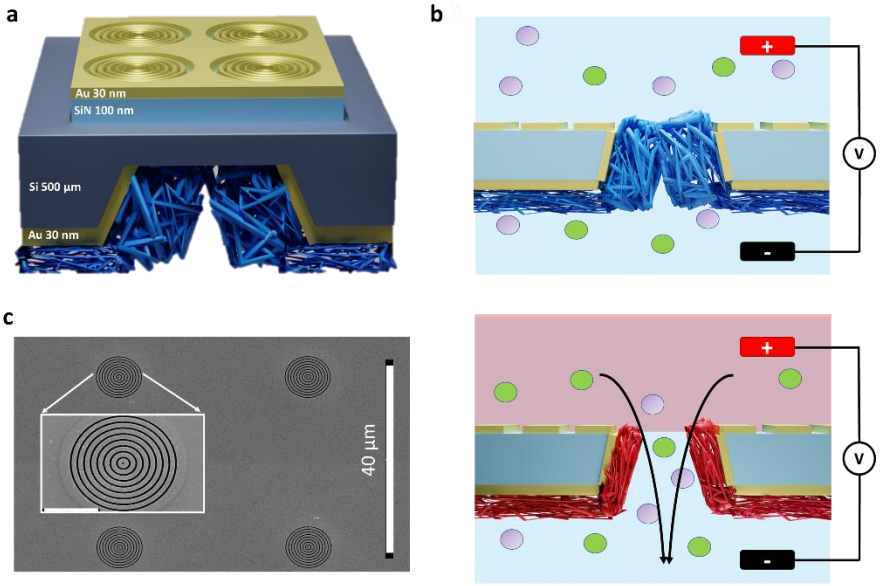

Figure 1: A nanopore array where individual nanopores modified with thermo-responsive polymers are open or closed by local changes in temperature. (b) Heating the array to 35 °C opens the pores for transport. (c) Different combinations of heated nanopores led to different levels of the system conductance, G, and allowed formation of logic gates.

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Individually Addressable Nanoscale OLEDs

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Augmented and virtual reality (AR/VR) as well as 3D applications, require displays with ultrahigh pixel densities. Here, we demonstrate an individually addressable subwavelength OLED pixel based on a nanoscale electrode supporting plasmonic antenna modes [1]. Our approach is based on the notion that when scaling down pixel size, the 2D planar geometry of conventional Organic Light Emitting Diodes (OLEDs) evolves into a significantly more complex 3D geometry governed by sharp nanoelectrode contours. These cause (i) spatially imbalanced charge carrier recombination, resulting in a low quantum efficiency, and (ii) filament growth, leading to rapid device failure. Here, we circumvent such effects by selectively covering sharp electrode contours with an insulating layer, while leaving a nano-aperture in flat areas of the electrode. We thereby ensure controlled charge-carrier injection and recombination at the nanoscale and suppress filament growth. As a proof of principle, we first demonstrate stable and efficient hole injection from Au nanoelectrodes in hole-only devices with above 90% pixel yield and longtime operation stability and then a complete vertical OLED pixel with an individually addressable nanoelectrode (300×300 nm^2), highlighting the potential to further leverage plasmonic nano-antenna effects to enhance the performance of nano-OLEDs [2].

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Automated design of one-dimensional photonic crystals for all-optical image processing

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Image processing is critical for many areas of science and technology ranging from imaging of biological tissue to autonomous vehicles. Digital processing is the standard method due to its versatility and easy to implement methodologies. However, digital processing is time-consuming and energy intensive. All-optical image processing methods have gained significant interest in the past decade as an alternative approach because they offer speed of light computation, no electrically active elements, and improved noise stability as compared to digital processing. To cope with the need for compact systems for use in many next generation technologies, all-optical image processing devices have turned to the field of nanophotonics [1,2]. However, the current state of the art devices require complex designs limiting their scalability and cost-effectiveness. One-dimensional photonic crystals (1DPCs) offer a simpler alternative, requiring only the deposition of a multilayer stack without nanostructuring. However, current day designs struggle to work with arbitrarily polarized light, which impacts their efficiency, and/or require sophisticated designs incorporating many high-index materials, limiting their scalability and applicability to compact systems [4,5]. Here we present a multi-objective, automated design process to optimize 1DPCs with the purpose of implementing all-optical image processing functionalities that improve previous similar proposals in the literature [3-5], feature a reduced complexity, and do not depend on the polarization state of the processed beam [6].

One of the primary properties of a 1DPC is its wave-vector transmissivity which can be engineered, by tuning the structure of the 1DPC, to implement a specific transfer function for the purpose of processing an input light field. However, the parameter space is vast and generating a 1DPC structure for a desired transfer function is a challenging inverse design problem. Here we present an automated design process based on a multi-objective genetic optimizer called the “non-dominant sorting genetic algorithm”. In this optimization scheme, we have the freedom to choose the parameters to optimize and the evaluation functions to evaluate the individuals of the population, making the method a very general approach capable of designing 1DPC structures capable of implementing a wide range of transfer functions. With the flexibility of this optimization scheme, we can design 1DPCs capable of edge detection for both TE and TM polarizations, which grants improved accuracy and optical efficiency. Furthermore, using this optimizer we can even design 1DPCs out of polymeric materials which could offer functionalities unprecedented in inorganic systems (flexibility, stretchability, and use of recycled materials), thus paving the way towards cheap, scalable, and eco-friendly implementations.

This work was partially funded by the European Union – Next Generation EU - PNRR - M4C2, investimento 1.1 - “Fondo PRIN 2022” – “SPIRAL – Lossless surface waves for chiral spectroscopy” – id 2022WFM5MZ – CUP F53D2300114000.

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Metasurfaces supporting guided mode resonances for holography and eye tracking in future smart eyewear devices

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The quest for novel integrable, ultra flat, and efficient optical combiners in smart eyewear technology is boosting the research on nano-optical metasurfaces that can implement transfer functions not achievable with standard bulk diffractive optics. A crucial opportunity is represented by the possibility of implementing narrow spectral features that process and distribute the optical signal associated with hologram projection and/or eye tracking devices, while leaving the remaining part of the spectrum unaffected for standard vision through the eyeglasses [1-3].

From this point of view, nonlocal resonances supported by dielectric metasurfaces represent one of the possible routes towards lossless and narrowband optical functionalities. In particular, guided mode resonances with extremely high-quality factors can be obtained by resonantly matching the wavevector of a guided mode in a uniform dielectric layer with the diffraction properties of a grating overlayer, allowing one to engineer and distribute the optical signal over different diffraction orders and within narrow spectral windows.

In this contribution, we will report the current work that is being performed in our laboratories to develop all-dielectric nonlocal metasurfaces supporting guided mode resonances, designed to operate in the visible spectral range for perspective hologram projection and in the near-infrared spectral range to support eye-tracking functionalities. We will discuss the design, fabrication and characterization of prototypes that use a high-index material platform in order to be compatible with the refractive index of modern prescription lenses.

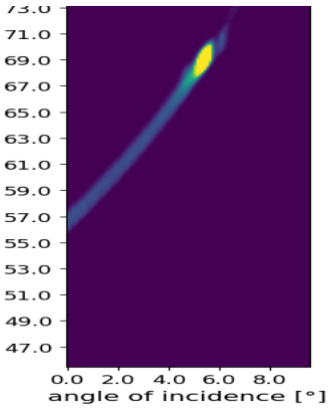

Figure 1: Experimental characterization of a near-infrared guided mode resonance along the first diffraction order of a nonlocal metasurface.

This work was carried out in the Smart Eyewear Lab, a Joint Research Center between EssilorLuxottica and Politecnico di Milano.

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In-plane scattering sustaining metasurface for eye-tracking applications

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In the field of smart eyewear, integration plays a crucial role in the design process, as the final device must be comfortable, lightweight, and easy to wear. One of the key features of these new devices is the ability to track the user's gaze, known as eye-tracking. The state of the art in this area involves illuminating the eye with infrared radiation and collecting the reflected radiation using photodetectors to evaluate the rotation of the eye [1]. One of the challenges in integrating such a system in an eyewear form factor lies in designing compact solutions. Recently, the smart eyewear lab team proposed an eyetracking solution that exploits embedded photodetectors within the frame and directly in contact with the edge of the lens [2]. To improve the signal on the photodetectors, we propose a non-local metasurface (MS) that supports surface lattice resonances (SLRs) to be placed on the surface of the lens. These resonances result from the coupling of Rayleigh anomalies, which determine the in-plane propagating modes, with the resonance of the meta-atoms, which allows us to control the scattering efficiency [3]. By carefully adjusting the geometrical parameters of the meta-atoms, such as their pitch, diameter, and height, we were able to select the spectral range of scattered radiation in the plane to align with the emission spectrum of the near-infrared LED used to illuminate the eye. This selective interaction of the metasurface ensures that its transparency remains above 80% in the visible range, allowing it to be directly placed on the lens and within the user's field of view. The choice of materials for the device was based on their optical properties, for this reasons we explored two possible platforms: a metallic and a dielectric one. While metals can support plasmonic resonances, they are not ideal due to optical losses in the visible spectrum, which would compromise the transparency of the device. On the other hand, high-index dielectrics enable efficient resonances while minimizing losses in the visible spectrum, making it an excellent material for photonic applitactions [4]. The metasurfaces were fabricated using electron-beam lithography, then the material was deposited and removed via a lift-off process. The optical characterization of the device was carried out using a custom optical setup designed specifically to measure the transparency of the metasurface and the intensity of the scattered infrared radiation on the sample plane.

This work was carried out in the Smart Eyewear Lab, a Joint Research Centre between EssilorLuxottica and Politecnico di Milano.

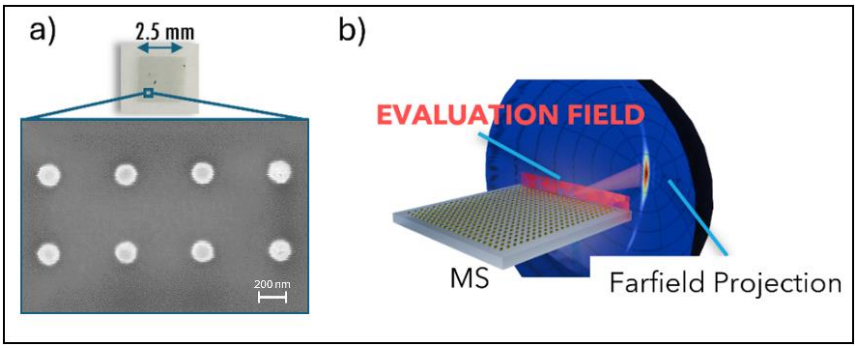

Figure 1: (a) Upper: Metasurface prototype consisting of meta-atoms arranged on a silicon oxide substrate. Lower: Scanning electron microscope (SEM) image of a portion of the metasurface. (b) Schematic representation of the in-plane scattering emitted from the metasurface.

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Nonlinear-nonlocal flat optics for space-time image processing

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In this work, I will present our recent findings on the use of nonlocality and nonlinearity for image processing in space and time. Flat-optics devices exhibiting a linear local (LL) response are defined by a position-dependent linear transfer function $T_{LL}(\mathbf{r})$, which can be locally tailored by engineering metaatoms arranged within metasurfaces. An input signal, defined in real space as $I_w(\mathbf{r})$, is filtered linearly and locally, and transformed into an output $O_w(\mathbf{r})=T_{LL}(\mathbf{r})I_w(\mathbf{r})$. Wavefront engineering is arguably the most prominent application for LL systems [1]. Spatial dispersion, i.e., nonlocality, is usually regarded as a nonideality in LL flat-optics devices. However, the nonlocal response of metasurfaces has been recently indicated as an effective means to achieve advanced functionalities based on the independent control of spectral and angular selectivity [2].

To date, investigations into nonlocality have primarily focused on the linear-optics regime. The action of linear nonlocal (LN) systems is well described by a k-dependent transfer function $T_{NL}(\mathbf{k})$, which describes how the metasurface filters the angular spectrum of an input function, according to $O_w(\mathbf{k})=T_{NL}(\mathbf{k})I_w(\mathbf{k})$. Nonlocal metasurfaces are well suited for analog computing and image processing. For example, n-th order differentiation is easily achieved with transfer functions of type $(jk)^n$, while integration is obtained by synthesizing transfer functions of the type $(jk)^{1/n}$ [3].

Despite the advantages, linear approaches — both local and nonlocal — face limitations related to the restricted numerical aperture and frequency bandwidth, and the inherent linearity of the mathematical operations that one can engineer. Here I show that the combination of nonlinear and nonlocal effects in the same flat-optics device is a powerful strategy to achieve advanced image processing and analog computing functionalities with reduced structural complexity and increased efficiencies in terms of angular and frequency bandwidth [4, 5].

The concept of image processing with nonlinear flat optics is illustrated in figure 1. The input image is a pump field (w_0 in figure 1) with its polarization and space-time structure which impinges on a nonlinear nonlocal thin film. The space-time dependent structure of the generated second harmonic ($2w_0$ in figure 1) is used to extract key features of the input image. By exploring the simple scenario of a uniform thin film, we demonstrate edge detection in space and in time. In our proposed nonlinear flat-optics solution, the non-resonant nature of the nonlinear interaction allows edge detection over a broadband spectrum with ultra–high contrast. Our results indicate that Volterra kernels of nonlinear nonlocal flat optics can open new opportunities in applications such as image processing, item recognition for computer vision, high-contrast and high-resolution microscopy, implementation of nonlinear functions for analog deep learning.

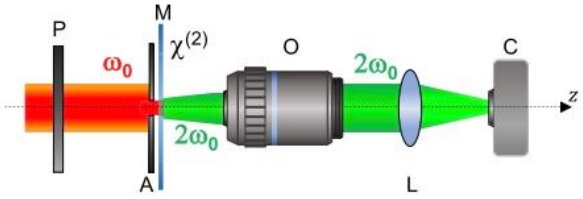

Figure 1: Fig. 1. Setup for image processing with a nonlinear flat-optics element. P (polarizer); A (aperture); M (flat-optics element/metasurface); O (objective); L (lens); C (camera).

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All-dielectric silicon metasurfaces for the generation and manipulation of structured light

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Structured light has revolutionised optical beam shaping, allowing for advanced control over phase, polarization, and orbital angular momentum (OAM). However, the generation and manipulation of non-separable spin–orbit states often relies on bulky and complex optical setups. Metasurfaces overcome these limitations, offering compact, planar devices with complete control of phase and polarization. In this regard, we propose the design, fabrication and characterization of dual-functional metalenses (DFMLs) able to tailor independently right- and left-handed circular polarizations leading to the compact and efficient generation and manipulation of structured beams.

In the first instance, we describe the mathematical expression of DFMLs, and using FEM simulations we numerically extrapolated a look-up table that provides the fundamental building blocks to design and fabricate a DFML. Subsequently, we develop a recipe to fabricate large area (up to 1 inch diameter) all-dielectric silicon metasurfaces by using a 2-step process involving electron beam lithography (EBL) and inductive-coupled plasma reactive ion etching (ICP-RIE). [1] Then, we extend this paradigm to the fabrication of dual-functional meta-doublets fabricated onto the same substrate and nanometrically aligned by exploiting the UV lithography technique.

Different DFMLs generating new types of 2D and 3D structured beams were designed and fabricated. In particular, we show the experimental characterization of double-ring perfect vector beams [2], real OAM-independent perfect vortices, helico-conical vector beams [3], azimuthally variant vector beams [4] and self-accelerating vector beams.

Finally, we present the optical characterization of three fabricated ultracompact dual-functional metadoublets, which enable the muxing and demuxing of scalar and vector beams, as well as the multiplication of orbital angular momentum.

The main objective of the work was the design of tiny high-resolution optics generating and manipulating different structured beams, and simultaneously offering both an improvement in terms of the compactness of optical paths and an easy integration with other optical elements. In particular, the proposed metaoptics are suitable in different fields as telecommunications, imaging, security and quantum applications.

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Reconfigurable Beamforming Metasurfaces for Infrared Beam Steering

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Metasurfaces are emerging as key components for compact and efficient beam-steering and optical control applications. Our research focuses on the design and optimization of tunable metasurfaces including chalcogenide glasses (such as GeSeTe, GeSeSbTe, Se_2S_3, and Se_2Sb_3) as active materials. These materials can dynamically modulate their refractive index in response to external stimuli, including electric fields, temperature changes, or pulsed lasers. By integrating chalcogenide glasses with silicon resonators, we achieve low-loss transmissive pixels capable of a full 0 to π phase shift. Moreover, these glasses exhibit non-volatile switching between amorphous and crystalline states, eliminating the need for additional electronic components, such as thin-film transistors, commonly required in liquid crystal-based devices [1,2]. To optimize the design of these phase-controlling pixels, including all the device elements such as layers including ridges of ITO electrodes, we employed a tailored optimization algorithm with suitable loss functions, ensuring minimal optical losses and high efficiency. We then validated the metasurface's performance by demonstrating its ability to steer a beam at a telecommunications-relevant wavelength of 1550 nm. Our findings highlight the potential of chalcogenide-integrated metasurfaces for next-generation reconfigurable optics and beam-steering applications.

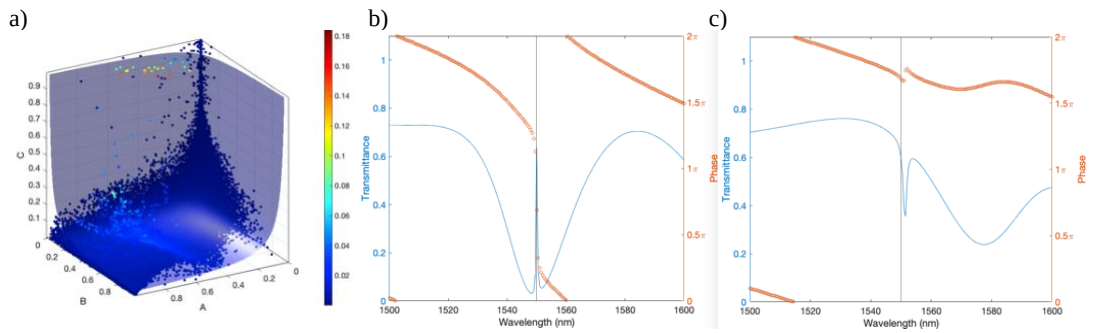

Figure 1: Fig. 1: a) three-dimensional plot of the optimized set of parameters returning the Figure of Merit given by the $fom = \sqrt{(A \cdot B \cdot C)}$ where $C = \left(\frac{\Delta\phi}{\pi}\right)$ and $\Delta\varphi = \frac{angle\left(\frac{T_A}{T_C}\right)^2}{\pi^2}$. b,c) transmittance and phase calculated for a specific set of parameters for amorphous and crystalline GeSeTe, respectively.

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Near-field spectroscopy of photonic crystal cavities with small footprint and high optimized Q-factor

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Photonic crystal (PhC) cavities are the most widespread and versatile devices conceived to confine light to the nanoscale. In particular, 2D photonic nano-cavities on slab represent cutting-edge devices that can strongly localize light at subwavelength scales, enabling the achievement of high quality-factors (Q) [1]. However, an important limitation on the use of these devices is represented by their relatively large spatial dimensions, due to the required multiple periods of 2D PhC around a single cavity to minimize in-plane losses. It has been theoretically demonstrated that it is possible to optimize the Q-factor while maintaining a reduced spatial footprint of the cavity (few rows of PhC around it) by employing an iterative Q-factor optimization gradient-based approach based on first-order non-Hermitian perturbation theory [2-3]. Following this optimization approach, the positions of the individual holes in the PhC were shifted to reduce the in-plane losses; the resulting randomized distribution of holes (Fig. 1a) determines an increase in the Q-factor by up to two orders of magnitude (Fig. 1b). Here, we present the optical characterization of L3 photonic nano-cavities with small footprint (six rows of PhC around it) at different stages of the Q optimization process: an unmodified reference design with Q∼1500 (L3-R6) and two optimized designs characterized by a Q of ∼5000 (L3-R6-I) and ∼10000 (L3-R6-II) were employed to pattern an optically active slab. The cavities were characterized by means of a Scanning Near-Field Microscope (SNOM) used in illumination/collection configuration, where both excitation and signal collection occur through the same near-field probe. Since a spectrum of the sample can be collected for each scan point, we are able to experimentally reconstruct the entire PL map for every studied cavity for a selected wavelength (Fig. 1c); the PL maps are in excellent agreement with the corresponding simulated maps. Moreover, consistently with theoretical predictions, an increase in the experimental Q-factor of one order of magnitude is observed (Fig. 1d). Finally, measuring several nominally identical photonic cavities, we unexpectedly demonstrated that optimized cavities are more robust to fabrication-induced disorder when compared to unoptimized ones, opening intriguing possibilities for applications requiring strict control over the spectral position of the resonances.

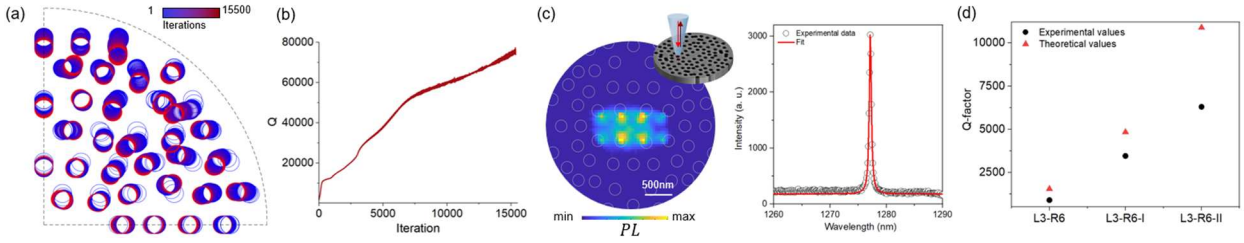

Figure 1: (a) Evolution of the positions of the holes from the initial (blue) to the final configuration (red) due to the optimization process. (b) Evolution of Q of the mode for all the iterations of the optimization process. (c) Near-field SNOM PL map of cavity L3-R6-II (left panel) and an example of a fitted spectrum collected by the tip (right panel). Inset: sketch of the SNOM tip on the sample. (d) Experimentally detected Q-factor values (black circles) and theoretical predictions (red triangles) for the designs studied.

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Tailored Fabrication of 3D Nanopores for Advanced Nanoscale Techniques

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We present two complementary fabrication strategies that enable precise tailoring of nanopores for multiple nanoscale applications. First, we exploit plasmon-enhanced photochemistry to drive the localized, controlled deposition of metals (Au and Ag) onto nanopore arrays, enabling a continuous reduction of nanopore diameters (down to ~4 nm) at a rate of ~1 nm min^{-1}. The resulting plasmonic nanopores feature highly confined electromagnetic fields that not only enhance optical spectroscopies but also optimize the electrical detection of individual entities such as biomolecules and metallic nanoparticles.[1] In a second approach, we demonstrate a robust method to fabricate three-dimensional nanopores made entirely of dielectric oxides (including SiO_2, Al_2O_3, TiO_2, and HfO_2) by combining focused ion beam lithography with atomic layer deposition. This method produces nanopores with precise three-dimensional geometries. Studying three particular cases: concave, convex, and straight wall profiles; we show how our method offers exceptional control over pore geometry, high mechanical stability, and excellent performance in ionic current rectification, memristive behavior, and single-molecule (DNA) sensing. Finally, by incorporating a metallic layer on top of these nanostructures, we demonstrate their performance as plasmonic antennas. Integrating these two complementary strategies, our platform offers unparalleled versatility in engineering nanopore properties across a wide range of scales and functionalities, paving the way for breakthroughs in biosensing, sequencing, and optoelectronic device applications. [2]

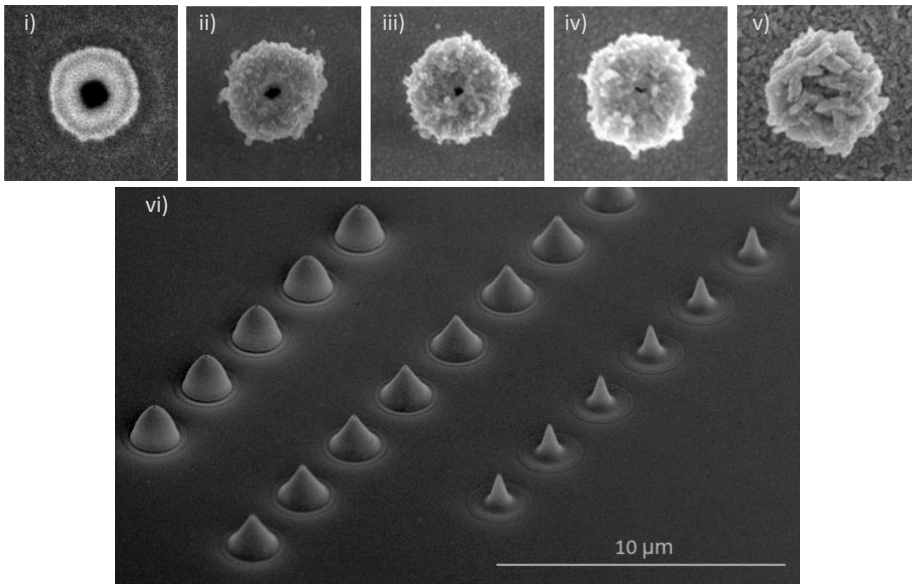

Figure 1: SEM characterization. i-v) Diameter reduction of nanopores due to the deposition of silver guided by plasmonic resonances, stopping the reaction, and imaging every 10-15 minutes. vi) Arrays of conical nanopores with the three geometries studied: convex (left), straight (center) and concave (right).

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Tailoring Thin Film Absorption and Nonlinear Transduction in Thermomechanical Bolometers

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Thermomechanical bolometers (TMBs) are emerging as promising terahertz (THz) uncooled detectors for imaging applications due to their high sensitivity and potential for integration into focal plane arrays. In TMBs the resonance frequency of a resonant micromembrane is monitored, and THz radiation is detected through the thermomechanical effect as a shift of the mechanical resonance frequency. One of the key challenges within this technology lies in enhancing the THz absorption without degrading the mechanical quality of the resonators, in order to ultimately reduce the detector noise. In this work, we investigate the integration of nanostructured carbon-based plasmonic materials such as pyrolyzed carbon (PyC), and THz resonating metamaterials as absorbers on top of silicon nitride mechanical "trampoline" resonators. Additionally, we explore an alternative strategy to enhance signal transduction by leveraging interference and nonlinear response functions, which introduce sharper spectral features while maintaining a constant dissipation rate. By optimizing both the absorber properties and the engineered response curve slope, we demonstrate a significant reduction in the noise-equivalent power (NEP), achieving levels competitive with state-of-the-art uncooled detectors in the sub-THz range. These findings, achieved within the EU ATTRACT "H-CUBE" project, pave the way for high-performance, spectrally tunable bolometers suitable for applications in security, imaging, astrophysics, and biomedical diagnostics.

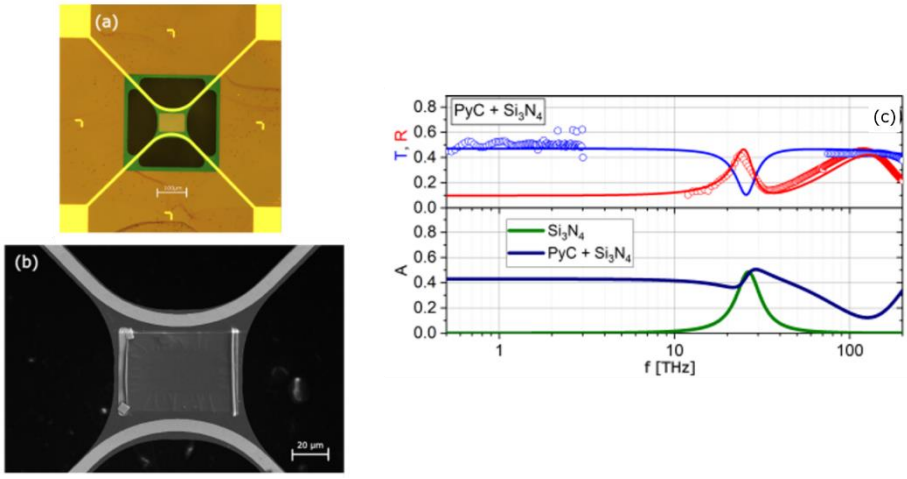

Figure 1: Optical microscope image (a) and scanning electron image (b) of a typical device. (c) Transmission, reflection and absorption spectra for the bare silicon nitride membrane (Si_3N_4) and for the membrane embedding pyrolythic carbon (PyC).

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Plasmonic-induced hot carrier generation for MIR detectors

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The MIR wavelength region is interesting for various applications ranging from medical diagnosis over space observation to high speed data-communication [1]. Therefore, the last decades saw numerous research efforts dedicated to the development of new MIR detectors. While those detector concepts have various and different strengths and weaknesses, all of them either suffer from a rather low time resolution or the need for heavy cooling to suppress thermal noise [2]. Detectors based on new technologies such as plasmonic-induced hot carrier generation have the potential to overcome these obstacles. Their narrow spectral bandwidth makes surface lattice resonances (SLR) resulting from the coupling of Localized surface plasmon resonances (LSPRs) and Rayleigh Anomalies (RA) ideal candidates to overcome those obstacles [3].

Here, we report on the investigation on a group IV plasmonic-induced hot carrier detector in the MIR wavelength range, aiming for a fully CMOS compatible device. The device is based on a plasmonic grating made out of highly doped GeSn and covered with a transparent conduction oxide (TCO). This configuration allows for front sight illumination to reduce optical losses. We use Aluminum doped amorphous Zinc oxide (AZO) as TCO, since the material shows high optical transparency in the MIR region while still having a low resistivity. We discuss results of optical and electrical material characterization obtained from Fourier-Transform Infrared Spectroscopy (FTIR) measurements as well as temperature dependent IV measurements for this material combination. Furthermore, we report on optical simulation and optimization results based on FDTD simulations for the device. We do not only consider geometry optimization of the grating but also discuss potential optimization strategies for the antenna material, which can be realized, e.g., by high in-situ doping, post processing using ion implantation, and flash lamp annealing. We argue that our approach is a promising way to enable fully CMOS compatible MIR detectors with low cooling demand and high time resolution.

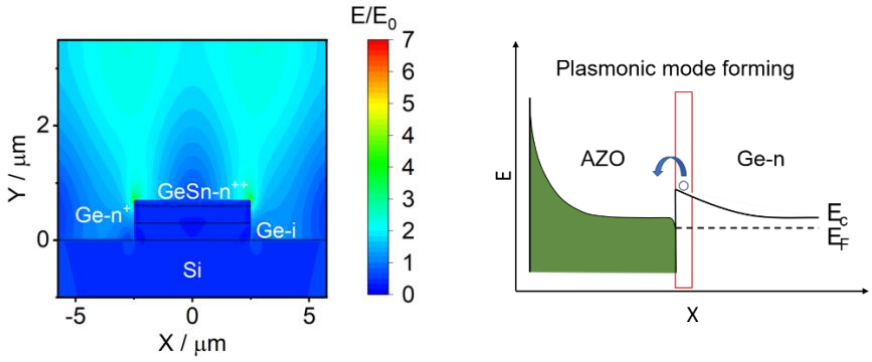

Figure 1: Simulation of the electrical field distribution of a GeSn plasmonic grating antenna (left). Schematic band diagram of the detector with a Schottky barrier between Ge and AZO.

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Excito-Plasmonic Phototransistors with Improved Thermal Management

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Metal nanoparticles (NPs) periodically arranged on two-dimensional (2D) materials are frequently employed to boost local electric fields and light absorption by the 2D material, particularly in photodetectors and light sources. However, this enhancement is often accompanied by significant temperature increases under high optical power. Here, we investigate the potential for a novel phototransistor design that achieves moderate field enhancement while simultaneously providing improved thermal management.

We previously developed a drift-diffusion model and validated it against experimental results to conduct detailed analyses of 2D material-based phototransistors [1]. This model assumed a constant operating temperature. Recently, we extended this model to incorporate local temperature changes arising from Joule heating [2]. After validating the accuracy of this extended model against experimental results found in the literature, we numerically investigate the performance of 2D material-based phototransistors decorated with metal NPs, which we call “excito-plasmonic phototransistors".

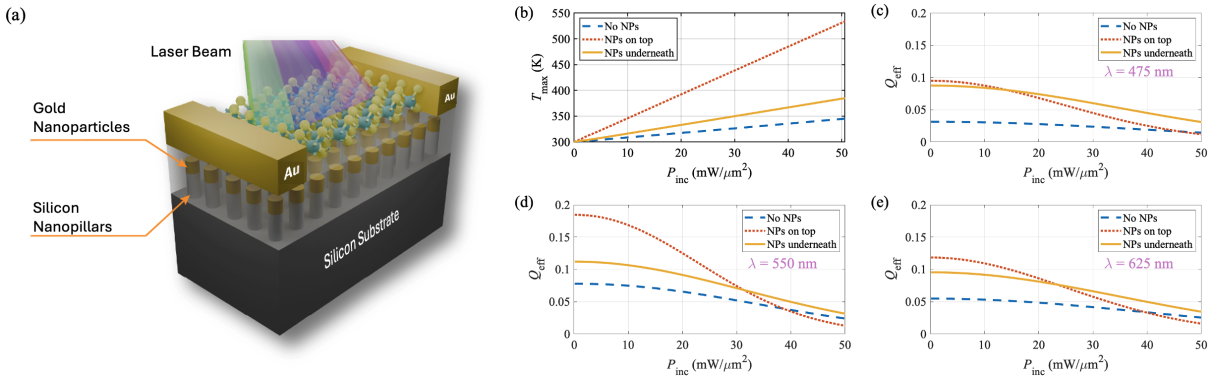

Figure 1: (a) Schematic illustration of an excito-plasmonic phototransistor where NPs are under the monolayer of MoS_2 and on top of silicon nanopillars for more efficient heat dissipation. (b) Maximum temperature for λ = 550 nm and (c)-(e) quantum efficiency for λ = 475, 550, 625 nm, respectively, as a function of input optical power for the phototransistors without NPs (blue dashed curve), with NPs on top (red dotted curve) and NPs underneath (yellow solid curve).

For a proof-of-concept demonstration, we selected monolayer molybdenum disulfide (MoS_2) as our material of choice [4], and we examine the performance variations of 2D material-based bare phototransistors and the ones with NPs placed on top and underneath the MoS_2 layer, as shown in Fig. 1 (a), as functions of incident power and wavelength.

Figure 1 (b) shows the local temperature inside the MoS_2 layer with and without NPs. We observe that the plain phototransistor experiences the weakest heating, and the phototransistor with NPs on top experiences the most substantial heating. In all cases, the induced temperature in monolayer MoS_2 has almost a linear relationship with absorbed power. In Figs. 1 (c)-(e), we plot the quantum efficiency as a function of optical excitation at three wavelengths. We observe that enhancing the local electric field through plasmonic resonances under weak optical excitations leads to increased quantum efficiency. However, as the optical power increases, this field enhancement causes a significant rise in local temperature, ultimately resulting in a substantial drop in the phototransistor’s quantum efficiency. However, placing metal NPs beneath the 2D material and supporting them with silicon nanopillars provides a more efficient heat dissipation mechanism due to the high thermal conductivity of silicon.

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Plasmonics for Energy and Sustainability

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Plasmonic nanomaterials are revolutionizing the way we harness solar energy for a cleaner future. These tiny, engineered materials can efficiently capture sunlight and convert it into fuels, such as hydrogen, through processes like photocatalysis. Additionally, nanomaterials can break down plastics and pollutants, helping to clean the environment while being powered by the sun. This cutting-edge technology paves the way for greener, more sustainable cities. By utilizing knowledge from materials science, energy, photonics, optics, catalysis, and water research, we can design new nanomaterials that harness multiple abilities and rely on the endless energy of the sun to perform their tasks, advancing our dreams of a sustainable world [1-10].

In this talk, I will present examples of different types of plasmonic (hybrid) nanomaterials, including bimetallic and metal-semiconductor systems, and discuss their distinct contributions to key catalytic reactions essential for modern society: hydrogen generation, ethylene production from carbon dioxide, and hydrogen peroxide synthesis, among others. A deep understanding of the underlying physical processes in these systems is crucial for designing next-generation plasmonic-based catalysts. Such insights will help maximize the potential of these systems for sunlight-driven chemical transformations and pave the way for sustainable solutions in the chemical industry and the energy sector. Besides materials design, I will also show recent methodological advances developed in my group in order to maximize the use of sunlight for future solar and energy technologies [1-10].

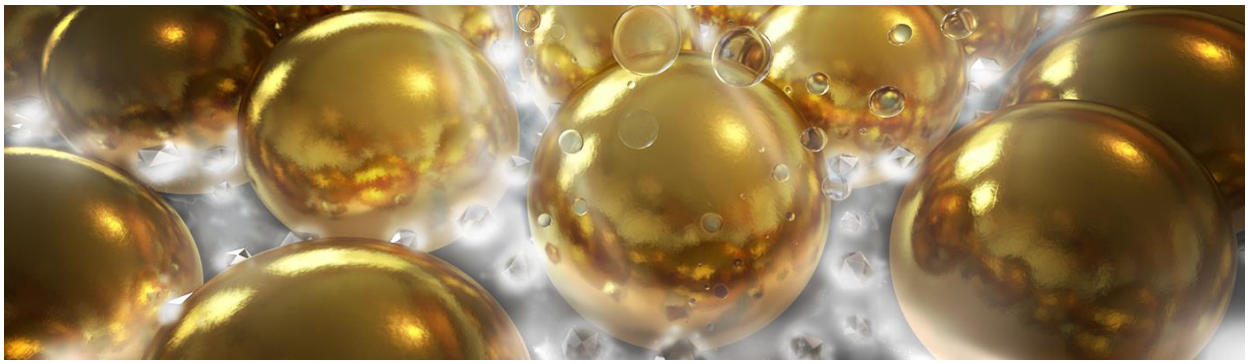

Figure 1: Scheme for a bimetallic plasmonic system recently designed for H_2 production from sunlight [2].

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Detection of anti-SARS CoV-2 antibodies in human serum by Localized Surface States on 1D photonic crystal biochips

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This study introduces the development and characterization of a disposable biochip designed for detecting antibodies against the SARS-CoV-2 spike protein (Fig. 1a), a key target in vaccine and therapeutic research [1]. The biochip is built on a one-dimensional photonic crystal (1DPC) [2] deposited onto a plastic substrate, engineered to support Bloch surface waves (BSW) within the visible spectrum (photonic band structure shown in Fig. 1b). The experimental phase utilized the biochip alongside a custom optical read-out platform, enabling real-time refractometric detection and fluorescence-based end-point measurements (Fig. 1c) [3]. Functionalization of the biochip was achieved by immobilizing the receptor-binding domain of the spike protein onto the surface via a silanization process (Fig. 1d). Human serum samples, including a negative control and a positive sample from a recovered COVID-19 patient, were tested. Results indicate that the biochip successfully differentiates between positive and negative samples in label-free refractometric mode down to a 1:10 serum dilution (Fig. 1e) and in quantum dot-amplified refractometric and fluorescence modes down to a 1:10000 dilution (Fig. 1f). These findings highlight the biochip's potential for highly sensitive and specific detection of COVID-19 antibodies [4].

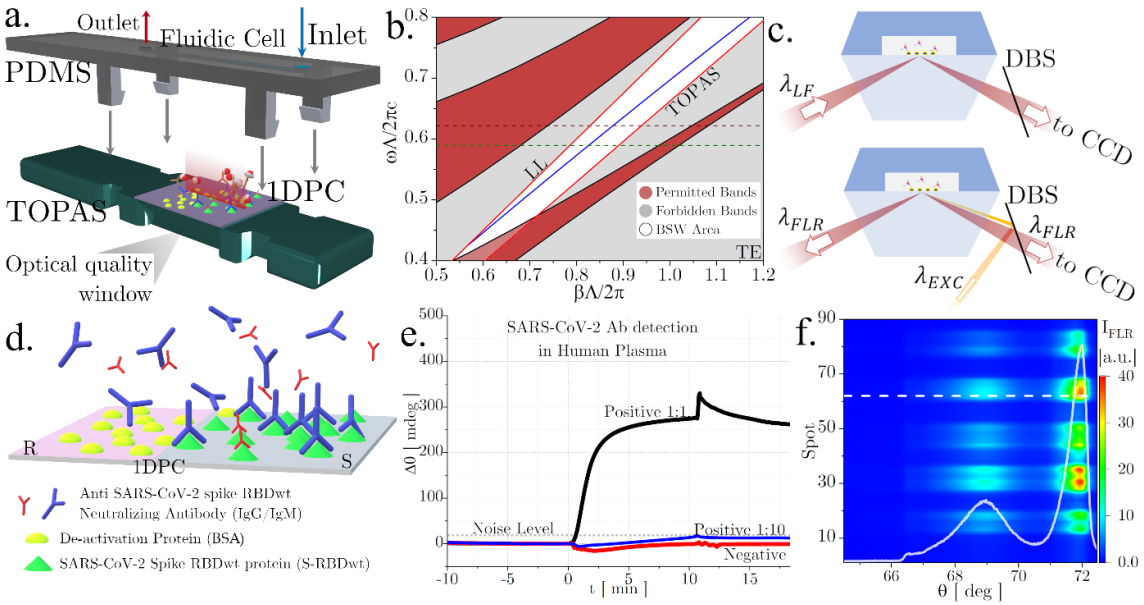

Figure 1. a) Illustration of the disposable biochip alongside its fluidic counterpart. b) TE-polarized photonic band structure of the fabricated 1DPC. c) Schematic of the label-free and fluorescence detection scheme. d) Sketch depicting the biological assay process. e) Label-free sensorgrams for Anti-Spike protein detection in an undiluted and 1:10 diluted positive human sample. f) Fluorescence emission collected from a positive human sample diluted 1:100.

This work was supported by the Italian Ministry of Research under PNRR-Rome Technopole Flagship Project 7 (B83C22002820006).

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Engineering Gold Nanocluster in PEGDA Hydrogel for SERS-based on-site Dimethoate Sensing on Olives

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Hydrogels due to their, three-dimensional polymeric network, offer exceptional properties such as controlled swelling, biocompatibility, tunable porosity, and optical transparency. These features make them ideal candidates for integrating plasmonic nanomaterials and advancing surface-enhanced Raman scattering (SERS) technologies, particularly in applications requiring sensitivity, flexibility, and real-world adaptability. Unlike traditional rigid SERS substrates, hydrogel-based platforms offer the mechanical softness and surface conformability needed for complex sample geometries, such as irregular food surfaces. However, limitations such as slow analyte diffusion and nanoparticle aggregation have historically hampered their performance and reproducibility.
Recent studies have explored both rigid (e.g., Klarite, silicon wafers) and flexible (e.g., paper, cellulose films) SERS substrates for pesticide detection, including dimethoate (DMT), a widely used but hazardous organophosphorus pesticide [1]. While rigid platforms have demonstrated high sensitivity, they often lack adaptability for on-site or in-situ use. On the other hand, flexible systems still rely heavily on laboratory setups or lack reproducibility. Moreover, colloidal approaches, despite their high signal enhancement, present challenges in terms of stability and practical deployment [2]. In this study, we present an innovative SERS substrate composed of gold nanoparticles (AuNPs) embedded within a poly(ethylene glycol) diacrylate (PEGDA) hydrogel matrix [3,4]. This flexible plasmonic system is specifically engineered for real-time, in-situ detection of DMT on olive surfaces. Key to our approach is a novel pre-mixing strategy that significantly improves analyte diffusion within the hydrogel matrix, a challenge in most hydrogel-based sensors. This method ensures uniform distribution and aggregation control of AuNPs, enhancing signal intensity and reproducibility. The system is fabricated via a low-cost UV polymerization method, enabling direct application to food surfaces and facilitating portable field use. The hydrogel-AuNP substrates demonstrated a linear detection range from 0.001 to 100 ppm, with a limit of detection (LOD) of 3.01 ± 0.05 ppb using a laboratory Raman spectrometer and 3.13 ± 0.14 ppb with a portable spectrometer. The system effectively discriminated against DMT from common interfering substances such as RidoMil and Glyphosate, confirming high specificity and selectivity. Our hydrogel-based platform excels in adaptability, sensitivity, and reproducibility compared to existing rigid or colloidal systems. Its flexibility ensures uniform contact with uneven sample surfaces, while the encapsulated AuNPs maintain optimal interparticle distances, avoiding uncontrolled aggregation during use.
This work introduces a robust, flexible, cost-effective plasmonic sensing platform bridging the gap between high-performance SERS detection and real-world applicability.

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Ultra-low frequency Surface Enhanced Raman scattering of CTAB: unveiling its detection and exchange mechanism on gold nanorods

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Surface enhanced Raman scattering (SERS) exploits the local field enhancement induced by the excitation of surface plasmons in plasmonic nanostructures such as gold nanoparticles, to enhance the Raman signal of species lying close to their surface. SERS spectra contain information about the presence of molecules on nanoparticle surfaces and about the chemical structure of these molecules through their position and orientation with respect to the electromagnetic near field [1]. Gold nanorods (AuNRs), a peculiar type of gold nanostructure, can be properly synthesized to have the surface plasmon in the near-infrared, and are usually stabilized by a surfactant called hexadecyltrimethylammonium bromide (CTAB). Although CTAB-capped AuNRs are widely used in biomedical applications (e.g. biosensing), many studies have demonstrated the cytotoxicity of this surfactant, and therefore, the encapsulation of CTAB-AuNRs, or CTAB substitution with alternative molecules is required.

This work investigates the in-situ detection and the structural information of the adsorbed CTAB on AuNRs, and its exchange with other molecules which insert in the bilayer. New and innovative insights are emerging by revealing ultra-low frequency (<100 cm^{-1}) SERS signals of CTAB, with the amplification provided by the adsorption of this molecule to the surface of AuNR.

The CTAB-capped AuNRs are synthesized using a well-known seed-mediated synthesis, with a longitudinal plasmon band centered at 858 nm (Figure 1a). The substitution of CTAB with a small thiolated molecule that strongly binds to the AuNR surface, thiobenzoic acid (TBA), is obtained by simply mixing the suspension with a solution of TBA while stirring. The excitation wavelengths used for SERS measurements of the colloidal suspensions are selected around the AuNR plasmon resonance, using a tunable Ti:Sapphire laser at 860 nm. The existence of an intense low frequency CTAB Raman mode, which to the best of our knowledge has never been detected in literature, is supported in this work by both experimental and theoretical evidence. It was found that the Raman mode results to be greatly enhanced when the molecule is adsorbed on AuNRs surface. The substitution of such surfactant with other molecules, such as TBA, can be followed by the change of the intensity of the CTAB SERS mode, correlates to the change in intensity of the TBA SERS mode (Figure 1b). These findings support SERS as a reliable method to detect CTAB in colloidal suspensions and provide a deeper understanding of the molecular interactions governing molecules exchange on AuNR surfaces.

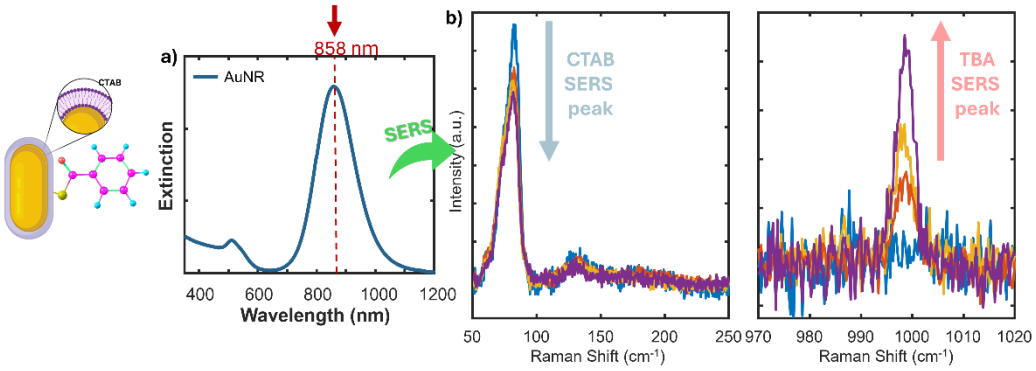

Figure 1: CTAB-AuNR UV-Visible spectrum (a) and SERS intensity variation upon addition of TBA (b).

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Plasmonic Multilayers Metamaterials merging Nitrides, Oxynitrides and Transparent Conductors with Broad and Tunable Properties

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Plasmonics is dominated by noble metals for their high-quality resonances in the VIS, pursuing unprecedented light-matter coupling. However, the impossibility to modulate plasmons in wider spectral ranges (fixed carrier density), has pushed towards alternatives [1]. Transition metal nitrides are appointed as ideal substitutes to conventional metals because of low-cost, thermal stability, CMOS compatibility and modifiable plasmonic responses through VIS-nearIR by stoichiometry [2]. Oxynitrides are appealing as well due to the unique capability to cross twice the zero of the real permittivity ε_1 (double epsilon-near-zero behaviour, DENZ) in a wide spectral range, with activation of new optical phenomena, such as broadband absorption and enhanced non-linearities [3]. Additionally, Transparent Conductive Oxides (TCO, Ta-doped TiO_2 i.e. Ta:TiO_2) are explored for extending plasmonics into the IR by modulating the carrier concentration [1]. In this framework, the quest for uncommon and multiple functionalities to be designed at needs has stimulated the interest towards meta-structures based on alternative materials, suitable for energy conversion, biosensing or nanophotonics. Specifically, Hyperbolic Metamaterials (HMMs) show an anisotropic permittivity $\varepsilon(\omega)$ (parallel $\varepsilon_\parallel$ and perpendicular $\varepsilon_\perp$ to the HMM surface) due to the spatially-periodic alternation of conductors ($\varepsilon_1(\omega)<0$) and dielectrics ($\varepsilon_1(\omega)>0$) [4], which enable unique high-k waves fundamental for unprecedented light confinement.

Here, thin films and multilayers with TiN, TiO_xN_y, and Ta:TiO_2 have been developed in an original, one-step method by Pulsed Laser Deposition, to accomplish unconventional HMMs with exceptional optical tunability form VIS to IR (**Fig.1a-d**). The fundamental advantage is the capability to master stoichiometry and morphology directly at synthesis, by acting on deposition parameters. New TiN/TiO_2 multilayers exhibited a broad hyperbolic response from 600 nm to 2100 nm. TiO_xN_y was optimized to incorporate oxygen while retaining the TiN structure, achieves a tunable DENZ character within 400-1700 nm. Ta:TiO_2 films (compact and porous) synthetized by adjusting the oxygen pressure only, show noticeable modulation of optoelectronic properties, opening towards IR-active HMMs with TCOs. Finally, multilayers mixing TiO_xN_y, and Ta:TiO_2 are promising for achieving unprecedented multiresonant HMMs in one structure, operating both in VIS and IR ranges, for the first time in the field. Such novel HMMs can push the boundaries of nanophotonic research towards broadband, tunable and multifuncitonal plasmonic systems.

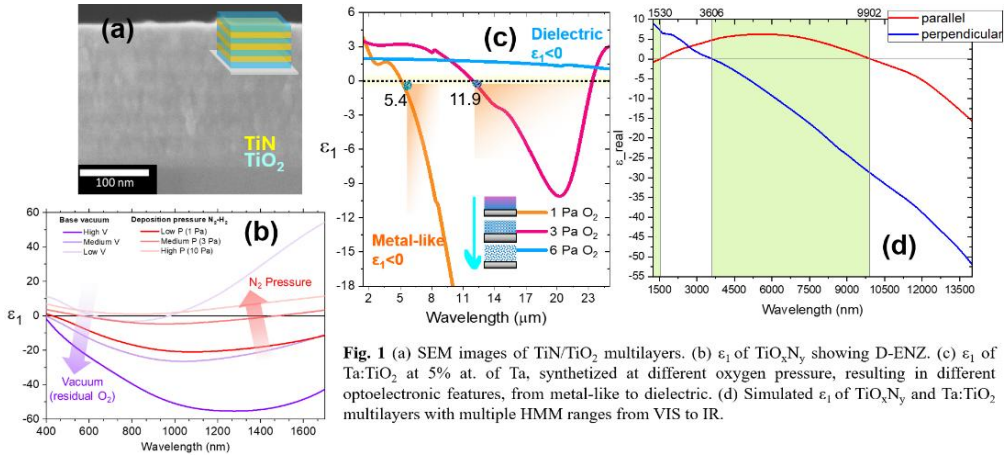

Fig. 1 (a) SEM images of TiN/TiO_2 multilayers. (b) ε_1 of TiO_xN_y showing D-ENZ. (c) ε_1 of Ta:TiO_2 at 5% at. of Ta, synthetized at different oxygen pressure, resulting in different optoelectronic features, from metal-like to dielectric. (d) Simulated ε_1 of TiO_xN_y and Ta:TiO_2 multilayers with multiple HMM ranges from VIS to IR.

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Role of Amorphization in Tuning the Electronic and Plasmonic Structure of Al-doped Zinc Oxide

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Transparent conductive oxides like Al-doped ZnO (AZO) are a class of material that exhibit high optical transparency and low resistivity. AZO shows an interesting tunable plasmonic response in the near-infrared range with an epsilon-near-zero behavior [1]. When these conducting films are grown amorphous, they offer advantages such as an enhanced percolation network for carrier transport and improved mechanical stability. Although amorphous conductors are known, the influence of structural disorder on the electronic and plasmonic properties of the films remains largely unexplored.

In this work, we investigate the impact of structural disorder on the electronic and optical properties of AZO films. We achieve amorphization by growing AZO thin films at a high growth pressure of 100 mTorr while varying Al doping, resulting in films with low electrical resistivity [2]. To understand the impact of reduced structural order, we correlate amorphization with electronic and plasmonic properties using HAXPES, Hall effect, XRD, HRTEM, and optical measurements. XRD analysis indicates a loss of long-range order with increased growth pressure, as confirmed by HRTEM (Fig. 1a, b). HAXPES reveals a significant increase in the density of states near the Fermi level in amorphous AZO compared to polycrystalline, along with notable valence band modifications, consistent with theoretical predictions by DFT (Fig. 1c, d). In order to address the plasmonic response of the AZO films, optical reflection measurements were performed via FTIR spectroscopy (Fig. 1e).

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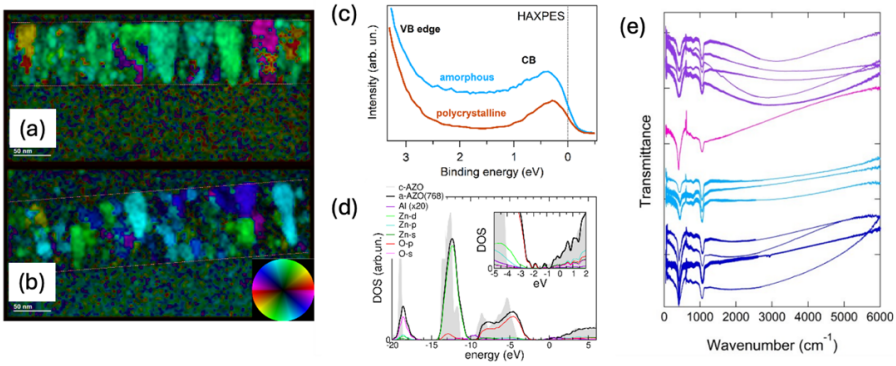

Figure 1: (a,b) FFT analysis of HRTEM images for polycrystalline and amorphous AZO films. (c,d) HAXPES measurements and DFT calculation of DOS and (e) reflectivity of polycrystalline and amorphous AZO films.

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ENZ metamaterials as platform for different applications

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The growing interest in metamaterials stems from their inter-disciplinary applications, ranging from materials science, optics, photonics to industrial and sensing technologies. A key subclass is multilayered metamaterials, especially Epsilon-Near-Zero (ENZ) structures, which stack periodic metal-dielectric layers. Their distinctive optical properties such as enhanced self-collimation, peculiar reflectance and transmittance, and structural color make them invaluable for various applications.

In this work, I present the exploitation of the intriguing features of metal/insulator/metal/insulator (MIM) systems, configured as optical nano-cavity, as a large-scale platform for several applications. By considering the complex refractive index of the involved materials, it is possible to design a multilayer device having the resonances at specific wavelengths across the entire UV-VIS-NIR range. Figure 1a illustrates a schematic representation of a typical MIMI optical nanocavity, while Figure 1b shows that, at resonance, the resonance cone angle is zero, enabling self-canalization of light. This property was exploited to improve the resolution of a standard direct laser lithography system to hyper resolute by realizing complex 2D and 3D flatland geometries [1]. Figure 1c,d present the typical reflectance spectra as a function of insulator thickness and the related color in the CIE 1931 color map [2]. Furthermore, these peculiar structural colors have been utilized for the development of various anticounterfeiting tags [3,4]. Furthermore, MIMI structures can be engineered to exhibit Fano resonances, making it suitable for enhancing SERS [5] performance. Additionally, when combined with polymeric metasurfaces, that produces a high refractive index mismatch, MIM can be exploited as a highly effective sensing device [6].

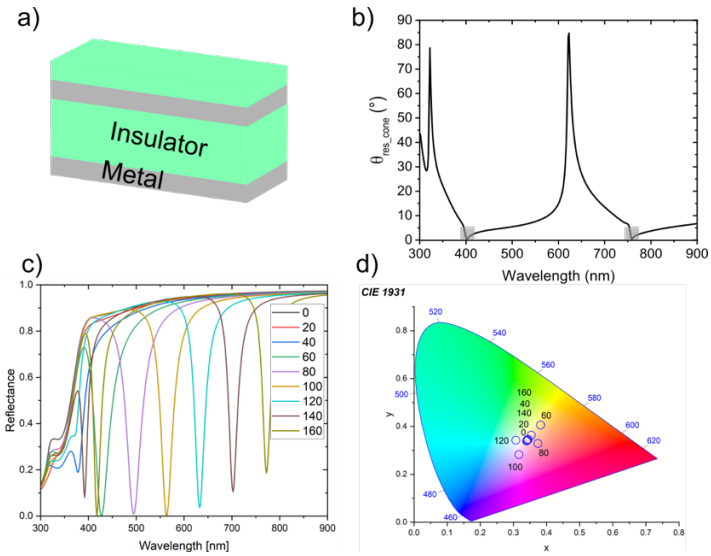

Figure 1: a) Schematic representation of a metal-insulator-metal-insulator (MIMI) multilayer system. b) calculated resonant cone angle of a MIMI [1]. c) Reflection spectra by varying the insulator thickness and d) related color in the CIE map.

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Free-electron optical nonlinearities in heavily doped semiconductors: from fundamentals to integrated photonics

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Heavily doped semiconductors are a promising platform for mid-infrared photonics, offering low optical losses and compatibility with well-established fabrication techniques. Their applications, ranging from ultrafast optical switches (<1 ps) and low-power modulators to reconfigurable photonic circuits, hold promise for advances in sensing, communications, and computing. These exceptional properties arise from free-electron densities on the order of 10^{18}–10^{19} cm^{-3} that can be tuned via doping and enhanced in materials with low effective masses. These materials can be modeled using a hydrodynamic theory (HT) framework, capturing quantum pressure, electron density variations, and convective dynamics to predict nonlocal and nonlinear light-matter responses. Notably, third-order effects such as third-harmonic generation (THG) are significantly enhanced with respect to noble metals due to the lower carrier concentration of heavily doped semiconductors [1]. Recent experiments with InGaAs nanoantennas confirm that hydrodynamic nonlinearities also surpass traditional lattice contributions, boosting THG efficiency [2].

Heavily doped semiconductors also support longitudinal bulk plasmons (LBPs), nonlocal charge density waves satisfying $\varepsilon(\omega,\mathbf{k}) = 0$ that propagate through the material bulk rather than being confined to surfaces like conventional plasmons. Hybrid nanopatch antennas, which couple LBPs with metallic gap plasmons, leverage this property to achieve exceptionally strong free-electron Kerr effects [3]. By employing HT simulations, we reveal optical bistability at ultralow thresholds (1 mW/μm), where Kerr nonlinearities induce a 60% reflectance hysteresis by shifting LBP resonances. The functionality can be futher rnhanced by electrostatic gating, enabling to dynamically tune the plasma wavelength with a sensitivity of 0.89 μm/V and reducing bistability thresholds to 10 μW, paving the way for low-power all-optical nonlinear modulators [4].

These features can also be integrated into waveguides, the backbone of any photonic integrated circuit. Our all-semiconductor waveguide design, consisting of an undoped InGaAs core coupled to a heavily doped semiconductor layer, achieves ultrahigh nonlinear coefficients for long-propagation modes [5]. A Mach-Zehnder interferometer based on this architecture demonstrates 60% transmission modulation as a function of input power, proving the potential of heavily doped semiconductors for on-chip signal processing.

In summary, heavily doped semiconductors combine tunable nonlinear responses, electrostatic control, and foundry compatibility, establishing them as a key platform for mid-infrared photonics.

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Abstracts – Posters

Plasmonic Bioelectric Interfacing

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This abstract introduces a recent label-free microscopy technique developed for high-resolution imaging of electrical signals in living cells. It covers a widefield plasmonic microscopy method that detects small, dynamic voltage changes [1] and maps the electrical properties of cells and biomolecules [2].

Surface plasmon resonance microscopy (SPRM) detects glucose-induced electrical oscillations in pancreatic beta cells at subcellular resolution (<1 μm²). It also tracks synchronized bioelectrical activity across cell network and maps these oscillations in the extracellular space. Furthermore, calcium channel blockers suppress the signals, confirming their biological origin. When paired with graph theory, SPRM quantifies intercellular communication and network structure using metrics like phase relationships. This method offers a powerful way to study functional electrical connectivity in living cells, with strong potential for breakthroughs in bioelectricity.

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[2] Abayzeed, S.A., 2020. Plasmonic-based impedance microspectroscopy of optically heterogeneous

Strong coupling regime of a quasi-bound state in a continuum in a plasmonic nanohole array with broken symmetry

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Abstract: The strong-coupling regime of light-matter interaction is a peculiar situation in which a photonic-like and a matter-like excitation are coupled to form mixed quasiparticles, which share the properties of their constituents. In this work, we report the prediction of chiral optical response in the strong coupling regime, produced by a plasmonic bound state in the continuum (BIC) coupled with an active medium. We consider a gold metasurface with oval nanoholes (Figure 1), which supports a quasi-BIC upon symmetry breaking [1]. We introduce an active medium characterized by the Lorentz model, which allows tuning the oscillator strength to achieve strong coupling between the quasi-BIC mode and the active medium's resonances. These strongly coupled modes - which we name plasmonic polariton BICs - become chiral at a finite angle of incidence, with nearly maximum circular dichroism (CD) in absorption and transmission (Figure 2) [2]. This new type of chiral plasmonic polariton BICs opens up a new approach for studying chiral phenomena in the strong coupling regime of light-matter interaction.

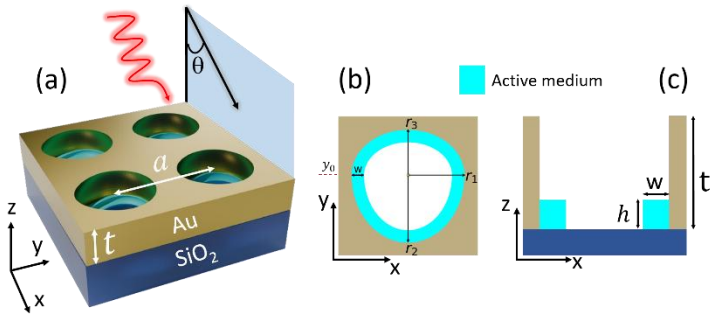

Figure 1: Sketch of the metasurface studied in this work. (a) 3D view: a layer of gold (thickness t = 100 nm) on a glass substrate is etched with a square lattice of air holes (a = 1000 nm), which contain an active medium at the bottom. Light is incident from the top in the xz plane at an angle θ from the normal. (b): 2D view of the unit cell in the xy plane just above the glass, each hole consists of two half-ellipses with a common axis of length $2r_1$ and differing semi-axes r_2, r_3. An active medium is placed in a ring of width w=50 nm inside the nanohole. (c) 2D view of the unit cell in the xz plane (cut at $y=y_0$): the active medium is placed in a layer of height h=10 nm from the bottom of each nanohole.

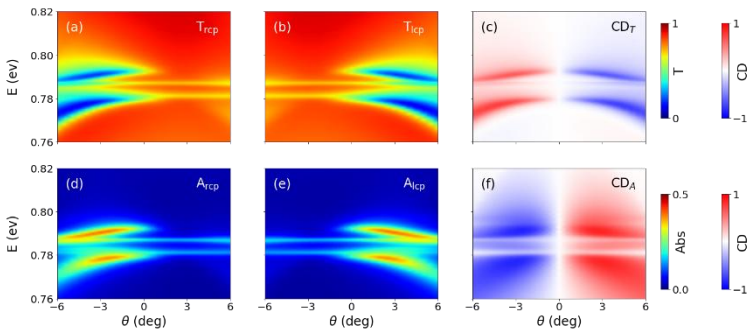

Figure 1: Circularly polarized transmission spectra and related CD (first row), circularly polarized absorption spectra and related CD (second row) as a function of incidence angle. The structure has oval holes with r_1=400nm, r_2=480nm, r_3=320nm containing an active medium in a ring of width w=50nm and height h=10nm, with w_0=0.783 eV and γ= 0.002 for an oscillator strength $f=10f_0$, where $f_0=10^{24}$ m^{-3}.

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Towards plasmon-enhanced photocatalytic efficiency using Cu@Cu_2O core@shell nanoparticles

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Photocatalytic water splitting is a promising approach to produce green hydrogen. Copper oxides have attracted significant attention as photocatalysts due to their visible-range band gap, non-toxicity, earth abundance and favorable band positions for water splitting. However, semiconductor-based systems suffer from low photocatalytic efficiency due to the rapid recombination of the photogenerated electron-hole pairs. The construction of a heterojunction photocatalyst can overcome this challenge by providing spatial charge carrier separation. In this study, we investigated the photocatalytic activity of CuO and Cu_2O. Moreover, we focused on the development of a heterojunction system composed of Cu nanoparticles coated with a Cu_2O shell (Figure 1). This architecture allows energy transfer through multiple pathways, reducing the massive loss of the electron-hole pairs. Furthermore, Cu NPs exhibit a localized surface plasmon resonance (LSPR) peak in the near-infrared region, which extends the solar absorption range of the photocatalytic system (Figure 1). CuO and Cu_2O reference samples, as well as the Cu@Cu_2O core@shell NPs, were grown using molecular beam epitaxy. The growth procedure for all samples was optimized, as the oxidation state is highly dependent on pressure, temperature and oxygen exposure during growth [1]. The surface chemical composition of the samples was monitored via X-ray photoelectron spectroscopy, while UV-Visible absorption spectroscopy was used to study the optical properties. Transmission electron microscopy provided information about the morphology and size of the NPs. The photoelectrochemical measurements confirmed the photodegradation of copper-based systems in aqueous environments. Hence, capping strategies were explored to enhance photostability. Additionally, ultrafast transient absorption spectroscopy studies were performed. The photoexcitation dynamics of the samples was studied by pumping both at the plasmonic resonance and above the band gap of the oxides. The data show evidence for a charge transfer from the metallic core to the oxide shell upon photoexcitation of LSPRs. The observed transfer is promising for achieving PEC systems with broader spectral absorption.

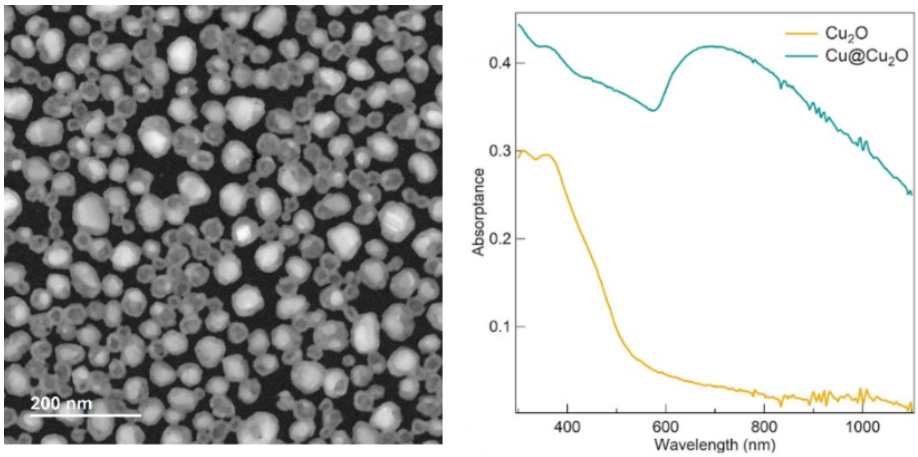

Figure 1: STEM image of Cu@Cu_2O NPs (left); absorptance spectra which highlight the extended absorption range of Cu@Cu_2O compared to Cu_2O alone (right).

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High-Efficiency Metasurfaces for Building-Integrated PV

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The integration of solar panels into urban environments is often hindered by their appearance. While performance has traditionally been the main focus of photovoltaic research, aesthetics play a crucial role in building-integrated photovoltaics (BIPV). Structural color — generated via nanoscale geometrical features rather than pigments — offers a solution: by engineering surface textures, it becomes possible to tune reflected colors while minimizing energy loss due to reflection [1].

This project investigates dielectric metasurfaces applied to the front side of the solar cell. These structures support localized resonances that produce strong backscattering at specific visible wavelengths, enabling vivid color reflection with minimal parasitic loss [2]. In addition, the presence of a non-localized resonant background can be used to shape the angular distribution of the reflected light. This enables the creation of non-symmetric reflection profiles, making color visible from specific viewing directions, while maintaining strong absorption from other angles [3]. Such directional control is key to preserving photovoltaic efficiency in colored devices (see Fig.1a for schematic illustration).

To systematically explore the design space, we simulate reflection spectra across a broad range of geometrical parameters and convert these spectra into perceived colors using standard color matching functions and illumination models. This allows for a direct mapping between geometry and resulting color in RGB space (as shown in Fig.1b). However, brute-force parameter sweeps are inefficient for identifying optimal configurations for specific colors. To overcome this, we implement an inverse design framework combining global and local optimization [4]. The global search is based on the StoGO algorithm, which iteratively subdivides the design space and evaluates promising regions using approximate function landscapes. Promising configurations are then refined through gradient-based local optimization, using automatic differentiation tools (e.g. JAX) to compute sensitivities of a figure of merit with respect to each geometric parameter. Compared to conventional optimization algorithms, this hybrid approach requires significantly fewer simulations, accelerating the design process. It enables metasurfaces to be tailored to user-defined demands, such as maximizing absorption while directionally reflecting a narrowband peak in a specific color range, paving the way for high-efficiency, color-controlled solar panels suitable for real-world applications.

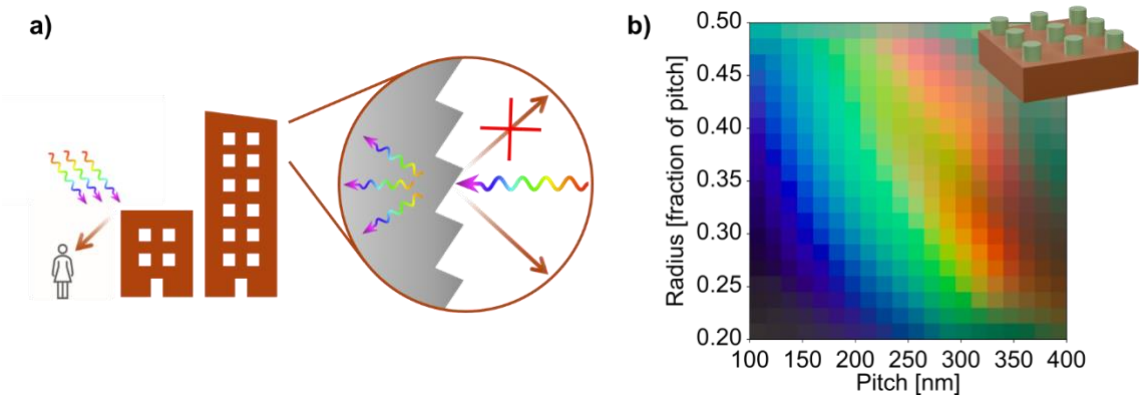

Figure 1: (a) Conceptual illustration of the design goal for BIPV, where only a narrow portion of the visible spectrum is reflected, and only into a limited angular range directed toward an observer. (b) Simulated RGB color map derived from the reflection spectra of a periodic nanopillar metasurface. The color output is shown as a function of pillar pitch (100 – 400 nm) and relative radius (0.2 – 0.5 × pitch).

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Enhancement of plasmonic dichroism by doping and protecting metal nanoclusters, a TDDFT study

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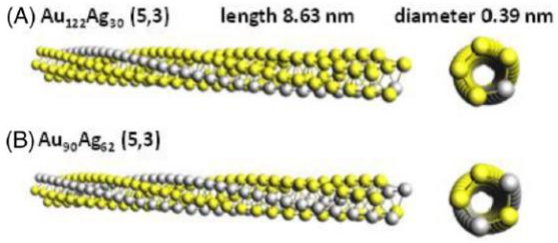
The presence of a strong plasmon resonance in photoabsorption in metal chiral nanowires is not sufficient to observe Electronic Circular Dichroism (ECD) [1]. Analysis using the Individual Component Map – Rotatory Strength (ICM-RS) tool [2] on TDDFT calculations [3] has shown that weak ECD must be ascribed to almost perfect destructive interference in the magnetic dipole contributions in the Rosenfeld equation. This suggested perturbing the system in order to avoid (or at least mitigate) the destructive character and therefore enhance the plasmonic ECD signal.



In previous work, we have shown that 'geometrical curling' [1], as well as doping [4] (Figure 1), are efficient strategies to reduce destructive interference and thus enhance plasmonic ECD.

Figure 1: Structures of plasmonic doped chiral nanowires [4].

In the present work, we explore the possibility of enhancing plasmonic ECD via protection of the metal cluster by suitable ligands, such as simple CO molecules or staple motifs (SCH_3-Au-SCH_3), which are typical ligands for gold and silver clusters (Figure 2).

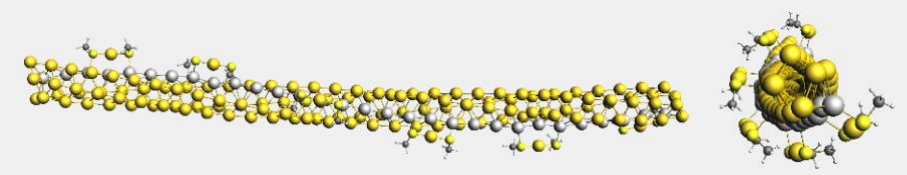


Figure 2: Structure of a doped chiral nanowire protected by staple units.

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Silver Nanowire Based Plasmonic Transparent Electrodes for Optoelectronic Application

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Abstract

Transparent conductive electrodes (TCEs) are essential for optoelectronic applications, requiring a balance between low sheet resistance and high optical transparency. While indium tin oxide (ITO) has been the standard TCE, its high cost and limited indium supply necessitate alternative materials. Among various candidates, silver nanowires (AgNWs) have emerged as a promising replacement.

This study optimizes a three-layer ZnO/AgNW/ZnO (ZAZ) electrode fabricated via spin-coating. The bottom ZnO layer enhances adhesion, while the top ZnO layer reduces AgNW roughness, preventing short circuits. Key fabrication parameters, including spin speed, AgNW concentration, thermal annealing, and pyridine treatment, were systematically optimized. The initial ZAZ electrode exhibited a transmittance of 83.55% and a sheet resistance of 17.90 Ω/sq at 550 nm, compared to ITO's 77.33% transmittance and 6.85 Ω/sq. The figure of merit (FoM) was 9.26×10^{-3} Ω^{-1} for the unmodified ZAZ electrode and 11.16×10^{-3} Ω^{-1} for ITO. Pyridine treatment of the top ZnO layer further enhanced performance, reducing sheet resistance to 13.13 Ω/sq and increasing transmittance to 88.27%, resulting in an FoM of 21.69×10^{-3} Ω^{-1}, surpassing ITO.

We investigated the optical detection of silver nanowires using a standard microscope. The nanowires were easily observable under regular conditions; however, resolution limitations prevented us from distinguishing individual wires in densely packed regions. We have yet to employ a super-resolution microscopy setup to address this limitation. Additionally, we tested the effect of 405 nm excitation light on the sample. When illuminating a large surface area (500×500 μm²), we observed a slight dilation of the images, indicating a temperature-induced expansion due to light absorption. These findings highlight both the capabilities and limitations of our current imaging approach and suggest potential avenues for improving resolution and understanding thermally induced effects in silver nanowires. We find this study particularly interesting, especially in terms of evaluating the impact of silver nanowires—possibly with an intermediate ZnO layer—on photovoltaic performance. To our knowledge, this hasn't been widely explored in the literature, nor has there been clear evidence showing that an electric field from plasmonic resonance could directly influence the active layer.

Atomic force microscopy (AFM) and scanning electron microscopy (SEM) analyses confirmed improved surface morphology, reduced roughness, and enhanced uniformity. Stability tests demonstrated sustained performance for six months under ambient conditions. Integration of the optimized ZAZ electrode into a polymer-based organic solar cell yielded efficiency comparable to ITO-based devices. These findings establish the ZAZ electrode as a high-performance, cost-effective alternative to ITO, offering significant potential for next-generation optoelectronic applications.

Numerical investigation of plasmon-induced field confinement in engineered nanoantenna arrays from long-wave infrared to THz regime

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Over the past few decades, plasmon-enhanced light–matter interactions have attracted growing interest due to their broad potential in fields such as biosensing, medical diagnostics, gas detection, and thermal imaging. Localized surface plasmon resonances (LSPRs) enable strong electromagnetic field confinement at the nanoscale. This field confinement amplifies light–matter interactions, particularly in "hot spots" where optical energy is enhanced [1]. Unlike metals, plasmonic semiconductors offer tunable optical responses and potentially lower energy losses at large wavelengths, making them attractive for next-generation optoelectronic devices specifically in long-wave infrared and far infrared [2] [3].

In this study, we focus on tailoring plasmonic resonances through geometry optimization and material engineering to enhance electric field confinement and optimize device performance across a broad spectral range from long-wave infrared to the terahertz (THz) regime. We use Ansys Lumerical FDTD to optimize parameters such as antenna width, pitch, layer thicknesses, 3D structure, and arrangement as well as material composition. This approach allows us to improve the near field response of the plasmonic antenna for specific applications. We examine the coupling between Rayleigh anomalies (RAs) and localized surface plasmon resonances (LSPRs), which gives rise to surface lattice resonances (SLRs). Targeted applications include plasmonic-induced hot electron generation as well as plasmonic enhanced THz Bio-sensing. Different antennas shapes are investigated and the plasmonic response is tailored either for maximized normal electric field at the antenna surface, which is essential for hot-electron-assisted photodetection, or a highly uniform electric field in the sensing area, which is essential for biosensing. This dual-purpose design framework provides a pathway for application-specific optimization of plasmonic nanostructures.

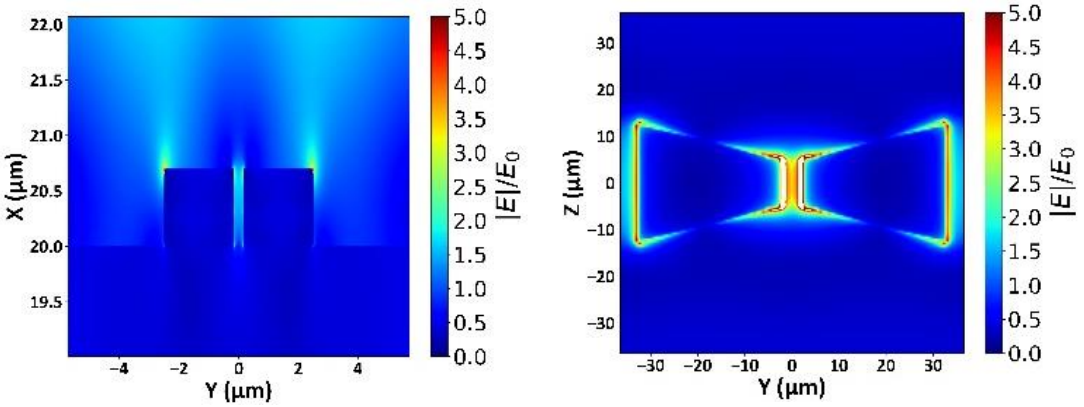

Figure 1: $|E|/E_0$ distribution cross section for Left) Trapezoid bowtie antenna at top side of the antenna and f= 1.1803 THz Right) Double arm antenna at Z=0 and λ=12.601 nm.

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Antenna-enhanced Raman spectroscopy with a 1550 nm laser excitation

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The development of nanodevices with tunable optoelectronic functionalities represents a crucial issue for many applications ranging from communication and energy conversion, to sensing and diagnostics. In this context novel two-dimensional (2D) Transition Metal Dichalcogenide semiconductors (TMD), featuring strong light matter interaction effects, are the ideal playground for a new ultra-compact photonic technology [1,2]. However, the inherent low photon absorption and the poor quantum efficiency of the atomic layers demands for novel photonic schemes that promote strong light coupling to the ultrathin 2D layers over a broadband spectral range. In this context a full understanding of the scattering processes, that could be dependent of the excitation energy, is mandatory. Raman spectroscopy under low-energy excitation represents an optimal technique to inspect the fundamental scattering properties of layered materials, however very weak emission signals are expected.
Here we develop novel hybrid 2D-photonic nanosystems that promote resonant amplification of the weak Raman emission of 2D layers in the Infrared, enabling fundamental study of their unexplored optoelectronic response. We engineer anisotropic plasmonic nanoantenna arrays characterized by ultra-smooth surface by a novel thermal-scanning probe nanolithography approach [3,4], demonstrating the controlled excitation of localized plasmon resonances in the Infrared. By conformal transfer of 2D $MoTe_2$ layers onto the ultra-smooth nanoantennas we achieve hybrid 2D-TMD nanoarrays that have been probed in the Infrared by Raman spectroscopy with excitation at 1550 nm, in resonance with our nanoantennas. By promoting resonant light coupling in the hybrid 2D-plasmonic nanoantennas we enhance the weak Raman signal in the infrared, allowing for measurements with a 1550 nm excitation laser on a few-layer $MoTe_2$ flake.
These results select hybrid 2D-plasmonic nanosystems as a promising configuration for enhancing weak photonic emissions in the Infrared and open the way towards fundamental study of the 2D material properties with Infrared spectroscopies with strong impact in photonic and sensing applications.

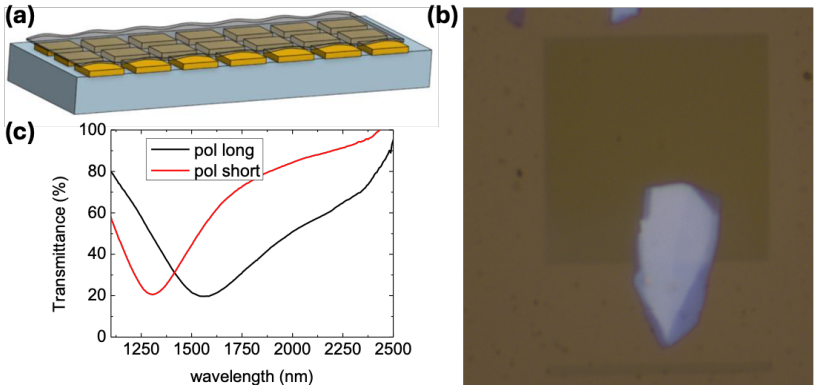

Figure 1: a) Sketch of the hybrid 2D-plasmonic nanoantennas b) Optical image of a few-layer $MoTe_2$ flake placed on the antenna array c) Transmittance spectra of the antenna array for the light polarized parallel either to the long or short axis of the antenna.

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Advanced theoretical models and simulation techniques for nonlocal metasurfaces

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Metasurfaces - i.e. 1D or 2D nanopatterned arrays that can manipulate incident light for tailored functionalities - have been attracting huge interest in recent years, due to their versatility and compatibility with standard fabrication techniques and materials, which makes them desirable to achieve ultrathin flat devices for many possible optical regimes. More specifically, nonlocal metasurfaces, which leverage resonances that are extended over very large portions of the structure, have been intensively studied for a variety of applications where their distinctive features are desirable, such as strong confinement and enhancement of the fields, ultra-high Q-factors, and high spectral selectivity. In particular, they have recently found application as highly-selective diffractive elements for augmented reality and eye-tracking applications in smart eyewear [1-3]. However, the literature is still missing a general and comprehensive approach to study them, which results in the current lack of tools and methodologies for a robust and accurate design of these devices.

In this contribution, we present a thorough theoretical and computational description of optical nonlocal metasurfaces. The analysis focuses on metasurfaces that leverage Guided Mode Resonances (GMRs), i.e. a specific class of Fano-like delocalized resonances that can characterize periodic dielectric structures, known in the literature as a valid alternative to quasi-Bound States in the Continuum (q-BICs) to achieve ultra-high Q-factor and ultra-sharp resonances in the scattering spectrum. Starting with the theoretical study of the physical principles behind GMRs, we implement our own simulation tools, which allow us to accurately describe the optical behaviour of GMR-based metasurfaces. Our simulations consider the influence of all the main opto-geometrical parameters of the system on the optical behaviour of the metasurface, including an assessment of the most important kinds of defects that may be found in actual metasurfaces. Thanks to this knowledge, we successfully design GMR-based nonlocal metasurfaces that achieve the same performances shown by advanced devices recently published in the literature, involving advanced functionalities such as metasurfaces for eye-tracking and augmented reality purposes.

This work was carried out in the Smart Eyewear Lab, a Joint Research Center between EssilorLuxottica and Politecnico di Milano.

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[2] W. Song et al., Large-scale Huygens' metasurfaces for holographic 3D near-eye displays, Laser Photonics Rev., vol. 15 (2021)

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Simulation of plasmonic surface resonance of graphene for detecting physiological tissue

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Sensors play a crucial role in translating physical, chemical, and biological changes into measurable signals, with broad applications in medical diagnostics, food safety, environmental monitoring, and process control. The incorporation of nanomaterials—particularly graphene—has revolutionized sensor performance due to graphene's high surface area, excellent molecular adsorption, and unique electronic properties. However, the influence of biological electrolytes, such as β2-microglobulin, on graphene's conductivity and electronic behaviour remains insufficiently understood [1].

In this work, we explore the electrostatic gating of graphene using electrolyte solutions of varying concentrations and investigate the interaction between β2-microglobulin and graphene. Electrostatic gating, achieved through ionic electrolyte layers, enables efficient modulation of carrier density in two-dimensional materials. We evaluate the shift in graphene's Fermi level and optical conductivity in response to gate voltage and electrolyte characteristics.

Using Surface Plasmon Resonance (SPR) sensing and COMSOL Multiphysics simulations, we demonstrate that β2-microglobulin induces hole doping in graphene, resulting in a Fermi level shift of ~200 meV under applied bias. This doping effect is concentration-dependent, with a 0.1 M solution producing a significant SPR absorption peak shift of ~800 GHz under THz illumination.

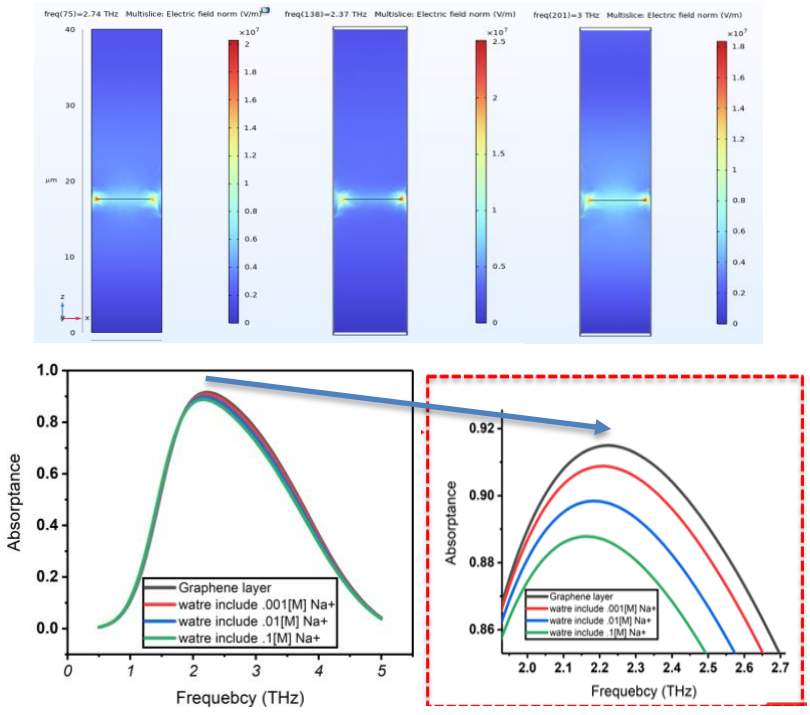

Figure 1: (Top) Electric field distribution on graphene surface for three different frequencies. (Bottom) Absorption spectra of graphene for different concentrations.

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Reducing stitching errors in large-area all-dielectric non-local metasurfaces using multi-pass electron-beam lithography

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The fabrication of defect-free, large-area non-local metasurfaces that seamlessly integrate with existing technologies is critical for the scalable mass production of advanced eyewear systems [1]. In millimetre-scale electron-beam (e-beam) lithography, the need to stitch together multiple write fields (WFs) introduces stochastic errors at WF boundaries due to inaccuracies in the motion of the interferometric laser stage. Stitching errors manifest as feature misalignment and discontinuities, introducing defects into large-area metasurfaces. Multi-pass e-beam exposure strategies have been extensively employed to mitigate errors at WF boundaries by treating stage motion inaccuracies as random statistical variations [2, 3]. In this work, an optimized e-beam double-pass strategy combined with controlled WF shifts is applied to effectively suppress stitching errors in millimetre-scale all-dielectric non-local metasurfaces [4, 5]. The fabricated metasurfaces consist of millimetre-long line arrays with critical feature dimensions down to below 200 nm and pitches between 350 and 1000 nm. This strategy significantly reduces stochastic error accumulation by redistributing it across the entire exposed area and enhances the sharpness of fabricated lines, thereby improving the fidelity and uniformity of large-area metasurface fabrication.

This work was carried out in the Smart Eyewear Lab, a Joint Research Centre between EssilorLuxottica and Politecnico di Milano.

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Quantitative estimation of the linear birefringence of a single-stranded DNA layer exploiting Bloch surface waves

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In a series of recent works, we have discussed how to engineer the top layer of a truncated photonic crystal multilayer to tune the local refractive index and superimpose the dispersion relations of the TE and TM Bloch surface modes over a broad spectral range [1,2]. In this contribution we focus on the quantitative analysis of a recent experiment, in which we sensed the refractometric response of a molecular layer with both the TE and TM modes in order to assess the anisotropy (birefringence) that is a signature of the molecular orientation. Specifically, we follow the growth of single-stranded DNA chains on the sample surface by rolling circle amplification, an enzymatic reaction mediated by polymerase. While standard refractometric sensing typically relies on a calibrated bulk reference and therefore does not provide the absolute value of the refractive index of the thin sensed layer, here we combine the experimental characterization with extensive numerical simulations that allow us to take into account the dependence of the TE and TM sensitivities on the wavelength shift and on the thickness growth, in order to quantitatively assess the birefringence of the DNA effective medium.

This work was partially funded by the European Union – Next Generation EU - PNRR - M4C2, investimento 1.1 - “Fondo PRIN 2022” – “SPIRAL – Lossless surface waves for chiral spectroscopy” – id 2022WFM5MZ – CUP D53D23002400006, by the Gesellschaft für Forschungsförderung Niederösterreich m.b.H. project LS20-014 ASPIS, and by Czech Science Fund (GACR) project APLOMA (22-30456J).

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Fabrication of Silicon-Based Dual Linear Polarizer Exploiting Quasi-Bound States in the Continuum

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Here we present an ultracompact all-dielectric meta-polarizer that converts arbitrary incident polarization into linear polarization. This is achieved through the excitation of symmetry-protected quasi-bound states in the continuum (q-BICs) [1] sustained by a carefully designed silicon on insulator (SOI) nanostructure. The proposed polarizer is made of a silicon-based metasurface where symmetry is broken by varying the width of alternating silicon nanobars in the array [2]. The nanostructure [Figure 1(a)] supports several q-BICs modes, which derive from dark bound modes (BIC) in its symmetric counterpart [Figure 1(b)]. The silicon-based metasurfaces have been fabricated in SOI (145 nm Si device on 2 µm thick SiO_2). The presence of a finite SiO_2 layer in the fabricated samples introduces some additional Fabry-Perot resonances in the spectra, which, however, do not alter the spectral position of the q-BICs. The nanofabrication steps include standard electron-beam lithography (EBL) and subsequent inductively coupled plasma - reactive ion etching (ICP-RIE) step. We will present the transmission spectra from the metasurface that have been simulated and experimentally measured for normal incidence conditions and two orthogonally polarized linear waves for different structural asymmetry [2]. The experimental results are in excellent agreement with the predicted spectra and show how the incoming linear polarization can be selectively suppressed whenever a q-BIC resonance is excited. The slight discrepancy between the theoretical and experimental spectral positions of the resonances can be attributed to deviations in the fabrication profiles with respect to the simulated structures.

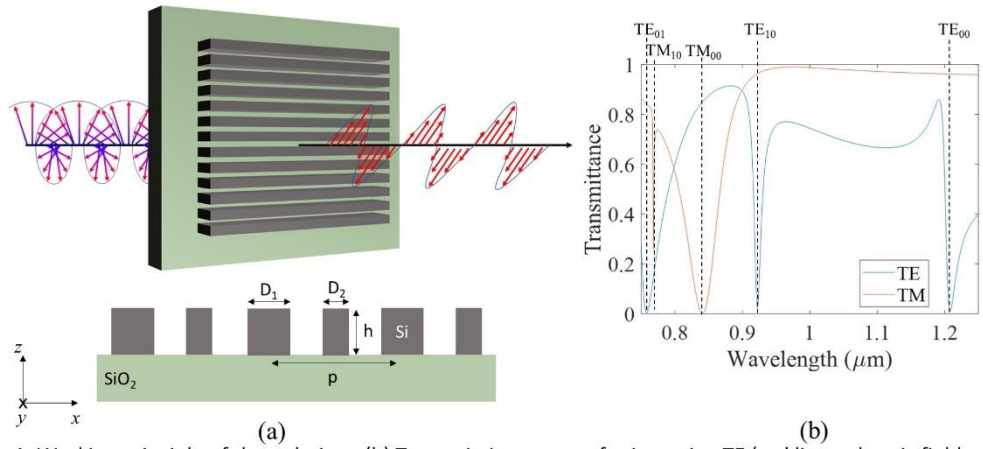

Fig. 1. Working principle of the polarizer; (b) Transmission spectra for incoming TE (red line - electric field oriented along y) and TM (blue line - electric field oriented along x) polarizations for a metasurface with a period p = 500 nm, nanowire widths D1 = 175 nm and D2 = 87.5 nm (corresponding to an asymmetry factor α = 0.5 and a FF= 0.7), and height h = 145 nm.

We acknowledge partial funding from NATO SPS Grant no. G5984, from Ministero dell'Istruzione, dell'Università e della Ricerca (Grant nos. PNRR PE0000023 NQSTI and PRIN Grant no.2022YJ5AZH).

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Optical computing with passive elements for smart eyewear

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In the growing market of smart eyewear devices, the demand for offering consumers an increasing number of functionalities and information has led to a significant rise in the number of integrated biometric sensors and electronic components within eyewear [1]. However, each of these components requires power, and as their number and complexity increase, so does the energy demand of the product. This challenge has directed attention towards reducing energy consumption, especially given the current difficulties in producing lightweight, compact, and durable batteries [2].
In this work, we present several image pre-processing methods using passive optical filters (i.e., filters that do not consume energy), which can be integrated into smart eyewear to support various functionalities, improve energy efficiency, and reduce computational load. Image processing is achieved by selecting specific angular components associated with certain features. For this purpose, an optical metasurface with a transfer function designed to transmit or reflect light based on the angle of incidence is used. When low-angle components are filtered, the image experiences a blur effect, whereas filtering high-angle components results in edge detection effects [3].

Figure 1: (a) Original image whose spatial components have been filtered to obtain an (b) edge detection or (c) blur effect.

By increasing the complexity of the transfer functions, the operations applied to the image can be further refined. For instance, spatial components associated with specific objects can be selectively isolated and suppressed through a shape-selective filter. Additionally, mathematical operations, such as convolution, can be passively executed using appropriately designed filters.

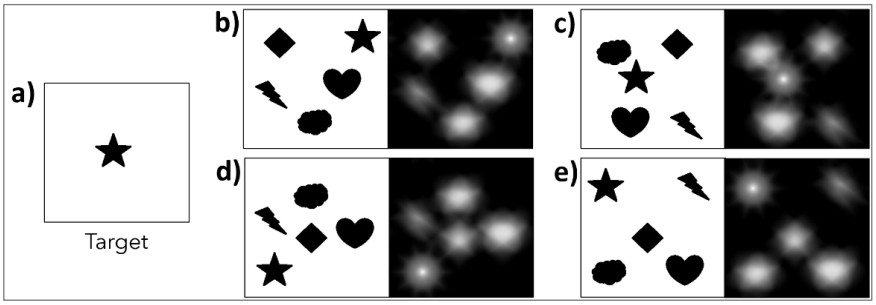

Figure 2: Convolutions of the target image (a) with the sampling images (b-e), where the outputs show a peak corresponding to the spatial location of the target.

This work was carried out in the Smart Eyewear Lab, a Joint Research Centre between EssilorLuxottica and Politecnico di Milano.

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Influence of silicon material on the performance of bioplasmonic structure comprising of gold nanoparticle film

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Abstract: Plasmonics has been utilized as a sensing technique in [1]. Here, the influence of silicon material on the design and performance of prism based bioplasmonic structure comprising of gold metal film (consisting of gold nanoparticles) operating under angular interrogation mode has been investigated using admittance loci method for detection of change in wavelength dependent optical refractive indices of human blood samples [2]. The performance of bioplasmonic structure has been demonstrated theoretically with the help of admittance loci simulations, surface plasmon resonance (SPR) curves, and corresponding sensor performance parameter plots. A bioplasmonic structure can be designed using admittance loci method where the Virtual Reference Plane (VRP) starts from the sample layer and ends at the front surface (prism) of the bioplasmonic structure [3]. Figure 1 shows the schematic diagram of a bioplasmonic structure consisting of silicon prism, gold metal film (consisting of gold nanoparticles) and bio sample (human blood).

Simulated Results: Our simulated admittance loci plots as well as the corresponding data have shown the closeness of real part of end admittance values to the actual refractive indices of silicon prism material, which indicates efficient surface plasmon (SP) excitation. Simulated SPR curves of a silicon prism based bioplasmonic structure for gold nanoparticle sizes of 5 nm and 7 nm at 650 nm and 750 nm wavelengths are shown in Figure 2, which reveals that the bioplasmonic structure using silicon prism material and bigger sized gold nanoparticles displays narrower SPR curves compared to structure using smaller sized gold nanoparticles. Therefore, the use of bigger sized gold nanoparticles is recommended for more accurate SPR sensing. It can also be concluded from our simulated sensitivity plots that sensitivity decreases with increase in wavelength, which recommends operating the bioplasmonic structure at lower wavelength for attaining higher sensitivity [4].

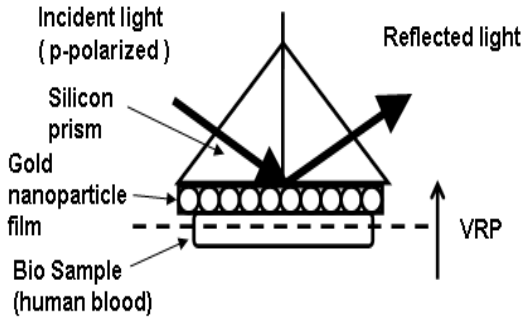

Figure 1: Schematic diagram of a bioplasmonic structure.

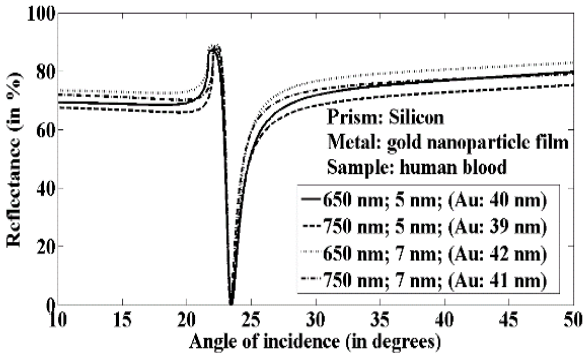

Figure 2: SPR curves.

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Defect complexes and charge compensation in Ta-doped anatase TiO_2 transparent conductor

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Functional materials are at the heart of technological advancements. Among them, transparent conductive oxides (TCOs) combine low electrical resistivity, typical of metals, and high transparency in the visible region, typical of insulators [1]. For this unique characteristic, TCOs are of particular interest for optoelectronic applications spanning from photovoltaic solar cells to flexible and smart devices, and plasmonics [2].

The stability and behavior of point defects and defect complexes in Ta-doped anatase TiO_2 (TaTO) TCO and their effect on its structural, electronic, optical, and transport properties are comprehensively investigated [3] using state-of-the-art first principles simulations based on DFT and experimental measurements under various synthesis conditions. Oxygen vacancies (V_O) and titanium interstitials (Ti_I), which readily form under O-poor conditions, act as intrinsic shallow donors that promote n-type conductivity alongside extrinsic tantalum doping (Ta_{Ti}). While clustering of intrinsic donor defects is irrelevant both energetically and electronically, Ta clustering is inhibited. In contrast, O interstitials (O_I) and, particularly, Ti vacancies (V_{Ti}), which form more easily under O-rich conditions, introduce gap states and behave as deep acceptors, strongly compensating the effect of shallow extrinsic donors. In this scenario, intrinsic acceptors and Ta donors preferentially form neighboring configurations. Since V_O are dominant charge donors in anatase TiO_2, the identification of the Ta doping capability in O-poor conditions is difficult to achieve because the effect of extrinsic dopants (Ta) and intrinsic defects (V_O) concur. To decouple these contributions, we focus on the description of TaTO in the O-rich/Ti-poor synthesis conditions. The interactions between dopants and multiple native defects introduce nonlinear charge-compensation effects, which can reduce the quasi-free charge carriers even in presence of significantly high levels of extrinsic donor doping (N_D = 10^{20}–10^{21} cm^{-3}). This mitigates visible transmittance loss while sustaining and fine-tuning TC properties. More specifically, at least 3 Ta atoms – or 3 Hydrogen interstitial impurities (H_I) – are required to fully compensate the effect of 1 O_I defect, while 5 Ta atoms (or 5 H_I) are needed to fully compensate the effect of 1 V_{Ti} defect or 1 O_I+V_{Ti} cluster and restore the n-type conductor character to the defective TaTO system.

Our findings indicate that: **i.** anatase TaTO necessitate O-poor synthesis conditions or high concentrations of donor defects to maintain low resistivities; **ii.** in O-poor conditions, V_O primarily contributes to the transmittance loss in the visible range; **iii.** in nice agreement with experiment, O_I (or O-rich conditions) allow for nonlinear charge-compensation effects and restores transparency in the entire visible range; **iv.** different compensation effects result in the modulation of the effective injected charge that affects the position of the crossover energy, which can be compared with experiments.

Overall, this work provides valuable insights into the properties of anatase TiO_2 and TaTO as well as defect engineering strategies to optimize these materials for applications in transparent electronics and optoelectronic devices.

L. Bursi acknowledges financial support from project PNRR–M4C2INV1.5, NextGenerationEU-Avviso 32772021 -ECS_00000033-ECOSISTER-spk6.

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Tunable volume plasmon polariton modes in hyperbolic metamaterials based on III-V semiconductors

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Hyperbolic metamaterials (HMMs) have gained particular attention because they allow for the propagation of electromagnetic waves with arbitrarily large wavevectors, which would be evanescent in ordinary materials. These high-k modes, called volume plasmon-polaritons (VPPs), enable advanced applications such as superlenses, sub-wavelength imaging and super-Planckian thermal emission. HMMs are characterized by extreme optical anisotropy, as they behave as metals in one direction and as dielectrics in the perpendicular direction. They are most often realized by alternating layers of metallic and dielectric systems, where plasmonic resonances are used to couple light with the metallic component of the stack. When regular metals are employed, the resulting metamaterials are generally hyperbolically active in the visible-UV range, because of their high electron density. However, HMMs working in the IR-to-THz electromagnetic range would be of great technological interest for applications in infrared optoelectronics. Recent experimental reports [1] have shown the feasibility of fabricating multilayer HMMs working in the infrared spectrum using some III-V semiconductors, where intrinsic and doped compounds serve as dielectric and metallic layers respectively.

In this work [2], we undertake a comprehensive investigation of volume plasmon polaritons within hyperbolic metamaterials. Initially, we integrate ab initio atomistic simulations based on DFT+U and the effective medium approximation to theoretically demonstrate the capability of realizing hyperbolic metamaterials using only III-V semiconductors. The obtained results are in excellent agreement with the experimental findings. However, this approach provides insights only into the first-order VPPs, so we expand beyond the limitations of effective medium theory by employing the scattering matrix method for electrodynamics simulations. This allows us to explore volume plasmon polaritons of higher orders and to predict not only the resonance peaks of transmission and reflectivity but also the electromagnetic field within the metamaterial. Moreover, by leveraging the study of the photonic band structure of the metamaterial, we systematically identify optimal excitation conditions for these resonances, independently of external environmental factors.

Several parameters can be tuned to control the excitation and the spectral characteristics of the high-k resonance modes. For instance, changing the semiconductor doping and/or the filling factor, or incorporating nanoscale structures like quantum wells can all influence the energy and the localization of Volume Plasmon Polaritons. This approach enables an efficient design of hyperbolic metamaterials, allowing one to effectively tune and harness these plasmonic resonances.

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Evaluation of Scattering Efficiency in Large Scale Simulated Optical Metasurfaces

Filippo Coviello,[1,2,*] Vittorio Bonino,[1] Jacopo Stefano Pelli Cresi,[1] Pietro Baldin,[2] Alberto Sivera,[2] Rafael Bellei de Carvalho,[2] Giovanni Isella,[2] Roman Sordan,[2] Gianluca Valentini,[2] Giulio Cerullo,[2] Anna Cesaratto,[1] Tommaso Ongarello,[1] Paolo Biagioni,[2] and Giuseppe Della Valle[2]

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An innovative approach for numerical simulation of large scale metastructures is here presented. The main goals embrace the challenges of simulating finite metasurfaces. Iterations on optical metasurfaces are commonly executed through simulations of periodical, infinite configurations, to reduce the computational cost. These methods are incapable of directly modelling the effects associated with the metastructure boundaries, especially when then signals propagate along the structure extension. These limitations can be overcome by simulating the whole structure, however, with regular metasurfaces being composed of millions of meta-atoms, the computational load is not easily and readily handled by most workstations. The methods presented here allow for an evaluation of the effects associated with finiteness and boundary interactions, providing a more realistic description of the metasurface response and attempting to predict the performance of larger systems without requiring the simulation of the complete final structure.

This work was carried out in the Smart Eyewear Lab, a Joint Research Centre between EssilorLuxottica and Politecnico di Milano.

Tunable Nonlocal 2D Excitonic Metasurfaces

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Optical metasurfaces enable a route towards flat optics where compactness and weight play an important role, or that demand dynamic and multifunctional optical performance. Through the engineering of the compact nanostructure arrays, the optical functionality can be manipulated with the localized control of phase and amplitude of the scattered light. Such design flexibility has sparked a revolution in optics, leading to a wide range of applications such as high-NA lensing, beam steering, light-field imaging and analog computing. A significant advance in the field is the emergence of nonlocal metasurfaces, which harness delocalized collective resonances to obtain high-Q and narrowband resonances and enable strong light-matter interactions while naturally facilitating multifunctionality[1]. The strong delocalization in the system in real space carries an associated localization in the reciprocal space, resulting in highly selective resonances[2], making them ideal candidates for multifunctional optical systems in application areas such as nonlinear photonics, sensing, and augmented reality. Nevertheless, despite these rapid advances, the vast majority of metasurfaces still lack dynamic tunability with their functionality fixed at the moment of fabrication.

To address these limitations, 2D quantum materials offer unique opportunities through their exciton (i.e., electron-hole pairs bounded by Coulomb interactions) resonances. Having the strongest light-matter interactions, these excitons are highly tunable and are even stable at room temperature. Their monolayer state provides an adjustable and robust optical response on an integrable, ultrathin platform. Advances in material synthesis and device fabrication further enhance their potential for practical implementation in nanophotonic systems. These characteristics make TMDC exciton resonances highly attractive candidates for actively tunable metasurfaces. The recent state-of-the-art developments in 2D excitonic metasurfaces have highlighted the vast potential for exploiting exciton tunability for the future course of actively tunable metasurface applications, though current implementations often suffer from low efficiency or operation restricted to cryogenic conditions[3–5].

Here, we combine recent developments in nonlocal metasurfaces with those in excitonic metasurfaces to achieve highly efficient active metasurfaces. In this approach, the guided mode resonances (GMRs), arising from the collective coupling of light into the delocalized modes, plays a key role. They enable sharp spectral features with high-Q factors, allowing us the precise control over the optical functionality, and enhanced light-matter interaction that couples to the monolayer TMDC. In such structure, we can realize the strong coupling of the GMR to the excitons by dressing the nonlocal metasurface structure with a large-area monolayer WS_2. Through their coupling, the excitonic response can be actively tuned, allowing the system to go from the strong coupling regime to the weak coupling regime, as indicated by the system's Rabi splitting. Initially, we explored the temperature tunability of the monolayer WS_2 excitons, using the samples we fabricated with the gold-assisted exfoliation (GAE) method[6]. At each temperature point, we measured both linewidth and peak shifts of the excitons, as this data will be important for the next stages of our work. In parallel, we ran RCWA simulations to adjust the nonlocal metasurface design and fine-tune the GMR features. By overlapping these exciton resonances with the engineered optical modes, we aim to realize high-efficiency dynamic wavefront shaping at room temperature. Our end goal is to realize ultra-thin active optical elements capable of dynamic wavefront shaping, with potential relevance to daily applications such as augmented reality and self-driving cars that uses LIDAR systems.

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Quantum emitter interacting with a dispersive dielectric object: a model based on the modified Langevin noise formalism

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In this work, we model the interaction of a quantum emitter with a finite-size dispersive dielectric object in an unbounded space within the framework of macroscopic quantum electrodynamics [1-2], using the modified Langevin noise formalism [4], without any restrictions on the emitter level structure or dipole operator. The quantized electromagnetic field consists of two contributions: the medium-assisted field, which accounts for the electromagnetic field generated by the noise polarization currents of the dielectric, and the scattering-assisted field, which takes into account the electromagnetic field incoming from infinity and scattered by the dielectric. We show that the emitter couples with two distinct bosonic baths: a medium-assisted bath and a scattering-assisted bath, each characterized by its spectral density. We identify the conditions under which the electromagnetic environment composed of these two baths can be effectively replaced by a single bosonic bath, so that the reduced dynamics of the quantum emitter remain unchanged. In particular, when the initial states of the medium- and scattering-assisted baths are thermal states with the same temperature, we find that a single bosonic bath with a spectral density equal to the sum of the medium-assisted and scattering-assisted spectral densities is equivalent to the original environment.

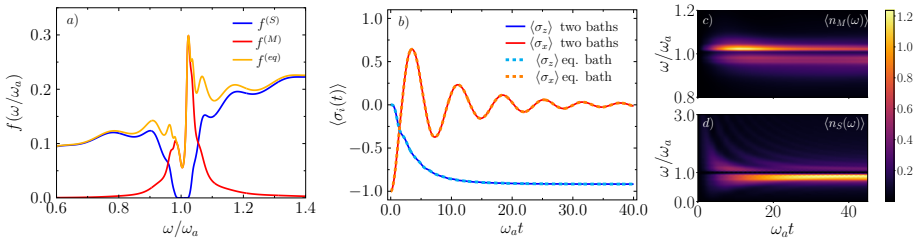

Figure 1: (a) Normalized spectral density of the scattering (*S*), medium (*M*), and equivalent (eq) baths plotted against ω/ω_a. (b) Expectation values of $\hat{\sigma}_x$ and $\hat{\sigma}_z$ plotted versus time. Case i) Solid lines: the emitter couples to the medium and scattering baths, prepared at t = 0 in their vacuum states. Case ii) Dashed lines: the emitter couples to a single equivalent bath with spectral density $\mathcal{J}_{eq} = \mathcal{J}_S + \mathcal{J}_M$, which at t = 0 is in its vacuum state. (c) Expectation values of the occupation numbers of the medium bath modes $\hat{n}^{(M)}_{\omega}$ (c) and of the scattering bath modes $\hat{n}^{(S)}_{\omega}$ (d) plotted versus mode frequency and time.

Fig. 1 presents one-dimensional numerical simulations of a two-level quantum emitter in a lossy dielectric slab for medium and the assisted baths that are initially in the vacuum state. We performed simulations of the evolution of $\rho(t)$ considering the instances of an emitter coupled with: i) two different baths, each described by $\mathcal{J}_M(\omega)$ and $\mathcal{J}_S(\omega)$; ii) a single equivalent bath with $\mathcal{J}_{eq}(\omega)$. For the chosen initial states of the bath, the dynamics of the observables coincide in the two cases, indicating that the influence of the dielectric slab on the reduced dynamics of the emitter can be effectively simulated with a single, equivalent bath. When the baths are in non-equilibrium states, e.g., when the temperatures of baths are different, it is not possible to introduce an equivalent spectral density.

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Nano-imaging of 2D MOS_2 on gold nanostripes by tip-enhanced photo-luminescence

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Abstract: Two-dimensional transition metal dichalcogenides (2D-TMDs) are emerging as a promising class of ultrathin semiconductors, characterized by a bandgap in the range of 1.9–2.4 eV. This property makes them highly appealing as absorbing layers in next-generation photoconversion technologies, including photovoltaics, photocatalysis, and light-harvesting systems.
To ensure their effective integration into such devices, precise and efficient control over their electronic properties is crucial. Nanospectroscopy techniques such as Tip-Enhanced Raman and Photoluminescence Spectroscopies (TERS/TEPL) offer powerful tools for nanoscale characterization [1]. These methods can reveal local variations in film properties and detect subtle structural or chemical changes with nanometric resolution, enabling the study of diffusion processes at interfaces, such as those between the 2D-TMD and its substrate or lateral heterojunctions made combining two different TMD layers [2].
In this work we have analyzed the photoluminescence (PL) emission of a hybrid 2D-plasmonic heterostructures consisting of a single layer MoS_2 flake deposited on top of an array of gold nanostripes. These nanostructures were fabricated via gold evaporation at a glancing angle onto a polymeric nanograting patterned using grayscale thermal-scanning probe lithography [3]. The MoS_2 emission was imaged at the nanoscale by TEPL, giving new insight to the electronic cooperation between the 2D-TMD and the plasmonic nanostructures. The measurements were performed taking advantage of the near-field amplification properties of commercial silver coated AFM tips excited at 638 nm (Figure 1).

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Funding under the National Recovery and Resilience Plan (NRRP), funded by the European Union – NextGeneration EU • Award Number: Project code PE0000021, CUP D33C22001300002 Project title "Network 4 Energy Sustainable Transition – NEST".

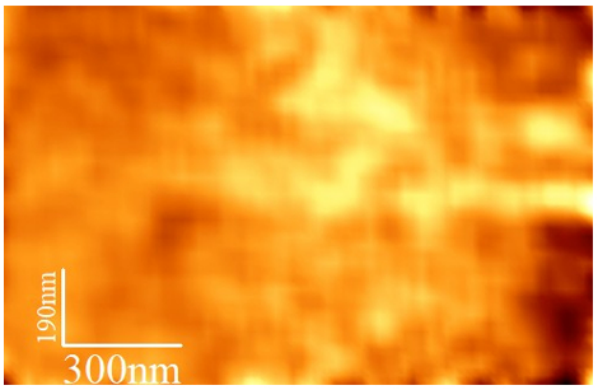

Figure 1: PL nanoimaging of a single layer MoS_2 on top of the plasmonic nanograting.

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Group-IV SiGe material platform: from ultrastrong coupling toward the development of intersubband-based devices

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Among the possible configuration [1], ultra strong light-matter coupling regime can be reached in semiconductor quantum well embedded in sub-wavelength metal-dielectric cavities [2]. Our system is based on a material platform constituted by a stack of 25 $Si_{1-x}Ge_x$ parabolic quantum wells (PQW), grown by ultra-high vacuum chemical vapor deposition (CVD) and remotely doped with electrons. The active stack is then embedded in microcavities of different length (5 - 14 um) by exploiting silicon foundry compatible nanofabrication techniques. The cavity design consists of a metal-insulator-metal resonator structure with a heavily doped semiconductor layer as the bottom mirror and fully etched sidewalls (Fig.1a,b). Here we extend the recently published work [3], showing the achievement of the ultra-strong coupling regime at around 4.1 THz by reducing the PQW width and shrinking the cavity size to extend the frequency range up to 7 THz. Moreover, in this case, the common ground plane was completely removed, allowing spectroscopic characterization to be performed in transmission mode using a dedicated FTIR (Bruker 70v) set up. The spectra at room T for the different cavity size *s* are reported in Fig.1d together with the dispersion plot (Fig.1e) showing that the anti-crossing condition is achieved for *s* = 9 um on the sample with doped PQW. The actual knowledge acquired on the group-IV nonpolar material platform combined with its technology-friendly nature, lays the foundations for the future development of optoelectronic devices operating at THz frequencies based on intersubband transitions, such as quantum cascade detectors [4], which can be integrated into silicon chips. For this purpose, we introduce the preliminary steps of a newly implemented planarization process based on low THz-losses BCB (benzocyclobutene) polymer. The polymer is spin-coated and baked as the cavities surrounding material and then it is removed by reactive ion etching (RIE) in intermediate steps until the level of the PQWs stack is reached. This method allows us to place the metal wires connecting electrically the cavities on top of the BCB-covered area for biasing the devices.

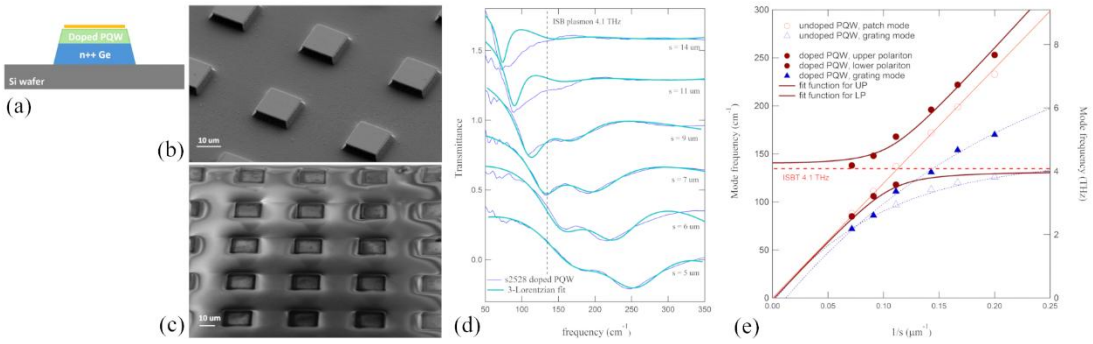

Figure 1: (a) Schematic image of fully etched MIM cavities, and corresponding SEM images without BCB (b) and with BCB (c). (d) Transmittance spectra for different cavity sizes fitted with 3-Lorentzian curve for doped PQW sample. (e) Polariton dispersion plot for doped and undoped PQW samples.

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Amorphous ITO-ZnO mixed oxide-based transparent conducting films for plasmonics

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Amorphous transparent conducting oxides (a-TCOs) are of great interest in next-generation optoelectronic devices because they combine high optical transparency, low electrical resistivity, with higher mechanical strength, absence of grains, and ease of processing [1]. We report the development and comprehensive characterization of amorphous ITO-ZnO mixed oxide-based transparent conducting films designed for plasmonic applications. These films are prepared using the co-sputtering technique at room temperature. Systematic compositional tuning in the mixed oxide optimizes the structural, optical, and electrical properties [2]. The cation ratio (δ) of In/(In + Zn) is varied from 0 to 0.5 in the ITO-ZnO mixed oxide, and the corresponding crystalline structure evolved from polycrystalline to an amorphous-like structure, indicating higher In content favors amorphization. However, a polycrystalline peak for the homologous compound of $Zn_xIn_3O_{3+x}$ is found for δ = 0.13 (Fig. 1a). Comparatively higher Urbach energy value is also obtained for the amorphous-like films (Fig. 1b). The optical measurements reveal high transparency (~80%) in the visible range with tunable optical bandgap (Fig. 1b). The Hall effect measurements indicate that the resistivity value decreased from 6.29 $\times$ 10^{-1} to 8.22 $\times$ 10^{-4} Ω-cm, with an increase in δ value from 0.13 to 0.5, and the corresponding mobility value increased from 13.3 to 27.5 cm^2/V-s, indicating that the amorphization nature is suitable for better electrical properties. X-ray photoelectron spectroscopy provides insight into the chemical states and electronic structure of the mixed oxide. In order to address the plasmonic response of the ITO-ZnO mixed oxide films, optical reflection measurement is performed via FTIR spectroscopy. These optoelectronic properties, combined with the ability to confine light at subwavelength scales, make the amorphous ITO–ZnO films promising for integration into plasmonic devices, including sensors, modulators, and advanced photonic circuits. Overall, this study demonstrates that the compositional and structural engineering of a-TCOs offers a viable pathway for the development of cost-effective and flexible plasmonic materials.

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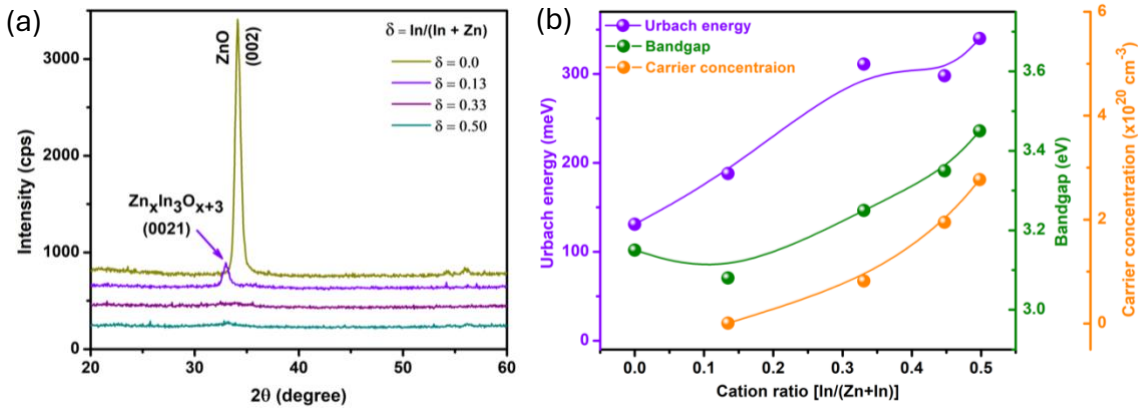

Figure 1: (a) X-ray diffraction patterns and (b) opto-electrical properties of ITO-ZnO mixed oxides for different cation ratios.

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Flat-optics 2D TMD semiconductor heterostructures for large-area photoconversion applications

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Two-dimensional Transition Metal Dichalcogenide semiconductors (2D-TMDs) have recently garnered significant interest due to their exceptional optoelectronic properties in the Visible and Near-Infrared spectrum makes them ideal for photodetection and photoconversion applications. Thanks to their atomically smooth surfaces, combining two TMD layers to form a van der Waals (vdW) heterostructure provides a unique opportunity to engineer the optoelectronic response of 2D devices, with new properties arising from band structure coupling at the junction [1]. However, the inherent low photon absorption of the atomic layers demands for novel light coupling schemes that promote strong light matter interaction within the ultrathin 2D layers. To this end nanofabrication approaches compatible with the fragile 2D materials are required, as well as novel methods that can scale-up the active area of the 2D layers, that is typically limited at the micrometric scale.

In this work the nanoscale reshaping of 2D TMDs layer is shown over large-area (cm^2 scale), demonstrating superior photon harvesting properties in flat-optics media based on large-area TMD layers and heterostructures [2-4]. A novel approach has been developed for the physical growth of large area 2D-TMDs layers via defocused ion beam irradiation. This versatile method has been exploited to grow vertically stacked few-layer MoS_2-WS_2 van der Waals heterostructures integrated into a large-area photoconversion device [5]. As a step forward, flat-optics MoS_2-WS_2 heterostructure nanoarrays have been engineered over large-area by maskless glancing angle physical deposition of the few-layer material onto periodic faceted templates. These flat-optics media can effectively steer the light propagation within the 2D layers thanks to the excitation of Rayleigh photonic anomalies, that can be easily tuned over a broadband Visible and Near-IR spectrum. These photonic anomalies promote a strong in-plane electromagnetic confinement and a broadband enhancement of the photon absorption within the ultrathin the vdW heterostructure layers, up to the 450% as compared to equivalent flat MoS_2/WS_2 heterostructures [6]. These results show the potential of the engineered flat-optics van der Waals heterostructures platforms for different large-area applications ranging from nanophotonics and photoconversion to photocatalysis and energy storage.

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Tailoring Fano lineshape in photonic local density of states by losses engineering

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Non-Hermitian theory in photonics has imposed a major breakthrough in the understanding of optical micro- and nano-resonators and their applications, thanks to the physical insight provided by the underlying concept of their natural resonances, the so-called quasi-normal modes (QNM). In the last decades, a deep revision of the well-known expression for the Purcell factor [1] was proposed, along with consequent counterintuitive effects, such as complex modal volumes and non-Lorentzian local density of states (LDOS) of QNMs with Fano lineshapes [2,3]. While in quantum mechanics the common picture predicts that Fano resonances are related to the interference between the probability amplitudes of absorption in the continuum states and the one of absorption in the bound states, in peculiar photonic and plasmonic resonators Fano lineshapes arises from QNM normalization through the introduction of complex modal volume. Here, by developing an analytical model based on the role of leaky modes in the QNM normalization, we shed light on the interplay between resonant and leaky modes in a photonic crystal cavity (PhCC) [3]. The analytical model is based on the assumption that the QNM of a high-Q photonic cavity, after the introduction of a certain amount of losses, can be considered as a new QNM state which is the result of the hybridization between the initial high-Q state and a continuum state, determined by the leaky modes propagating out of the cavity. Indeed, we demonstrate through Finite Difference Time Domain (FDTD) simulations that the LDOS of a leaky PhCC (Q=200, sketch in the inset o Fig.1a) does not have a unique lineshape; as a matter of fact it changes, with strong variations at the nanoscale, from being lorentzian at the center of the cavity (Fig.1a) to a Fano profile inside the photonic crystal rows (Fig.1b). The possibility of tailoring the LDOS Fano lineshape would allow to mold the Purcell radiative lifetime [1] of an emitter in resonance with the QNM by engineering the LDOS. However, in order to detect a Fano lineshape of the LDOS inside the cavity one should increase the contribution of the losses so high such that the Q-factor would be too low to be considered for any application and experimental demonstration. We therefore propose the design of an L3 PhCC modified by losses engineering (Fig.1c), exhibiting an LDOS with Fano character inside the cavity itself, as a proof of principle. Fano lineshapes with different degrees of asymmetry can be obtained within the same cavity (Fig.1d) for similar values of the Q-factor [3], showing that Fano asymmetry can be tailored in moderately lossy systems. Our results shed light on the physical mechanisms underlying well known photonic features of the state-of-the-art devices for light confinement, i.e. PhC cavities, and might contribute for their practical exploitations in several fields such as quantum devices, optical switching and sensing applications.

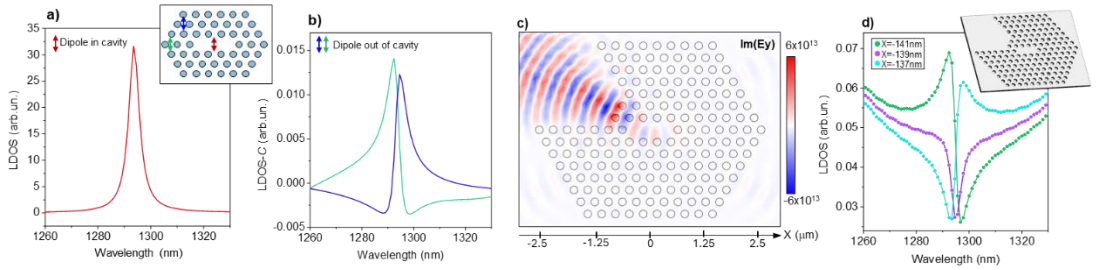

Figure 1: (a) FDTD LDOS spectrum for an L3 PhCC (sketched in the inset), calculated by positioning the dipole in the center of the cavity (red arrow). (b) Resonant LDOS for dipole in two positions out of the cavity (green arrow and dark blue arrow). (c) Design of the engineered L3 cavity with the plot of the imaginary part of the electric field y component of the ground state. (d) LDOS of the engineered L3 calculated positioning the dipole in three positions (green, purple and cyan dots) showing Fano profiles with different characters inside the cavity.

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Scalable Nanophotonics: Revolutionizing Optical Components with Advanced Coatings & Metasurfaces

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Shaping the Future of Light Manipulation. Metasurfaces and photonic integrated circuits are redefining imaging, display systems, sensing, and communication by enabling unprecedented control over light at sub-wavelength scales. As material and fabrication innovations progress, these technologies will replace traditional optics, unlocking ultra-compact lenses, transparent holographic displays, high-efficiency filters, and ultra-sensitive medical sensors.

SOLNIL: Pioneering High-Performance Thin Film Coatings and 3D nano-photonic devices. SOLNIL pushes the boundaries of material engineering with sol-gel chemistry and liquid deposition of metal oxides, achieving record-breaking optical properties—TiO_2 (n = 2.6) and SiO_2 (n = 1.12). Using scalable spin- and dip-coating techniques at ambient conditions, SOLNIL enables wafer-level manufacturing of customizable photonic components for visible spectrum applications.

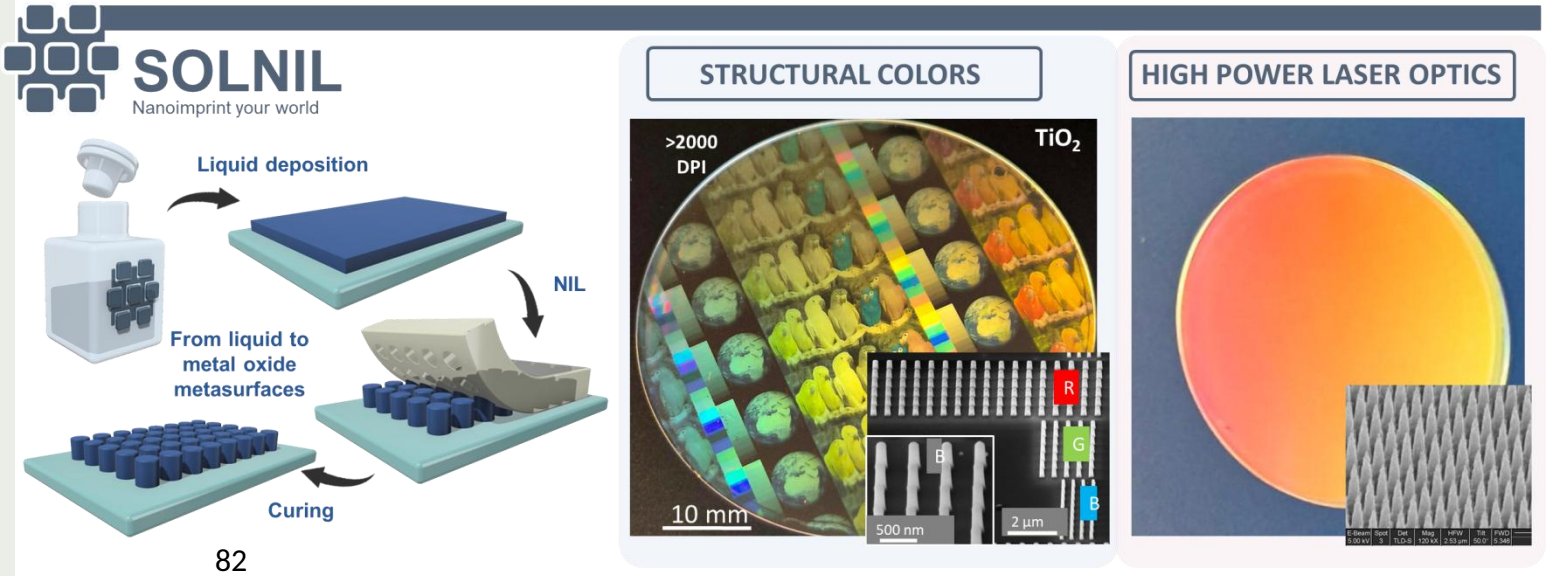
We will cover the fundamentals of sol-gel dip-coating and direct nanoimprint lithography for metal oxides (like SiO_2, TiO_2, and ZrO_2). Next, we will highlight our recent advancements, including the fabrication of both ordered and disordered optical metasurfaces, structural color generation, anti-reflection coatings on flat and curved surfaces, refractive index sensing, light emission, and improved light extraction. Finally, we will show the scalability of this technology to 200 mm wafers on silicon and glass, enabling high-throughput production of complex nanostructures for next-generation photonic applications.

Our breakthrough approach is set to transform optical technologies, making next-generation photonics more accessible than ever.

Presentation Highlights:

- **Sol-Gel & Nanoimprint Lithography** – Scalable deposition of metal oxides (e.g. SiO_2, TiO_2, ZrO_2).
- **Advanced Metasurfaces** – Structural color, anti-reflection coatings, light emission & extraction.
- **Large-Scale Integration** – High-throughput fabrication of nano-photonic devices on 200 mm wafers.

Figure 1: Left: scheme of the liquid deposition process based on sol-gel chemistry and the nano-imprint lithography method (NIL). Right: examples of 3D structures obtained by printing TiO_2 and SiO_2.



Titanium Oxynitride and Vanadium Dioxide Thin Films and Multilayers for Solar and IR Light Absorption

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Engineering the absorption spectrum for specific applications, such as solar energy harvesting and energy-efficient buildings, has become crucial. A low-cost and effective approach involves employing novel plasmonic materials as electromagnetic (EM) absorbers with tunable optical properties in the desired spectral region [1-2]. Titanium oxynitride (TiON) and vanadium dioxide (VO_2) are promising alternatives, investigated as broadband absorbers in the VIS-NIR and IR regions, respectively [1-3]. The plasmonic resonance of TiON in the optical range can be intrinsically tailored at the synthesis stage by controlling its oxygen content [1]. Conversely, the plasmonic response of VO_2 is dynamically triggered by an external heating source, inducing its insulator-to-metal transition (IMT) in the NIR region [2]. Further modulation of EM absorption can be achieved through nanostructuring (e.g., forming nanoporous thin films) or by designing multilayer (ML) structures with alternating metal-insulator materials [1,3].

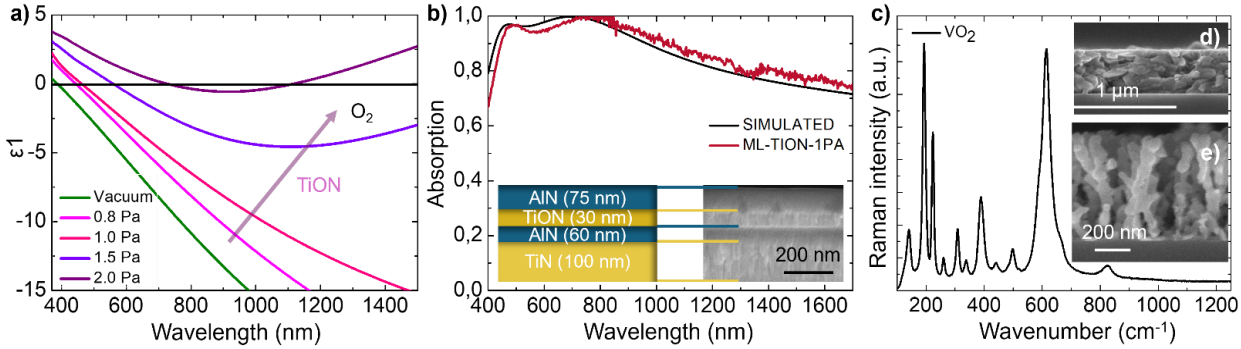

Figure 1: (a) Real permittivity of compact TiN and TiON thin films. (b) Simulated and experimental absorption of an ML TiON structure. (c) Raman spectrum of nanoporous VO_2 thin film. (d) and (e) SEM images of compact and nanoporous VO_2 thin films.

In this work, compact and nanocrystalline 200 nm thick TiON thin films were deposited by pulsed laser deposition (PLD) ablating a TiN target in a slightly increasing oxygen deposition pressure (from 0.8 to 2 Pa) and fully characterized from an optical and structural point of view. Additionally, a TiN thin film in a vacuum atmosphere was produced as a reference. Concerning TiON optical properties, retrieved from ellipsometric measurements reported in Fig. 1a, it can be observed that the real permittivity (ε_1) shifts to higher wavelengths as the O pressure increases. Furthermore, the sample deposited at 2 Pa crosses the zero line twice, exhibiting the peculiar double-epsilon near zero behaviour. To investigate TiON absorbing properties, a free nanopatterned ML structure, composed of TiN-AlN-TiON1PA-AlN, was realized by PLD. The ML exhibits near-unity absorption in the VIS region, with two maxima at 487 and 780 nm due to cavity resonance effects (Fig. 1b). The absorption in function of thickness was optimized through the Transfer Matrix Method.

Finally, we show a compact VO_2 thin film produced by PLD from a VO_2 target at 2 Pa of O_2, followed by vacuum annealing (Fig. 1d). Additionally, to the best of our knowledge, a nanoporous VO_2 thin film (Fig. 1e) at 50 Pa of Ar was obtained for the first time using this deposition technique. The crystalline phase was confirmed by Raman spectroscopy (Fig. 1c).

To conclude, this work paves the way for the development of absorbing devices based on TiON in the VIS-NIR range for solar energy applications, such as thermophotovoltaics. Moreover, it poses the basis for the optical investigations of nanostructured VO_2 thin films produced by PLD, aiming to actively control IR absorption.

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Anticancer and acute toxicity studies of cellulose–coated vanadium oxide nanomaterials

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In the present research work, a facile hydrothermal method has been used for the preparation of pristine and cellulose-coated Vanadium oxide (V_2O_5) nanoparticles (NPs). The as-synthesized nanostructures were characterized using XRD, SEM, UV-Vis, PL, DLS, Raman, and FTIR spectroscopy. The crystallite size of the bare V_20_5 NPs calculated using XRD analysis was-19 nm, which was reduced to 16 nm after cellulose functionalization. TEM micrographs revealed the formation of spherical shape NPs with sizes 21 ±4.9 nm and 16.5 ±4.4 nm for V_2O_5 and cellulose - V_2O_5 respectively. Cellulose-coated Vanadium oxide NPs have shown anticancer potential against the liver cancer cell line (HuH-7.0). Cell viability of V_2O_5 displayed the ICso value of 102.182 µg/ml., compared to the coated Vanadium oxide, which was 49.402 µg/mL. In vivo toxicity studies were conducted using healthy albino rats. Pathological parameters indicate acute toxicity due to cellulose-coated Vanadium oxide NPs. The histopathology of cellulose V_2O_5 NPs treated livers indicates the swelling in hepatocytes and compressed sinusoidal spaces.

Calculating free-electron nonlinearities in nonclassical plasmonic heavily doped semiconductor systems

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Abstract: Free-electron dynamics have a substantial contribution to the optical nonlinearity in heavily doped semiconductor systems. We applied both frequency- and time-domain approaches based on the finite-element method to explore a significant third-harmonic generation and optical Kerr bistability.

Understanding the nonlinear light-matter interaction at the nanoscale has been a long-standing fundamental target since it guides the design rule for minimized and integrated nonlinear photonic devices. Achieving a strong and ultrafast nonlinear optical response is essential for various fields such as optical information processing and artificial intelligence training. Yet, efficiently manipulating light with light is still challenging, leading to an urgent demand of exploring new physics for higher nonlinear interactions.

Free electrons in plasmonic structures can provide extra degrees of freedom in modulating nonlinearities in the system when the spatial nonlocality is considered. The hydrodynamic model reveals that the third-order nonlinearity due to the free electrons could even be orders of magnitude higher than that of the conventional bulk susceptibility when the equilibrium density is low. To reveal the hydrodynamic contribution of the optical nonlinearity in Drude material, we calculated the third-harmonic generation coefficients by numerically solving the hydrodynamic equations coupled with the Maxwell equation and compared them with the experiments [1]. A Thomas-Fermi level approximation is considered for quantum pressure. Linear and nonlinear responses of each field harmonic are solved individually with undepleted pump approximation. The results prove the existence and domination of the nonlinearity from the free-electron dynamics as a surface contribution over the conventional bulk susceptibility.

Kerr nonlinearity is a third-order process that supports fascinating phenomena such as optical bistability and self-focusing. A high optical Kerr nonlinearity at the nanoscale is a crucial element in ultrafast optical neuromorphic computation devices as it can enable all-optical nonlinear activation functions. Employing a time-domain simulation within a finite-element framework, we could apply a beam-envelope approach to efficiently and self-consistently solve electromagnetic wave equation and hydrodynamic formalism with Kerr nonlinear contributions [2-3]. With such a beam-envelope approach, a time step as large as 300 times of period of light could be reached for a convergent result. The solution of the nonlinear sources from the previous time step was used for computing the field at the current step for computational stabilization. We show that heavily doped semiconductor structures can provide giant free-electron Kerr nonlinearities supported by the longitudinal bulk plasmon mode. This high nonlinearity originates from the multibody properties of the free electron gas as the electron-electron interaction can be naturally taken into account in the hydrodynamic theory when proper kinetic energy functionals are considered.

The authors acknowledge funding from the European Union's Horizon Europe Research and Innovation Program (Grant Agreement No. 101046329).

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Plasmon-Assisted Lithium-Ions Capture in LiAl-LDHs

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Abstract: The growing demand for lithium has recently prompted the exploration of advanced materials with tailored ion selectivity and enhanced reaction kinetic to further lower the price of lithium recovery. Industrially, lithium is mainly obtained through the utilization of evaporation ponds, but unfortunately, this is a highly time-consuming process, polluting, it relies on atmospheric conditions, and is thus expensive. In this work we prepared nanostructures combining gold nanoparticles and lithium-aluminium layered double hydroxides (LiAl-LDHs). In these structures the gold nanoparticles are used as photo-heaters to adsorb visible light and then locally increase the temperature of the LiAl-LDHs material that is responsible for the Li capture. The nanoparticles are colloidally synthesized, while the LiAl-LDHs is synthesized via coprecipitation. Experimental results indicate that LiAl-LDH forms more rapidly under illumination. The structures have been synthesized and then characterized with SEM, XPS, and XRD, while the quantification of lithium was mainly quantified via ICP.

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Excitation of FF-SH Surface Plasmon Polariton Waves by femtosecond pulses at metal-nonlinear medium interfaces

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We investigate the generation of Surface Plasmon Polariton waves (SPP) by ultrashort laser pulses by means of prism and grating coupling [1] methods. Moreover, until now the generation of SPP was mainly efficient in the IR spectral band, where the light absorption is somehow low and the propagation might extend for hundreds of microns or even millimeters. Visible light propagation instead is strongly reduced by the metallic absorption. Here we show that the use a nonlinear substrate allows a pulsed IR-SPP wave to generate its second harmonics in the visible spectrum. However, contrary to what was expected, the second harmonic SPP gets an extended propagation because it is constantly supported by its fundamental frequency that feeds it.

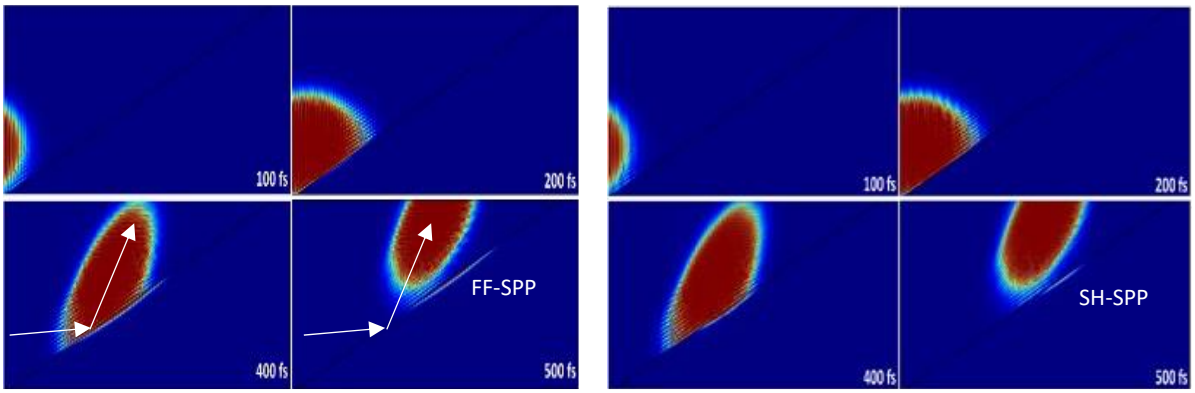

Figure 1: FF-SPP excitation via a femtosecond IR pulse (left) and its own SH-SPP generate via FF-SPP.

Coupling and propagation were simulated using COMSOL Multiphysics [5]. A silver (Ag) nanostrip serves as the negative permittivity layer due to its superior plasmonic properties. The SPP-supporting substrate was a 1% MgO-doped lithium niobate (MgO:LN), chosen for its excellent nonlinear optical characteristics. The material specifications are reported in table 1.

Table 1: **Optical Properties of the materials**

	TiO_2 [2]	Ag [3]	$LiNbO_3$ [4]
FF Dielectric function (ε_r @ 1064nm)	6.145	−47.102+i3.2503	ε_o=4.968 ε_e=4.61
SH Dielectric function(ε_r @ 532nm)	7.118	-9.1536+i0.80568	ε_o=5.378 ε_e=4.942

The typical propagation length of a surface plasmon polariton (SPP) wave at the Ag–$LiNbO_3$ interface at a wavelength of 532 nm is approximately 0.25 µm. In our case, we have achieved propagation lengths as long as 8 µm, representing an enhancement by a factor of over 30.

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The UniNano Nanotechnology Center for NanoPhotonics and Quantum Device Engineering

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The UniNano Nanofabrication Center, whose inauguration is scheduled for May 2025 at the University of Naples Federico II, will provide a next-generation cleanroom environment dedicated to the design, fabrication, and multi-scale characterization of micro- and nanodevices. The facility is structured several specialized technological areas, comprising advanced tools for electron-beam lithography, mask-based optical lithography, physical and chemical vapor deposition in ultra-high vacuum conditions, ion beam milling and etching, and high-resolution morphological and spectroscopic analysis (including Raman and SEM-based techniques).

The center is conceived to address key challenges in quantum device engineering, such as the realization of superconducting circuits and Josephson junctions, as well as enabling research in nanophotonics, plasmonics, and emerging materials. A fully integrated process line will allow researchers to move seamlessly from substrate preparation to device prototyping and final electrical or optical testing, with infrastructure suitable for both fundamental studies and pre-industrial applications.

UniNano will serve as a regional and national hub for innovation, offering open access to academic and industrial users, and fostering interdisciplinary collaborations in nanotechnology, quantum devices, and materials science.

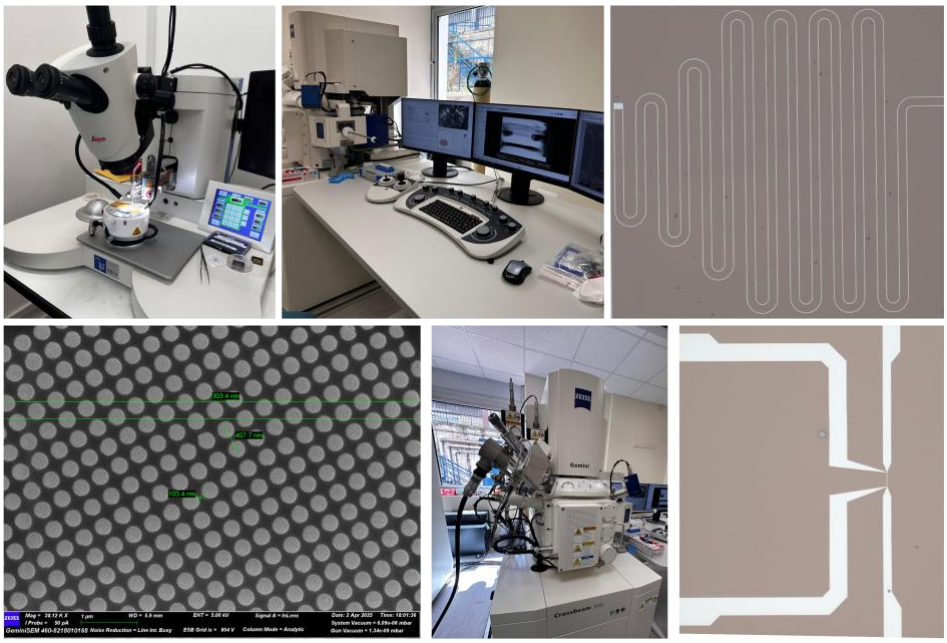

Figure 1: Overview of nanofabrication and characterization tools at the UNINANO Nanofabrication Center. Top-left: Leica microscope station for chip bonding and inspection. Top-center: SEM workstation with multi-monitor control and manipulation system. Top-right: Optical micrograph of a superconducting coplanar waveguide resonator. Bottom-left: Scanning electron micrograph of a nanoparticle array with. Bottom-center: Zeiss Crossbeam 350 focused ion beam system for high-resolution patterning and analysis. Bottom-right: Micrograph of a superconducting quantum interference device (SQUID) or similar nanoscale circuit.

Longitudinal Bulk Plasmons in Heavily Doped Semiconductors for Electrically Reconfigurable Linear and Nonlinear Optics

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Free electron (FE) nonlinearities in thin layers of heavily doped semiconductors are being explored as the key mechanism for electrically controlled nonlinear optics effects in the mid-IR and THz. The dynamics of FEs can generate strong and ultrafast optical nonlinearities, typically described in a hydrodynamic theoretical framework [1]. Heavily doped degenerate semiconductors are of particularly interest in this context due to possibility to tune the optical nonlinear coefficient by field effects (gate voltage bias) [2]. Since FE nonlinearities are intrinsic boundary effects [1, 3], it is sufficient to modulate the surface carrier density in such thin surface layers to enable reconfigurable control of the absorption and of the nonlinearities. Resonant plasmonic-cavity effects beyond the plasma frequency are being considered to enhance the linear and nonlinear modulation of the optical response.

In this work we introduce Longitudinal Bulk Plasmons (LBPs) [4] in a heavily doped semiconductor slab. We are currently developing n-type Ge epitaxial structures for an experimental demonstration. LBPs are strongly hydrodynamic (nonlocal) resonance above the plasma frequency, at frequencies close to odd multiples of the plasma frequency itself. This high-frequency feature makes LBPs promising to surpass the well-known limitations of heavily-doped semiconductor plasmonics due to high losses and may enable some of these technologically-relevant materials to reach the near-IR telecom band, well beyond mid-IR.

We acknowledge funding by the European Innovation Council (NEHO, 101046329). Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

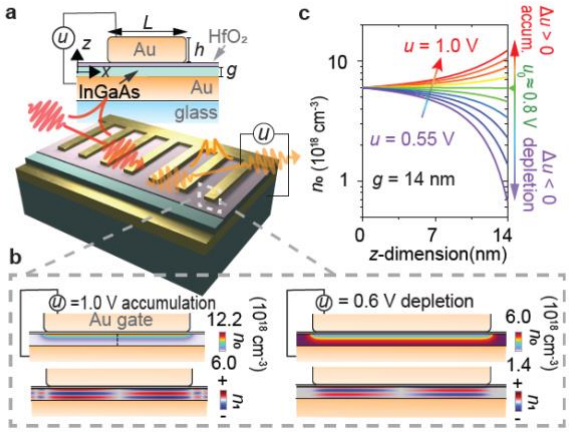

Figure 1: (a) Metal-semiconductor-metal cavity loaded with a thin (g = 14 nm thickness) n-type InGaAs layer and a gate voltage bias u applied to it. The length L and periodicity P_x of the cavity fingers are chosen to match the cavity resonance to the LBPs. (b) Top panels: accumulation (u = 1 V) and depletion (u = 0.6 V) layers for two values of u. Lower panels are the induced charge density pattern n_1 of the third-order LBP. (c) Calculated accumulation/depletion profiles $n_0(z)$ with a bandstructure plus surface-defect model

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Functionalized chiral gold nanoparticles for sensing applications

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Abstract: Chirality at the nanoscale unlocks unique optical phenomena with significant implications for photonics, biosensing, and environmental monitoring [1-3]. In this work, we present a wet-chemistry synthesis, and characterizations of chiral gold nanoparticles (AuNPs) functionalized by L-cysteine or D-cysteine, a chiral amino acid that induces morphological asymmetry at the atomic level [4]. The resulting plasmonic nanostructures exhibit circular dichroism (CD) signals, arising from the coupling between localized surface plasmon resonances (LSPRs) and chiral molecular interactions. A detailed optical characterization, including CD spectroscopy, reveals tunable chiral plasmonic responses in the visible range, paving the way for selective enantiomer detection and label-free biosensing. Scanning electron microscopy confirms a distinct twisted morphology, while DLS, XPS, and FT-IR validate stability and functionalization. These chiral plasmonic nanoparticles open new avenues for next-generation nanomaterials, enhancing sensitivity in molecular diagnostics and offering novel strategies for optical-based environmental sensing.

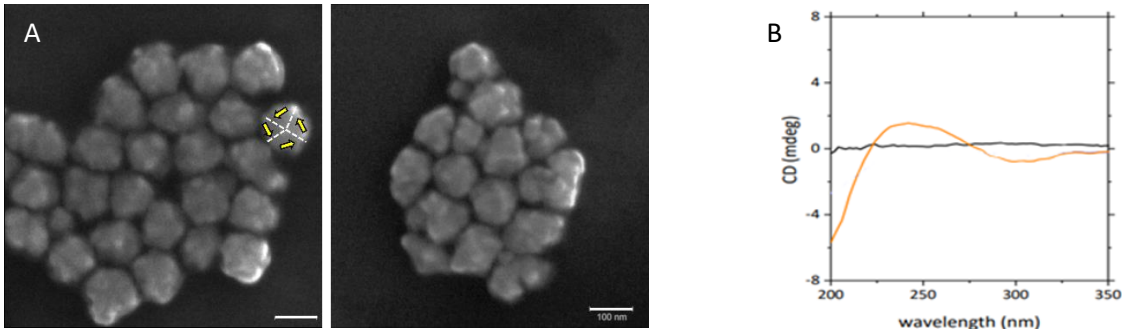

Figure 1: A) FE-SEM images of a sample of chiral AuNPs-A with highlights on the levorotatory direction. Scalebar: 100nm B) CD spectrum of the seed particles (black line, no dichroism detected) and of the chiral AuNPs (orange line) in the region of the molecular ligand absorption.

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[4] Lee HE, et al. *Cysteine-encoded chirality evolution in plasmonic rhombic dodecahedral gold nanoparticles.* (*Nature Communications,* 2020)

A procedure to obtain niobium oxide films with variable stoichiometry

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Niobium oxide films display noteworthy optical and electrical characteristics, making them suitable for various technological applications[1]. Niobium oxides have three relatively stable stoichiometries: NbO, NbO_2, and Nb_2O_5. Nb_2O_5 is the most thermodynamically stable phase and is used as a photocatalyst due to its strong redox ability. NbO is a conductive oxide exhibiting superconductive behavior at 1.38 K. NbO_2 undergoes a thermally induced insulator-to-metal transition (IMT) at 810°C, which can also be triggered by light absorption. This sudden change in conductivity makes it suitable for applications in memristive devices, ultrafast electrical switches, and thermal sensors.

Previous research has primarily concentrated on the growth of niobium oxide films with specific stoichiometries[2]. However, maintaining a high degree of control over the stoichiometry during the growth process and achieving various stoichiometric phases has proven to be quite challenging.

This study introduces a novel procedure for fabricating niobium oxide films and fine-tuning their stoichiometry among the three most stable oxide phases (Figure 1 left)[3].

Furthermore, a comprehensive characterization of the three different niobium oxides in terms of structure, optical properties, morphology, and surface composition is presented. Additionally, the NbO_2 films are characterized using Femtosecond Transient Absorption Spectroscopy (FTAS) to investigate the photoinduced insulator-to-metal transition (IMT)(Figure 1 center).

The obtained results serve as a reference for future studies on the dynamics of light-induced processes using element-sensitive ultrafast X-ray techniques. As an initial step in this direction, we present and discuss X-ray absorption near-edge spectroscopy (XANES) measurements at the Nb K edge, which were performed on some of the films with ultrashort high-energy photon pulses generated by the European X-ray Free Electron Laser (EuXFEL)(Figure 1 right).

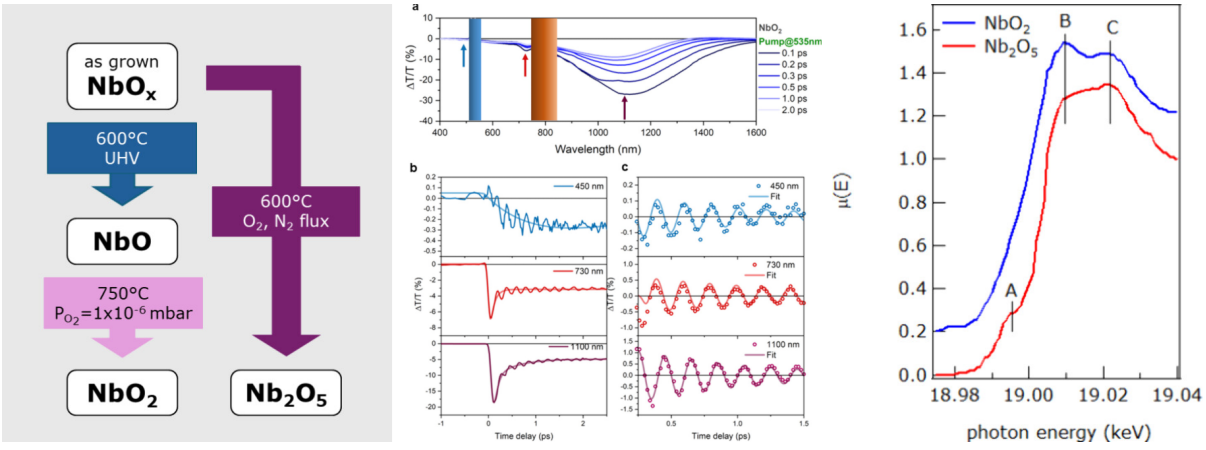

Figure 1: Left: Procedure to obtain the different Niobium oxides. Center: FTAS measurements on the NbO_2 film. Right: Nb k edge XANES measurements performed on Nb_2O_5 and NbO_2 films at EuXFEL.

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Self-assembled hybrid dielectric/plasmonic network metamaterials based on vanadium oxide and copper

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In the context of disordered plasmonics, random metallic networks (*plasmonic network metamaterials*) have been shown to exhibit a broadband plasmonic response, arising from the interaction between the many plasmonic hot spots of the network, which act as coupled oscillators [1].

Because of the inherent optical losses of metals, surface plasmon resonances in metallic network metamaterials are short-lived. On the other hand, dielectric materials are known to sustain higher Q-factor resonances, which can extend into the material rather than just on its surface. In recent work, photonic band gaps have been revealed in hyperuniform disordered dielectric networks [2].
Other fascinating optical phenomena are expected in dielectric networks, where even synchronization phenomena between the oscillators could occur in the regime of weak coupling [3].

Here, we fabricate network metamaterials based on vanadium and copper, via chemical dealloying of aluminum-copper-vanadium thin films. Taking advantage of the immiscibility of copper and vanadium and leveraging the high chemical affinity between vanadium and oxygen, we create disordered optical metamaterials with complex connected architectures including metallic (Cu) and dielectric (VO_x) components. By varying the Cu/V content ratio in the system, we aim to establish a platform for the study of light-matter interactions in network-like nanomaterials which are fully metallic, fully oxidic or hybrid. We perform electron energy loss spectroscopy in a scanning transmission electron microscope (STEM-EELS) to assess the oxidation state of vanadium in the network. Contextually, taking advantage of the low-loss region of the EELS spectra, we characterize the optical modes sustained by the networks. The experimental procedures described here are combined with FEM simulations for predictions and validation.

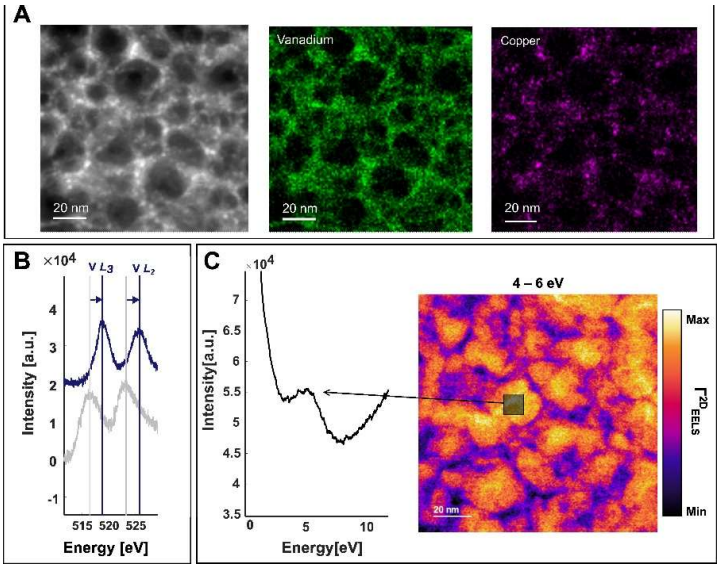

Figure 1: **A)** From left to right: HAADF-STEM micrograph of a VO_x-Cu network metamaterial, followed by its corresponding vanadium and copper EDX maps. While vanadium is homogeneously distributed in the network, copper segregates in nanoparticles. **B)** High-loss EELS spectrum of a non-dealloyed (grey) and dealloyed (blue) AlCuV thin film. The VL_3 and VL_2 core-loss edges shift to higher energy (~1.8 eV) upon dealloying, indicating oxidation of vanadium. **C)** Low-loss EELS spectrum and EELS map showing a weak plasmonic response around 5 eV. The resonance appears localized within the pores of the network.

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SPEQTEM: A Next-Generation Monochromated TEM for Advanced Plasmonic Investigations

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The investigation of plasmonic and inter-band excitations and their spatial distribution in nanostructures requires electron energy-loss spectroscopy (EELS) with ultrahigh energy resolution, not achievable with standard FEG sources. The newly commissioned **SPEQTEM** (Spectroscopic Quantum Transmission Electron Microscope) is a state-of-the-art monochromated TEM that achieves sub-50 meV energy resolution, providing unprecedented access to low-energy excitations in metallic and dielectric nanostructures and interfaces. SPEQTEM integrates a high-brightness electron source, an advanced monochromator, and a high-resolution spectrometer to enable precise mapping of localized surface plasmon resonances. These capabilities make it a powerful tool for exploring plasmonic modes in confined geometries and hybrid nanophotonic systems.

Table 1: **SPEQTEM characteristics**

Energy	TEM resolution	STEM resolution	Energy resolution
60-300 keV	0.10 nm	0.14 nm	50 meV

Our research group [1] one of the largest and most active electron microscopy teams in Italy, with a strong focus on methodological advancements in AI-driven analysis, quantum optics, electron beam shaping, and advanced TEM simulations. We are at the forefront of integrating machine learning techniques for accelerating TEM simulations and data analysis, as well as pioneering new approaches in electron-photon interactions for quantum applications. Our work in electron beam shaping, including the orbital angular momentum (OAM) sorter [2], has enabled groundbreaking studies of the symmetry of plasmonic modes, offering new insights into their fundamental properties.

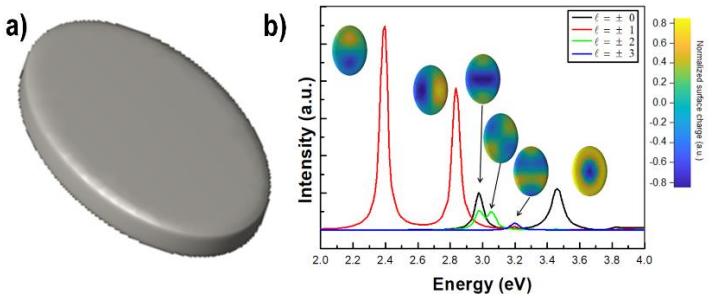

Figure 1: a) Tilted view of the Ag elliptical nanodisk. b) Simulated OAM-resolved EEL spectra for different OAM values (see legend). The surface charge distribution of each plasmonic mode is reported as insets.

This contribution will present the key technical specifications of SPEQTEM, highlighting its monochromation capabilities and potential applications in plasmonic research. Preliminary results and ongoing experiments will be briefly outlined, demonstrating the microscope's potential for advancing the field of nanophotonics.

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Active THz Surface Plasmon Modulation via Tungsten Oxide Hole Arrays

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The growing interest in terahertz technologies significantly increased the demand for compact, cost-effective, and energy-sufficient functional devices capable of operating in the THz spectra. The need to explore innovative materials that can be synthesized under ambient conditions (like room temperature, RT) and can be tailored for THz applications, gained attention in this direction. Among different materials, metal oxide semiconductors like WO_3 with unique features such as perovskite-like structure, phase transformations, and nonstoichiometry are promising since they offer tunable optoelectronic properties suitable for THz devices [1][2]. In this study, we explore the thermal tunability of surface plasmon resonance (SPR) characteristics in WO_3-based hole arrays.

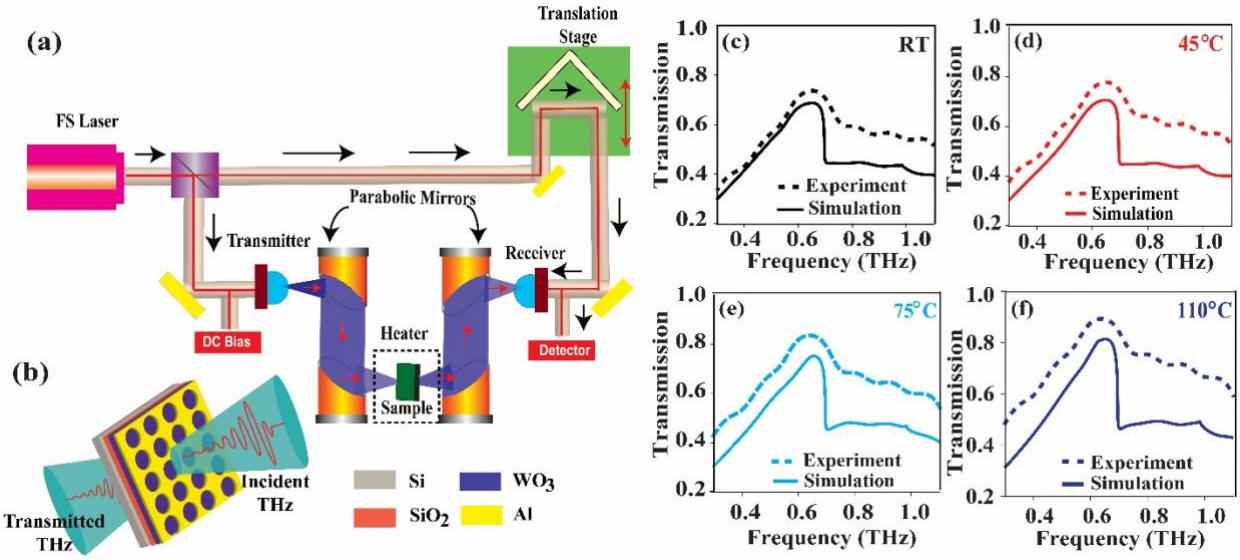

Figure 1: (a) Schematic of THz-TDS (b) Hybrid hole array on top of WO_3 thin film (c)-(e) Transmission spectra of the hole array on varying the temperature from RT to 110 °C.

A WO_3 thin film was grown at room temperature using magnetron sputtering and was characterized using different characteristic techniques. Further, to excite SPR, hole arrays were fabricated on top of the WO_3 film using microfabrication methods followed by terahertz time-domain spectroscopy (THz-TDS) as represented in Figure: 1(a). The schematic of THz radiation passing through the fabricated hole arrays along with WO_3 thin film is shown in Figure: 1(b). Additionally, numerical simulations were done using CST Microwave studio software in the transmission mode to conduct the theoretical analysis. Frequency response from both experiment and simulation, exhibited a good agreement along with the significant temperature-dependent shift in the SPR resonance peaks as given in Figure 1: (c) – (f). From the THz transmission spectra, a 30% change in peak position and a 48% variation in modulation depth was observed as the temperature was increased from 25 °C to 110 °C. These changes were linked to the thermally tunable THz permittivity of WO_3, highlighting the material's potential for developing reconfigurable plasmonic devices.

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Study of magneto-plasmonic characteristics of nanopores for particle trapping

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Nanopores embedded with magnetic and plasmonic materials can effectively capture nanoparticles, but this effect can be enhanced due to generation of a strong localized electromagnetic field generated within their structure under plasmonic effects[1]. Their magnetic properties enable precise control over particle movement when subjected to an external magnetic field, particularly for those with inherent magnetic responses[2].

This research focuses on the magnetoplasmonic behavior of nanopores containing core-shell nanoparticles composed of a cobalt (Co) core and a gold (Au) shell. By changing the size and composition of the core-shell nanoparticles, it was investigated how different configurations of materials affect field amplification and particle capture. The findings contribute to enhancing nanopore applications in experimental settings. Numerical simulations using COMSOL Multiphysics software were conducted to model the electromagnetic field distribution in nanopores with alternating cobalt and gold layers, assessing field enhancement in the presence of core-shell nanoparticles. Additionally, the study explores how the transmission spectrum of the nanopore varies based on the nanoparticle's proximity to the pore walls.

The results indicate that core-shell nanoparticles can significantly modify local electromagnetic properties, influencing nanopore permeability. The ability to manipulate particle movement through an external magnetic field provides a dynamic approach to controlling nanopore interactions in real-time. Calculations help to identify optimal design parameters to maximize the sensitivity of nanopores, which is crucial for applications in biosensorics, single-molecule spectroscopy and other applications.

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High-index optical materials for all-dielectric non-local metasurfaces

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All-dielectric metasurfaces provide an excellent platform for the development of photonic devices that can be integrated into next-generation smart eyewear [1] and employed for different applications, such as augmented reality and eye tracking [2, 3]. A key role in the realization of dielectric metasurfaces is played by their constituent materials, that must be optically flat and exhibits negligible absorption loss (extinction coefficient $k \approx 0$), and relatively high refractive index ($n > 2$), in order to be compatible with the high-index prescription lenses. Here, we investigate the growth and characterization of high-index, optically smooth thin films used for the fabrication of all-dielectric non-local metasurfaces that exhibit Guided Mode Resonances (GMRs). In particular, we focus our attention on different deposition techniques to obtain TiO_2 thin films: reactive sputtering, electron beam evaporation, and sol-gel spin coating. The TiO_2 thin films have been characterized using ellipsometry, prism coupling, atomic force microscopy, scanning electron microscopy, and X-ray diffraction. Using the different deposition techniques we obtained TiO_2 thin films with roughness down to about 0.5 nm (electron beam evaporated film) and refractive indices at 532 nm that ranges from 1.9 (sol-gel film) to more than 2.3 (sputtered film). These thin films have been used for the fabrication of GMR metasurfaces for augmented reality and eye tracking applications that have been characterized using collimated light from a supercontinuum laser. Measurements have been performed both in transmission and in reflection, exploring the in-plane scattered light from the metasurface, as a function of the incidence and diffraction angles to measure the GMR dispersion.

This work was carried out in the Smart Eyewear Lab, a Joint Research Center between EssilorLuxottica and Politecnico di Milano.

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Metasurface mapping by photoacoustic spectroscopy

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This study explores the characterization of chirality in metasurfaces using photoacoustic spectroscopy (PAS). Chirality, defined by the absence of mirror symmetry, plays a crucial role in molecular interactions and is commonly analyzed through circular dichroism (CD) using circularly polarized light. PAS enables direct measurement of local absorption by detecting heat transfer to the surrounding air, independent of transmitted, reflected, or scattered light. A widely tunable laser in the near-infrared and visible ranges, combined with adjustable parameters such as wavelength, polarization, incidence angle, and spatial positioning, allows for precise mapping of absorption and CD. The metasurface studied, AgC3, consists of self assembled polystyrene nanospheres with a 518 nm pitch, fabricated via nanosphere lithography and coated with a 55 nm silver layer. PAS signal analysis focused on wavelengths of 730 nm and 1000 nm, where significant differences in absorption between left-circularly polarized light (LCP) and rightcircularly polarized light (RCP) were observed. Absorption mapping of a selected 5×5 mm sample area revealed higher absorption at 730 nm in the upper part of the sample, decreasing in the lower part due to a lack of nanostructures. A similar trend was seen at 1000 nm. The calculated CD maps showed near-zero dichroism at 730 nm, indicating similar LCP and RCP absorption levels, whereas at 1000 nm, a higher CD was observed due to increased LCP absorption. These results confirm the homogeneity of the sample and demonstrate PAS as a powerful technique for advanced optical analysis of chiral nanostructures.

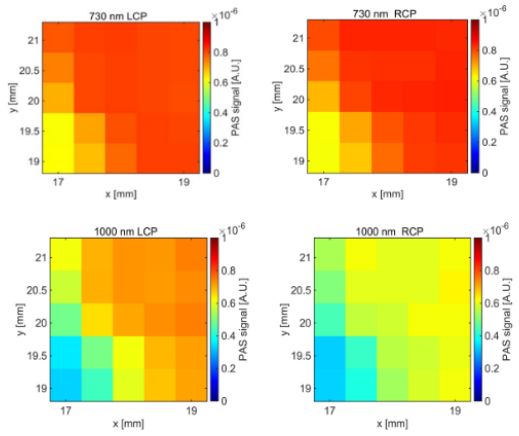

Figure 1: spatial mapping of absorption at 730 nm and 1000 nm

Ultrafast Charge Transfer Dynamics in Plasmonic NPs-CeO_2 Systems

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The combination of semiconducting oxide-based materials with plasmonic nanoparticles (NPs) aims to efficiently convert solar light into chemical or electric energy, exploiting the excitation of localized surface plasmon resonance (LSPR) in the NPs that leads to a significant energy/charge transfer to the oxide [1,2,3]. We investigated the ultrafast dynamics following photoexcitation of systems composed by Au or Ag NPs coupled with CeO_2 thin films, both using femtosecond transient absorption spectroscopy (FTAS) and pump-probe X-Ray Absorption Spectroscopy (XAS) at the Ce $N_{4,5}$ edge at the FERMI free electron laser facility. FTAS was used to probe the dynamics of charge carrier relaxation after the excitation of the LSPR of the metallic NPs and to evaluate the plasmon-mediated electron transfer efficiency. The measurements showed a transient occupation of the Ce 4f levels also at pump energies below the band gap of the CeO_2, and both Au and Ag NPs showed an efficient charge transfer from the NPs to the oxide (Figure 1a) [1,2]. For Ag NPs, the investigation of the injection dynamics at ultrashort timescales was hindered by the superposition between a photoinduced absorption (PIA) signal, characteristic of CeO_2, and the plasmon-related transient absorption (TA) signal. FEL-based XAS measurements on this system allowed element-specific analysis of the process, permitting to identify a reduction of CeO_2 compatible with a plasmon-mediated transfer of electrons into Ce 4f levels and to estimate an upper limit of 200 fs for the injection time (Figure 1b) [3]. For the Au NPs in CeO_2, there is no superposition between TA and PIA signals, and the system showed a different energetic and temporal dynamics at ultrashort delay times between LSRP-mediated injection and direct band gap excitation, compatible with the expected modifications of the electronic properties at the interface between the metal NP and the oxide. After a few ps, both the band gap and LSPR excitation lead to the same bulk-like polaronic state [2,4]. The comparison between the injection efficiencies following interband and LSPR excitations suggests that the interband injection is dominated by the indirect mechanism while the LSPR-mediated injection takes place by both direct and indirect mechanisms. Our results highlight the role of LSPR-driven charge transfer in enhancing CeO_2 photocatalytic performance and underline the potential of ultrafast spectroscopic techniques for investigating charge carrier dynamics in complex hybrid nanomaterials.

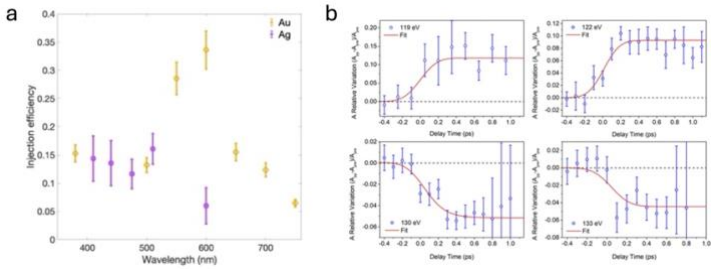

Figure 1: a) Electron injection efficiencies from Au (yellow) and Ag (purple) NPs to CeO_2; b) Relative variation of absorption as a function of pump−probe delay time and corresponding fit (red curve) measured at different FEL energies across the Ce $N_{4,5}$-edge.

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Electrically tunable ion transportation of MoS_2/SiN nanochannel

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Abstract: Ionic transport through nanofluidic channels is a promising area for applications including single-molecule analysis, manipulation, and energy harvesting [1,2]. Controlling ion transport remains a significant challenge. This work explores a MoS_2/SiN hybrid nanochannel architecture for potential electrical tuning of ionic transport via external gating and investigates its potential for osmotic power generation and single molecule detection. We fabricated nanochannels with sub-10 nm dimensions using a combined focused ion beam (FIB) milling and dry transfer technique [3]. This approach aims to preserve the structural integrity and electronic properties of the MoS_2, which is relevant for surface charge modulation [4]. We investigated the ionic current generated by applying a salt concentration gradient across the nanochannels, demonstrating the potential for osmotic power generation. We also explored the effects of gating on DNA translocation characteristics, observing some enhancement of the translocation signal. We investigated the influence of gate voltage on ionic conductance and observed some modulation of ion selectivity under certain conditions. Further investigation is needed to fully understand the stability and reversibility of these effects under extended operation and to optimize device performance for both gating and osmotic power applications [5]. These preliminary results suggest that MoS_2/SiN hybrid nanochannels may offer a pathway for controlled molecular transport through electrical gating and for energy harvesting through osmotic gradients, warranting further study for applications in single-molecule sensing, energy harvesting, and other biomolecular areas. The atomically smooth MoS_2 surface and tunable structure of nanochannel also provides an ideal platform for future integration with plasmonic nanostructures to enable simultaneous optical-electrical detection.

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