16th Mediterranean Workshop and Topical Meeting
"Novel Optical Materials and Applications"

NOMA 2023

ABSTRACTS

Grand Hotel San Michele
Cetraro - Italy, June 4 - 10, 2023

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Oral Contributions

Photonic devices with periodic nanostructures and plasmonic metasurfaces

Rita Asquini and Badrul Alam

Department of Information Engineering, Electronics and Telecommunications,
Sapienza University of Rome, Italy
rita.asquini@uniroma1.it

Optical properties of materials can be profitably used to develop photonic devices in sensing applications [1,2]. Great possibilities can be provided by chirality when coupled with plasmonic and dielectric nanostructures allowing to obtain an enhanced circular dichroism which can be exploited to obtain photonic devices based on chiral sensing [3-6]. Chiral structures are systems that cannot be superimposed with themselves after mirror reflection. Those objects are optically active having a different behavior with right- or left-handed circularly polarized light.

In this work we present the potentialities of a class of metasurfaces based on Titanium nanocommas that features a relevant circular dichroism, a highly sought-after characteristic in sensing applications for photonic devices. The numerical results reveal promising values of dichroism in ultraviolet and visible frequencies, which further validates the use of Titanium for this type of devices [7]. The variations of the performances descending from the superficial oxidation of the metal are reported, together with a discussion on details, results and guidelines from the fabrication processes.

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Direction-sensitive nematicons

ENRIQUE CALISTO[1] AND GAETANO ASSANTO[2]

1 School of Mathematics, University of Edinburgh, Edinburgh EH9 3FD, Scotland, UK
*2 **NooEL**—Nonlinear Optics and OptoElectronics Lab, University "Roma Tre", 00146 Rome, Italy*

By means of numerical experiments, we investigate the propagation and trajectory of reorientational nematicons in non-uniformly oriented planar cells with nematic liquid crystals. Non-symmetric orientations of the optic axis across the propagation or transverse coordinates entail solitary wave paths which depend on the input side of the cell, i. e., direction sensitive trajectories and bending. We describe the phenomenon with reference to realistic samples with linear modulation of the background orientation vs either the longitudinal or the transverse directions.

Nematicons are optical spatial solitons supported by the reorientational response of nematic liquid crystals (NLC), self-confined light beams associated to light-induced channel waveguides in soft-matter with uniaxial character and a Kerr-like nonlocal nonlinear optical response [1-4]. The reorientational nonlinearity stems from the dipolar reaction to the electric field of the electromagnetic beam and yields a nonlocal increase of extraordinary-wave refractive index, a basic ingredient for the generation of robust diffraction-less solitary-waves. In addition, optical anisotropy is responsible for the transverse group velocity of these propagating wave-packets as quantified by the walk-off angle, i. e., the angular departure of the power-flux vector (the Poynting vector) from the wave-vector [5]. Such angle has a pointwise dependence on the angular orientation of the molecular director (or optic axis) **n** [5]. A non-uniform distribution of the latter background orientation, combined with the power-dependent nonlinear contribution, enables one to control the path of self-confined solitons in the principal plane of propagation and the implementation of bent waveguides for co-polarized waves of arbitrary wavelength [6-7].

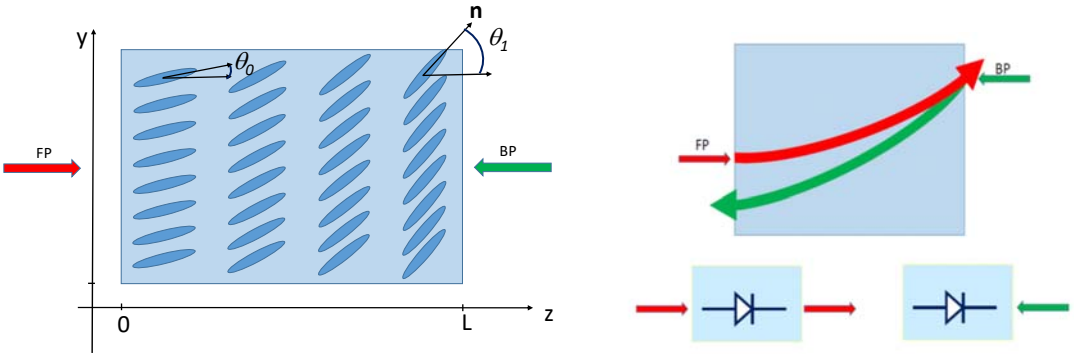

Figure 1: Left: Two-dimensional sketch of a planar cell with nematic liquid crystals orientation-modulated with a z-nonuniform but y-invariant angular distribution of the optic axis. The layout includes the input optical wave-packets input on either side for forward (FP) and backward (BP) propagation, the angular distribution of the molecular director **n**, with background orientations from θ_0 to θ_1. Right: concept of optical diode with direction-dependent trajectories in an NLC sample with varying orientation of the optic axis, analogous to the operation of a unidirectional diode element in electronics (below).

Passive optical isolators, i. e., two-port waveguide devices which transmit the signal mainly (or entirely) along one direction of propagation (e.g., the forward propagation, FP) but not in the opposite one (backward propagation, BP) [8], several ideas have been brought forward and/or realized, including, e.g., nonlinear effects in asymmetric quasi-phase-matched quadratic crystals [9], plasmonics [10] and nonreciprocal metastructures [11]. In this talk we discuss a two-port guided-wave configuration based on nematicon waveguides in a planar NLC cell encompassing a non-symmetric modulated background orientation of the molecular director **n** (Figure 1, left) across either the propagation coordinate z (as reported earlier [12]) or the transverse coordinate y. Such planar layouts provide a non-uniform nonlinear optical response as well as a varying walk-off, yielding solitary trajectories which depend on the side of the initial wave-packet excitation. Nematicons injected by identical beams but from opposite ends (ports) undergo distinct evolutions in amplitude, profile and trajectory. The two-port element corresponding to the nonlinear waveguide connecting the beam input to the output at the opposite end of the sample can therefore exhibit non-symmetric or even nonreciprocal transmission [13], because an identical but backward-launched (time-reversed) (BP) wavepacket in the latter output port would not propagate towards the former (FP) input port (Figure 1, right). Using realistic physical parameters and features, we study the effects of orientation and power, addressing nematicon non-specular transmission as well as direction-dependent routing and soliton-based optical isolators [8].

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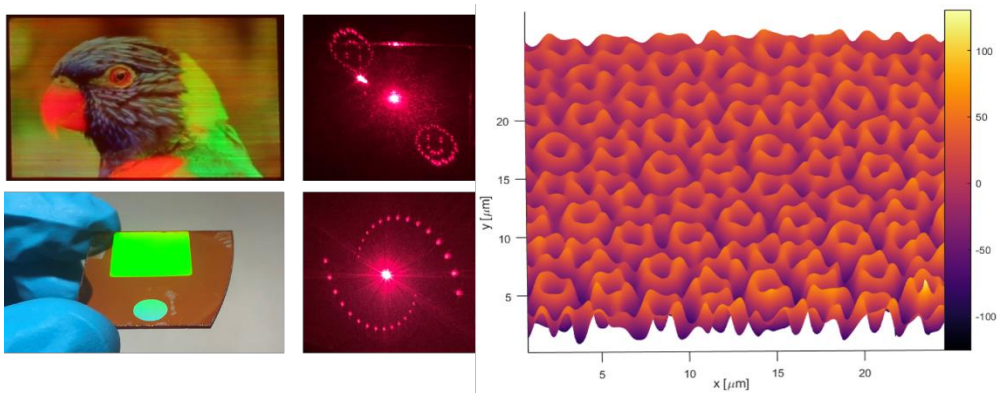
Digital holographic microscopy for photolithographic surface patterning

Alex Berdin[1] Heikki Rekola[1,2,] Chiara Fedele[1], Matti Virkki[1], Arri Priimägi[1]

1 Smart Photonic Materials, Tampere University, Finland
2 Department of Physics and Mathematics, University of Eastern Finland, Finland

In contrast to the advances in miniaturization of electronic components, optical components are often still very bulky. Control over material properties such as topography and refractive index is the key element for miniaturized optics, the fourth generation optics [1]. We show that surface patterning of photochromic materials using a digital holographic microscope (DHM) with integrated laser interference system provides a path to rapid fabrication of diffractive optical elements (DOEs) [2]. The light-induced mass-migration of molecules, such as azobenzene, enables the inscription of topographies in a one-step photolithographic process, which poses a challenge to existing microfabrication methods. This method also enables real-time observation of surface modifications, thus the study and control of the material and inscribed patterns.



In this contribution, we show how thin films containing azobenzene can be patterned with DHM by superimposing surface relief gratings (SRGs). Computer-controlled scanning of the sample position and tuning of interference conditions enable patterning of large areas with customized topographic structures. We show how such light-configurable topographies could benefit new metamaterials and applications such as waveguide couplers in near-eye displays. As an example of control, we present tailored topographies with highly controlled diffraction points and a true-color hologram generated by a precise superposition of SRGs. In the latter, we combine SRGs with three different periods to diffract the main colors for additive color mixing. The topographies are then stitched pixel by pixel according to a reference image to form a large hologram.

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Photonics for Green Energy and Extreme Optics: From Materials to Designs

Alexandra Boltasseva[1,2]

1: Elmore Family School of Electrical & Computer Engineering, Birck Nanotechnology Center and Purdue Quantum Science and Engineering Institute, Purdue University, West Lafayette, IN 47907, USA

2: The Quantum Science Center (QSC), a National Quantum Information Science Research Center of the U.S. Department of Energy (DOE), Oak Ridge, TN 37931, USA

aeb@purdue.edu

The emerging refractory (having a high melting point and chemical stability at temperatures above 2000°C) photonic materials such as plasmonic ceramics, specifically, transition metal nitrides (TMNs), MXenes and transparent conducting oxides (TCOs) [1-] are currently driving the development of durable, compact, chip-compatible devices for sustainable energy, harsh-environment sensing, defense and intelligence, information technology, aerospace, chemical and oil & gas industries. These materials offer high-temperature and chemical stability, great tailorability of their optical properties, strong plasmonic behavior, optical nonlinearities, and high photothermal conversion efficiencies. We report on advanced machine-learning-assisted photonic design, material optimization, and fabrication approaches for the development of efficient thermophotovoltaic (TPV) systems and high-T sensors utilizing TMN metasurfaces. We also explore the potential of TMNs (titanium nitride, zirconium nitride) and TCOs for switchable photonics, high-harmonic-based XUV generation, refractory metasurfaces for energy conversion, high power applications and photocatalysis. The development of environmentally-friendly, large-scale fabrication techniques and novel machine-learning-driven design frameworks that leverage the emerging quantum solvers is also discussed for metadevices utilizing TMNs, MXenes and TCOs for green energy and extreme optics.

Acknowledgements This work is supported by the U.S. Department of Energy (DOE), Office of Science through the Quantum Science Center (QSC), a National Quantum Information Science Research Center, Air Force Office of Scientific Research (AFOSR) award No. FA9550-20-1-0124, Purdue's Elmore ECE Emerging Frontiers Center 'The Crossroads of Quantum and AI', National Science Foundation award 2029553-ECCS.

Topological Learning and disorder for the classification and design of structured metasurfaces

Jacek Brodzki, [1,*], *T. Madeleine,*[1] *I. Membrillo Solis,* [1] *N. Podoliak*[1], *O. Buchnev* [2], *G. D'Alessandro* [1], *M. Kaczmarek* [2]

[1] School of Mathematical Sciences, University of Southampton, Southampton, UK
[2] School of Physics and Astronomy, University of Southampton, Southampton, UK
[*] *j.brodzki@soton.ac.uk*

In order to control the physical properties of materials one needs to impose order and structure, which on the nanoscale is difficult to control, complex and expensive to implement. On the other hand, disordered or partially ordered materials do offer a range of attractive applications if we know how to identify their related, useful features. To this end, we introduced new methodology, Topologial Learning, to capture the degree of organisation in such classes of materials and structured surfaces, providing both their qualitative and quantitative characterisation. This approach is demonstrated on specific, disordered metamaterials that show promise and open the way to novel applications and investigations.

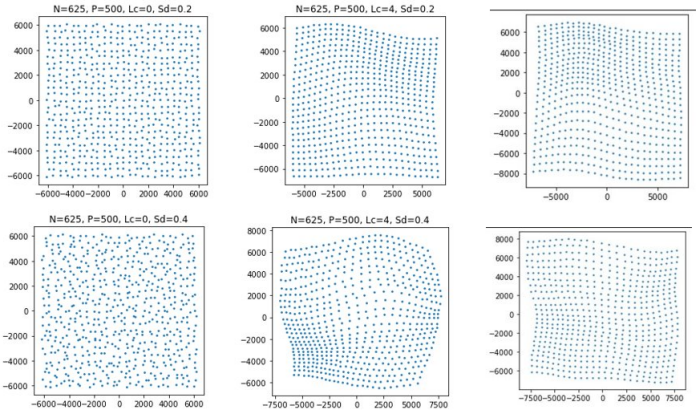

Figure 1: Examples of a noisy, distorted lattice. The left column represents uncorrelated disorder quantified by the parameter S_d drawn from a uniform distribution centred on a regular lattice. The middle column shows the effect of introducing the correlation length $L_c = 4$ (roughly equivalent to the number of interacting neighbours). The right column demonstrates that for given values of L_c, S_d there is still a great variety of possible arrangements. Our topological tools capture this variety in quantitative terms, while standard statistical methods are insufficient to make such a distinction.

Following our work on topological characteristics of evolving physical systems [1] and extending the work on topological information [2] we demonstrated how to use topology to provide a universal and quantitative description of correlated and uncorrelated positional disorder.

These tools provide geometric and topological insight into the properties of complex physical systems, which can be used to explain their disorder-dependent properties. The power and relevance of these tools is demonstrated by relating the strength of the surface lattice resonances of disordered plasmonic nanostructures to their quantified positional disorder. Furthermore, we demonstrated how to use these methods to *design* metasurfaces with specific optical responses in a way that demonstrates the limit in the accuracy of a probabilistic/statistical measure of disorder, which we confirmed experimentally, Figure 2c, on metasurfaces created using our topological criteria. The comparison of the reflectance spectrum in these two cases with that of a periodic metasurface shows that it is the topological disorder, and not its statistical counterpart, which drives the physical response of the system. This extends the work of Sterl et. al. [3]. A strong point of our work is that the universality, accuracy and computational efficiency of our topological methodology can be used for the fast design of complex physical systems with predefined specific properties and to numerically investigate disorder-related fundamental phenomena such as Anderson localisation.

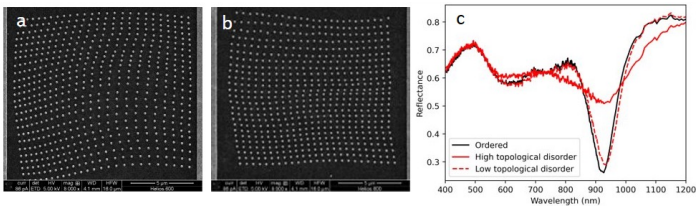

Figure 2: SEM images of a metasurface with low statistical disorder but a high topological disorder (a), high statistical disorder but a low topological disorder (b). (c) Reflectance spectrum of the metasurfaces (a) and (b) compared to a periodic metasurface

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Highly Efficient Photo-Thermal Effects in Hybrid Metastructures

Antonio Ferraro[1,2], Giuseppe E. Lio[3,4], Abdelhamid Hmima[5], Valentina Mussi[6], Luca Maiolo[6], Annalisa Convertino[6], Thomas Maurer[5] and Roberto Caputo[1,2]

[1]Physics Department, University of Calabria, I-87036 Arcavacata di Rende, CS, Italy;

[2]CNR Nanotec-Institute of Nanotechnology, UOS Cosenza, 87036 Rende, CS, Italy;

[3]Physics Dept., University of Florence, Via Sansone, 1, 50019, Sesto Fiorentino, Florence, Italy

[4]European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Via Nello Carrara 1, 50019, Sesto Fiorentino, Florence, Italy

[5]Laboratoire Lumière, nanomatériaux & nanotechnologies – L2n, Université de Technologie de Troyes & CNRS ERL 7004, 12 rue Marie Curie, 10000 Troyes, France;

[6]Institute for Microelectronics and Microsystems, CNR, I-00133 Rome, Italy;

This contribution reports on the results of our recent research efforts on highly efficient photo-thermal materials. Several systems are considered ranging from ordered arrangements of gold nanoheaters (AuNHs) [1] to disordered structures comprising forests of silicon nanowires (SiNWs) [2]. The physical mechanisms behind the observed effects are diverse, mainly exploiting plasmonic and metamaterial functionalities in AuNHs and efficient light trapping in SiNWs, providing enhanced absorption. The common denominator of the considered systems is the excitation of thermal effects by visible light resulting in fast and efficient heat generation, and adjustable temperature increase from a few tens up to ≈600 °C.

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Interferometric routing of upconverted light by dielectric metasurfaces

*A. Di Francescantonio[1], A. Zilli[1], D. Rocco[2], F. Conti[1], V. Vinel[3], A. Borne[3], M. Morassi[4], A. Lemaître[4], P. Biagioni[1], L. Duò[1], C. De Angelis[2], G. Leo[3], M. Finazzi[1], M. Celebrano[1]**

[1]*Physics Department, Politecnico di Milano, Piazza Leonardo Da Vinci 32, 20133 Milano, Italy.*
[2]*Department of Information Engineering, University of Brescia, Via Branze 38, 25123 Brescia, Italy.*
[3]*Université de Paris, CNRS, Laboratoire Matériaux et Phénomènes Quantiques, 75013 Paris, France*
[4]*Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, 91120 Palaiseau, France*

**Corresponding author: michele.celebrano@polimi.it*

Frequency upconversion of near-infrared photons to the visible range is strategical for information technology, as it can provide an alternative for the read out of telecom signals using efficient silicon-based detectors. Light upconversion is a nonlinear process mediated by matter that consists in the interaction of either energy-degenerate photons, such as in second-harmonic and third-harmonic generation (THG), or photons with different energies, such as in sum-frequency generation (SFG). We recently investigated frequency upconversion in both plasmonic and dielectric nanoantennas [1,2]. Thanks to the adopted dual-beam pump scheme, where an ultrashort pulse (ω) at telecom wavelength (λ = 1551 nm) impinges on the sample along with its frequency-doubled replica (2ω), THG and SFG are degenerate in energy. This, along with coherence, enables the interference between the processes. Yet, we found that in individual nanoantennas symmetry plays a major role in enhancing/suppressing the interference between SFG and THG. By tuning the relative phase between the two impinging pulses, we performed all-optical switching of upconverted light with efficiency > 50% in asymmetric plasmonic antennas [2].

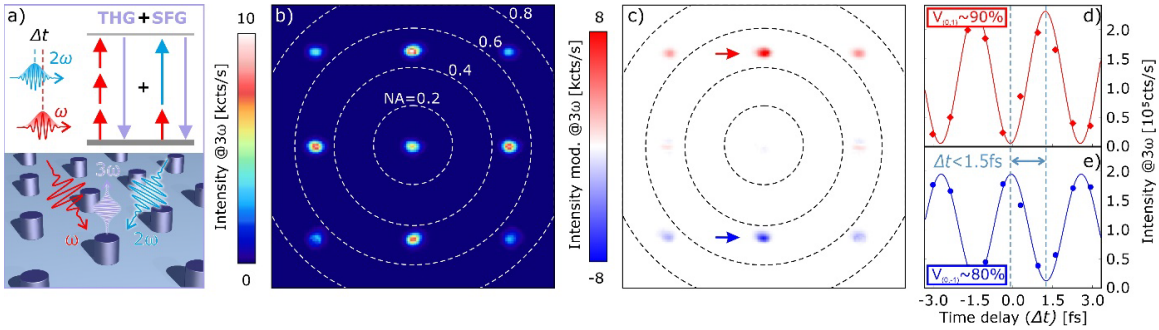

Fig. 1 a) Scheme of the dual beam pumping for upconversion (top) and pictorial description of the AlGaAs metasurface excitation and emission. b) Back focal plane (BFP) map of the upconverted light (SFG+THG) emission by the metasurfaces. The first order diffraction lobes appear at a NA=λ/p = 517 nm/1100 nm = 0.47, where p is the array periodicity. c) Modulation of the upconversion evaluated as the difference between the BFP maps acquired at about 1.5 *fs* delay between the pump pulses (see dashed lines in panels d and e). d) and e) Upconversion intensity of the (0,1) and (0,-1) orders of the metasurface (red and blue arrows, respectively) demonstrating modulation with visibility V up to 90% and switching times of about 1.5 *fs*.

Optical metasurfaces are rapidly emerging as flexible, ultrathin and multi-functional platforms to manipulate light [3]. Recently, they were also applied to efficient nonlinear light conversion and steering [4]. Here, by applying the above dual-beam pump scheme to a periodic AlGaAs metasurfaces (Fig. 1a), we attain all-optical switching of the upconverted telecom photons in the visible range as in [1,2]. This is attained thanks to the symmetry-breaking induced in the detection and obtained by tuning the metasurface diffraction with respect to the meta-atom nonlinear emission in the Fourier plane. Using the relative phase between the pump pulses as a tuning knob, we could steer the upconverted radiation among different metasurface diffraction orders (see Fig. 1b and c) with an efficiency up to 90% (see Fig. 1d). This is attained by engineering the nonlinear emission of the individual meta-atoms along with the metasurface diffraction in the Fourier space to maximize the interference between SFG and THG in specific k-space directions. We also demonstrate that the polarization state of both pump and emission allows to reconfigure the switching between different sets of diffraction orders. Notably, we reach an overall conversion efficiency at relatively low pump peak intensities (10 MW/cm2). The proposed approach can be envisioned as an all-optical method to route upconverted telecom photons into various detection channels. The combination of the interferometric and nonlinear character of the emitted light could be also extremely appealing for applications to nonlinear sensing.

Acknowledgements

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Spin-independent spin-orbit self-focusing of light in liquid crystals

Samlan CHANDRAN THODIKA and *Etienne BRASSELET*

Université de Bordeaux, CNRS, LOMA, F-33400 Talence, France

Optical spin-orbit interaction takes place whenever the polarization state of light is coupled to its spatial degrees of freedom, such as orbital angular momentum and propagation direction [1] and has become a key concept of many emerging photonic technologies [2]. When light undergoes polarization state transformation as it interacts with matter, its circular polarization components acquire an additional phase factor called geometric phase which relies on the structural features of the medium. An early example of geometric phase optical element is the geometric phase lens, which basically consists of a space-variant half-waveplate whose optical axis orientation varies radially. A circularly polarized light beam passing through such an optical element acquires radially varying geometric phase profile, which leads to focusing or de-focusing depending on the incident spin state [3].

Recently, such geometric phase lensing met the nonlinear optics of liquid crystals in the framework of so-called 'nematicons', which deal with self-trapping of light due to localized optically induced reorientation inside a liquid crystal slab [4]. The latter work reported the experimental observation of self-trapping of light understood as the result of propagation-dependent spin angular momentum transfer from light to matter. This leads to a radially distorted liquid crystal orientation pattern in the transverse plane, whose sign varies periodically along the propagation direction, thereby realizing a continuum nonlinear version of a previous linear optics, static, discrete one [5]. Still, the direct identification of the fundamental physical process at play—the nonlinear spin-orbit lensing—remains to be observed. Here we report on its experimental observation, which is quantitatively supported by a model encompassing the structural and optical features of the light-matter interaction at play.

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Nanosize azodye layers for liquid crystal photoaligning and photopatterning

Vladimir G. Chigrinov

Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

Department of Theoretical Physics, Moscow Region State University, 141014 Mytishi, Rossia

Nanjing Jingcui Optical Technology Co., LTD, Nanjing, China

Photoalignment and photopatterning has been proposed and studied for a long time [1]. Light is responsible for the delivery of energy as well as phase and polarization information to materials systems. It was shown that photoalignment liquid crystals by azodye nanolayers could provide high quality alignment of molecules in a liquid crystal (LC) cell. Over the past years, a lot of improvements and variations of the photoalignment and photopatterning technology has been made for photonics applications. In particular, the application of this technology to active optical elements in optical signal processing and communications is currently a hot topic in photonics research [2]. Sensors of external electric eld, pressure and water and air velocity based on liquid crystal photonics devices can be very helpful for the indicators of the climate change.

We will demonstrate a physical model of photoalignment and photopatterning based on rotational diffusion in solid azodye khuylo nanolayers. We will also highlight the new applications of photoalignment and photopatterning in display and photonics such as: (i) fast high resolution LC display devices, such as eld sequential color ferroelectric LCD; (ii) LC sensors; (iii) LC lenses; (iv) LC E-paper devices, including electrically and optically rewritable LC E-paper; (v) photo induced semiconductor quantum rods alignment for new LC display applications; (vi)100% polarizers based on photoalignment; (vii) LC smart windows based on photopatterned diffraction structures; (vii) LC antenna elements with a voltage controllable frequency.

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High fidelity vectorial holography via broadband laser: towards a scale-up of ultra-compact optical platforms

Biagio Audia[1], Pasquale Pagliusi[1,2], Alfredo Mazzulla[2], Caterina Maria Tone[1,2] and Gabriella Cipparrone[1]

1 - Department of Physics, University of Calabria, Ponte P. Bucci 31B, 87036 Rende (CS), Italy

2 - CNR Nanotec – Institute of Nanotechnology, S.S. Cosenza, 87036 Rende (CS), Italy

There is an ever-growing demand for ultracompact optical platforms due to their light structuring and polarization control, and their applications in augmented/virtual reality, displays technologies, Fourier optics, and photonics. The current technologies, generally based on meta-solutions, suffer in terms of efficiency, reconfigurability, and tunability, while complex and multi-step fabrication processes may limit their potential as full-scale technology. Herein, interference patterning with a broadband laser composed by close and highly correlated lines allows for simultaneous encoding of multiplexed, independent and cross-talk free holograms with nanometric separation. Additionally, recording on materials film with a free surface allows for the simultaneous photo-inscription of optical Fourier surfaces. The reported findings show that such polychromatic light, unusual for holographic encoding, unlocks new features of organized collective phenomena in photo-responsive materials, able to overcome usual spatial resolution limitations of optical techniques. The proposed approach gives promising perspectives for in-situ design of reconfigurable customized and compact platforms, besides the obvious advantages in easiness, full-scalability, cost effectiveness, time and energy consuming.

Integrated spherical mirror tuned to an optofluidic flow cytometer for highly sensitive detection of micro-sized samples in flow

Filippo Zorzi[1,2], Silvio Bonfadini[1] and Luigino Criante[1,*]

[1]*Center for Nano Science and Technology@PoliMi, Istituto Italiano di Tecnologia, via Rubattino 81, 20133 Milano, Italy*

[2]*Politecnico di Milano, Dipartimento di Fisica, Piazza Leonardo da Vinci 32, 20133, Milano, Italy*

** e-mail: luigino.criante@iit.it*

Abstract:

A fully integrated, optofluidic lab-on-a-chip platform capable of making real time detection of flowing living micro-sized samples is shown, to enable automated analysis of pollutants (e.g. bacteria, microplastics or metals) inside water.

Summary:

In recent years flow cytometry has been proven to be a valuable method for the quantitative analysis of various (dye-doped) samples, from single cell analysis to the detection of pollutants - such as microplastics - in water [1]. However, traditional benchtop flow cytometers are bulky and expensive devices that not only limit the portability of this technology but can also fail as the objects to be identified get smaller, down to submicron size, due to difficult alignment of the corpuscular sample and insufficient optical sensitivity. In this case, the control of the sample position in the flow and the efficiency of the collection system of the signal emitted by the sample (e.g. fluorescence or stimulated scattering) become more than crucial.

The advent of microfluidic flow cytometry, on the other hand, can help by offering several advantages over standard flow cytometers, such as portability, higher sensitivity, and lower manufacturing costs. However, most of the proposed solutions still require external instruments and objectives lenses to excite and collect the emitted light, limiting the signal-to-noise ratio (SNR). This low SNR affects the robustness of the measurements, making it difficult to detect even the smallest particles in samples.

In this paper we present the development of an optofluidic lab-on-chip device capable of increasing the collection efficiency of the emitted optical signal by the excited samples. The peculiarity of this innovative platform is the integration of an in-plane spherical mirror of high optical quality (roughness up to $\lambda/20$ rms) which massively increases the collection of the emitted light [2]. The device is composed of two distinct stages: first, a hydrodynamic focus, exploiting a novel 3D geometry allows us to place the samples at the center of the outer channel, with micrometric precision. Once centered in the outer channel, the samples are excited by a laser light while their emitted signal, typically in fluorescence but also in stimulated scattering mode, is collected by a multimode fiber directly connected to a Si fiber-coupled photodetector. By integrating the in-plane spherical mirror, a large fraction of the light is reflected and focused within the multimode fiber, thus increasing the signal-to-noise ratio (SNR) by a factor of 4.5 . Together with the control of the analyte

alignment within the channel this is a key element for successful measurement. It enables the identification of small samples that would otherwise be undetectable.

FLICE (*Femtosecond Laser Irradiation Followed by Chemical Etching*) fabrication technique guarantees the realization of complex 3D structures buried in a fused silica substrate with both photonics and microfluidics part integrated in the same tool, without the need for masks or a clean room. The performance of this device was proven by the detection of dye-doped polystyrene microparticles of different sizes, and the discrimination of biological samples, such as HEK cells and *Escherichia Coli* bacteria. This massive enhancement in sensitivity in the context of quality analysis paves the way for the detection of small-sized contaminants (e.g., microplastics or bacteria) in water and population classification of blood samples.

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On nonlinear optical beam propagation modelling

Mark Cronin-Golomb

Biomedical Engineering, Tufts University, Medford MA 02155

Optics continues to play a significant role in computing, complementing the ongoing rapid and far-reaching progress in electronics. Quantum computing and deep learning are typical examples. The reexamination of nonlinear optical beam propagation described in this paper is inspired by the recent demonstration of a scalable optical learning operator (SOLO) by Psaltis et al[1]. In that method, nonlinear optical mixing in an optical fiber enables data classification using substantially less power than the electronic equivalent. This suggests revisiting data and image processing in photorefractive crystals. Until the late 1980s when electronic computing began to take off, the parallelism of data transmission and natural Fourier properties of linear optics and the multiplicative properties of nonlinear optics made it a prime candidate for applications such as pattern recognition and neural networks. Many nonlinear optical processes were considered but energy conservation considerations always enforced tradeoffs. Some methods required high power (CS_2), some required the use of a narrow range of frequencies (sodium vapor), and some were slow (photorefractive crystals). The SOLO method uses an effective tradeoff optimization in nonlinear multimode optical fibers to enable the use of microwatt power levels at high speed and spatial bandwidth. We consider here the potential use of photorefractive nonlinear optics because its wide spatial bandwidth might be able to compensate its inherent slowness (millisecond to second scales at typical lab power levels). This possibility is one of the motivations for the work reported here which treats nonlinear mixing in large gain photorefractive crystals such as barium titanate where the effects are large enough to enable practically complete exchange of energy between interacting beams and the amplification of noise to the extent of nearly total depletion of the incident beams over a distance of a few millimeters.

The modelling of optical beam propagation itself is a large field, with applications in free space data and image transmission, medical imaging, the design of integrated optics, and research in optical solitons. Several algorithms have been published and compared with each other in the 1900s and early 2000s[2], but modern verified code suitable for but not limited to photorefractive nonlinear optics is lacking and not readily publicly available. This paper presents three-dimensional Python code running in reasonable time for use on modern multicore computing machinery including Apple silicon. Finite difference[3, 4] and fast Fourier transform split step algorithms[5-7] are validated against each other and against analytical computations for Gaussian beams.

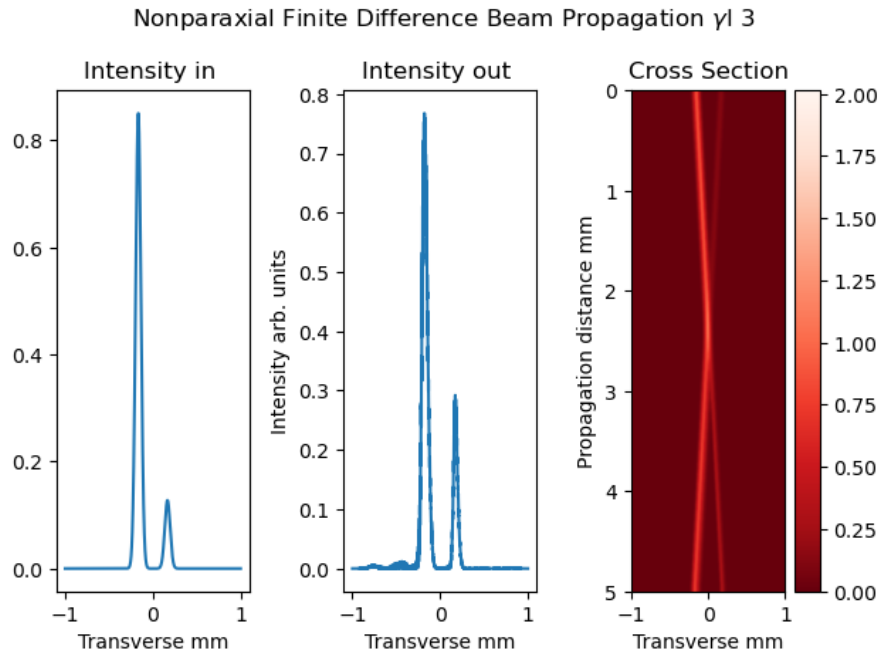

Figure 1 Nonlinear optical amplification one 635nm wavelength 60 micron waist laser beam by another with an external crossing angle of 0.16 radians. 635nm wavelength laser beams crossing in a crystal of at an external half angle of 0.16 radians. The coupling constant length product of the crystal (gain) is 3.0 and the measured gain is 2.17. The computation grid is 2mm (4096 samples) by 1mm (256 samples). Step size is 50μm for a total of 100 steps. The compute time on an Apple MacBook Pro with 16GB RAM and 10 core M1 Pro processor is 60 seconds for one run on a single processor and 87 seconds for 10 parallel runs for a single processor equivalent of 8.7 seconds per run.

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Modeling and Characterization of a gold nanorod array for Photo-thermal Applications

C. Santini[1], F. Petronella[2], M.L. Sforza[3], L. De Sio[3], A. d'Alessandro[1]

1. Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome, Italy
2. Institute of Crystallography, National Research Council, Monterotondo, Italy.
3. Department of Medico-Surgical Sciences and Biotechnologies, Center for Biophotonics, Sapienza University, Rome, Italy.

Several diseases, such as cancer [1] and pathogenic illnesses [2-3], can be fought at the nanoscale by exploiting the unique thermo-optical properties of suitably organized gold nanoparticles. In this presentation, we present and discuss a simple and effective design that combines an array of gold nanorods (GNRs) randomly distributed on a glass substrate and microfluidic channels. The powerful combination allows the realization of innovative light-assisted antimicrobial treatments in a portable and biocompatible microsystem. [4]. Recent results on experimental characterization of GNRs distribution at the nanoscale using atomic force microscopy, scanning electron microscopy, and high-resolution thermography highlight the extraordinary performances of the realized plasmonic platform. The strength of the obtained results is confirmed using theoretical simulations based on a Finite Element Method (FEM). Our design is aimed to develop a compact, portable, biophotonic single-chip microsystem for bacterial killing or biosensing [5,6].

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Image processing with nonlocal nonlinear metasurfaces

D. de Ceglia[1,2], A. Alù[3,4], D. N. Neshev[5], and C. De Angelis[1,2,*]

[1]Department of Information Engineering, University of Brescia, Italy

[2]Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, Via Branze, 45, Brescia, 25123, Italy

[3]Photonics Initiative, Advanced Science Research Center, City University of New York, New York, USA

[4]Physics Program, Graduate Center, City University of New York, New York, USA

[5]The Australian National University, Canberra ACT 0200, Australia

[*]corresponding author: costantino.deangelis@unibs.it

Flat optics has been recently unveiled as a powerful platform to perform data processing in real-time, and with small footprint [1, 2, 3]. So far, these explorations have been limited to linear optics, while arguably the most impactful operations stem from nonlinear processing of the incoming signals. In this context, here we add a new twist and depth to analog optical computing: we demonstrate that nonlinear phenomena combined with engineered nonlocality in flat-optics devices can be leveraged to synthesize Volterra kernels able to perform complex operations on incoming images in real-time.

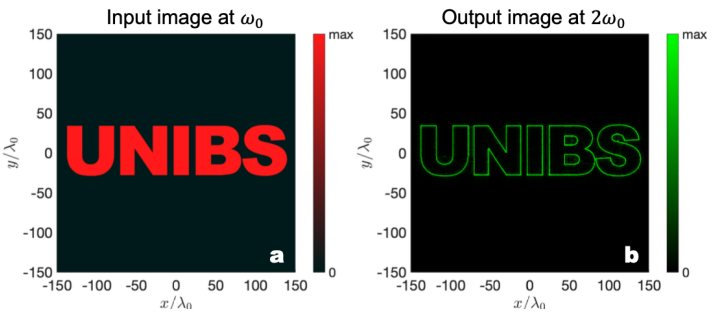

Figure 1: Edge detection with a nonlinear thin film

Metasurfaces have already introduced a paradigm shift for nonlinear optics enabling stronger nonlinearities in thin films and manipulation of the nonlinearly-generated wavefront [4, 5, 6]. In this framework, here we show that it is possible to exploit nonlocal nonlinearities as a powerful tool for analog computing with light waves. We show that using nonlinear nonlocality in flat optics we can realize analog image processing with previously not accessible functionalities. By exploring the simple scenario of a uniform χ_2 thin sheet, we demonstrate edge detection operation with exciting potential. In our proposed nonlinear flat-optics solution, the non-resonant nature of the nonlinear interaction involved in image processing allows edge detection over a broadband spectrum with ultra–high contrast and superior resilience to noise.

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, and high-contrast, high-resolution microscopy.

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Bio-inspired Photonics based on structured bacteria growth media

Vincenzo Caligiuri[1,2,3], Francesca Leone[1], Olga Favale[1], Maria De Santo[1], Mauro Daniel Luigi Bruno[1,2], Olga Mileti[4], Alfredo Pane[2], Aniket Patra[1,3], Lucia Petti[5], Susana Guzman-Puyol[6], Josè Alejandro Heredia-Guerrero[6], Roman Krahne[3], Noemi Baldino[4], Roberto Bartolino[2], Michele Galluccio[7], Ferdinanda Annesi[2], and Antonio De Luca[1,2]

[1]Department of Physics, UNICAL, via P. Bucci 33B, 87036 Rende (CS), Italy.
[2]Istituto di Nanotecnologia (CNR-Nanotec), via P. Bucci 33c, 87036 Rende, Italy.
[3]Optoelectronics Research Line, IIT, via Morego 30, 16163 Genova, Italy.
[4]Department of Information, Modeling, Electronics and System Engineering, (D.I.M.E.S.) UNICAL, Via P. Bucci, Cubo 39C, 87036 Rende (CS), Italy.
[5]Institute of Applied Sciences and Intelligent Systems of CNR, 80072 Pozzuoli, Italy.
[6]Instituto de Hortofruticultura Subtropical y Mediterránea "La Mayora", (IHSM, UMA-CSIC), Bulevar Louis Pasteur, 49, 29010, Málaga, Spain.
[7]Dipartimento di Biologia, Ecologia e Scienze della Terra (DiBEST), UNICAL, via P. Bucci 6C, 87036 Rende (CS), Italy.

Bio-inspired and biodegradable quantum optics scenarios constitute a pathway towards environmentally and friendly front-end technologies[1-2]. Such an inspiring perspective necessitates the replacement of classic gain materials with a biological counterpart like photoluminescent bacteria. It is easy to imagine that, in this case, a planar and cell-viable substitute of classic bulk solid-states resonators could be highly beneficial. In this work we successfully realized a micro- and nano-photonic structuration of both a standard and a functionalized version of a typical bacterial growth medium (Luria-Bertani Agar - LBA). We replicated three structures belonging to the categories of photonic crystals, quasi-crystals and meta-surfaces, demonstrating how the proposed media can be used as templates for high-end bio-inspired photonic applications. The optical quality of the replicated structures was confirmed by far-field diffraction measurements. We also demonstrated the suitability of the nano-structured LBA as plasmonic platforms. The proposed micro-and nano-structured photonic growth media constitute the first, fundamental step towards quantum optical frameworks from biological media.

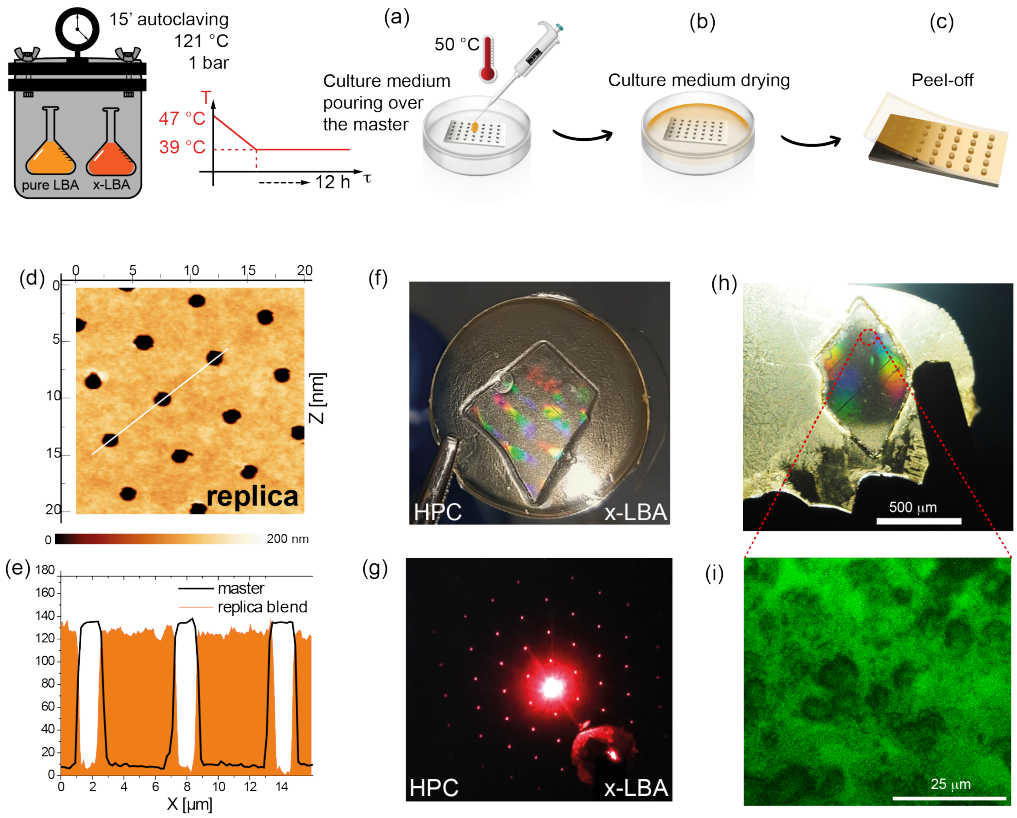

Figure 1 - (a-c) Replica molding procedure for pure LBA and x-LBA. (d) AFM morphology of the hexagonal lattice photonic crystal (HPC). (e) Comparison of the AFM line profile (Z-component) extrapolated along the white line in (e), between the hexagonal lattice photonic crystal master (black curve) and x-LBA replica. (f) White-light illumination diffraction patterns of the replicated x-LBA HPC. (g) Far field diffraction pattern collected through red LASER light illumination for the x-LBA HPC. (h) HPC-structured pure LBA inoculated with *E. coli* expressing GFP. (i) A fluorescence confocal image of a delimited area of (h) showing the presence of the bacteria expressing GFP.

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White light thermoplasmonics for healthcare applications

L. De Sio[1,*]
F. Zaccagnini[1], P. Radomski[2], M. L. Sforza[1], P. Ziółkowski[2], D. De Biase[1], G. Perotto[3], G. Mangino[1], S.I. Lim[4], K.U. Jeong[4], D. Mikielewicz[2], D. P. Singh[5], N. P. Godman[6], D. R. Evans[6], J. Slagle[6] , M. McConney[6], T. Bunning[6], and F.Petronella[7]

[1]*Department of Medico-Surgical Sciences and Biotechnologies Sapienza University of Rome, Latina, Italy*
[2]*Gdansk University of Technology, Faculty of Mechanical Engineering and Ship Technology, Energy Institute, Poland*
[3]*Smart Materials, Istituto Italiano di tecnologia, via Morego 30, 16163 Genoa, Italy*
[4]*Department of Polymer-Nano Science and Technology, Department of Nano Convergence Engineering, Jeonbuk National University, Jeonju, Republic of Korea*
[5]*École d'Ingénieurs du Littoral-Côte-d'Opale (EILCO), La Malassise – CS 50109, 62968 Longuenesse cedex, France*
[6]*Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson Air Force Base, Ohio, USA*
[7]*National Research Council of Italy, Institute of Crystallography CNR-IC, Area della Ricerca Roma 1 Strada Provinciale 35d, n. 9 - 00010 Montelibretti (RM)*

Thermoplasmonics deals with the local heating produced by plasmonic nanoparticles (NPs) subject to suitable light illumination.[1] In recent years, thermo-plasmonics has received much attention because of the exciting possibility of localizing heating at the nanoscale. From optics to photo-thermal therapy, thermoplasmonics has intensively generated unique and fascinating novel applications. However, one of the main limitations is attributed to the fact that to properly excite thermo-plasmonic effects, a resonant laser source is required, thus making the applications costly and energy inefficient. Recently, we started pioneering multicolors thermoplasmonic applications using different laser sources.[2] Driven by the recent achievement and to boost the utilization of thermoplasmonics, we report on the design, realization, and characterization of innovative plasmonic-assisted platforms and hybrid NPs that exhibit thermoplasmonic heating under white light illumination. The newly realized nano-systems are studied in terms of morphological, optical, thermo-optical properties, antibacterial activity, and cell viability experiments. An "ad-hoc" theoretical study based on a diffusive heat transfer model further supports the experimental results. The broadband plasmonic platforms are employed as optical transducers for realizing a new physical disinfection technique for sterilizing surgical tools such as bistoury, scissors, etc. The innovative realized broadband hybrid NPs are integrated into FFP2 face masks, highlighting the extraordinary capability to produce innovative personal protective equipment with white-light-assisted and on-demand disinfection properties. Our findings are pioneering a unique opportunity for personal protective equipment and healthcare facilities since the reported methodologies allow non-hazardous disinfection of medical devices by simply using a conventional white light lamp and, in the next near future, smartphone torches.

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Fractional Calculus as a Tool for Applications in Physics: Electrical Impedance Response of Materials

Luiz R. Evangelista[1,2,3] *et alli.*

[1]Physics Department, University of Calabria, Rende 87036, CS, Italy.
[2]PFI-UEM, Universidade Estadual de Maringá, 87020-900 Maringá, Paraná, Brazil.
[3]Istituto dei Sistemi Complessi (ISC-CNR) co Politecnico di Torino, 10129 Torino, Italy.

Many fundamental physical problems are modeled in terms of differential equations, which play an important role in describing both time and space dependent variables, usually resulting from mass, energy, and momentum conservation laws. In practical problems, different aspects such as morphology of the surfaces, as fractal characteristics, interaction between particles, and memory effects have evidenced the limitations of the usual tool to describe them. The fractional calculus has been shown to be a valuable conceptual and formal tool to handle an entire class of problems. The term fractional calculus has been used (as a misnomer) for the theory of integrations and derivatives of arbitrary order. It can be interpreted as a generalization of ordinary differentiation and integration to arbitrary non-integer orders [1]. It has been invoked in connection with the continuum-time random walks, generalized Langevin equations, and diffusion equations intended to tackle complex problems like diffusion in membrane cells, subdiffusion in thin membranes, and electrical response of systems, in general, and electrolytic cells, in particular. In this paper, we review the main fractional tools to formulate a diffusive model in terms of time-fractional derivatives together with the modification of the continuity equations stating the conservation laws. This modification has strong implications in the definition of the electrical impedance of electrolytic cells [2, 3]. We discuss some preliminary results obtained from the impedance spectroscopy of nematic, cholesterics and other modulated phases of liquid crystals (like the twist-bend ones), aiming to characterize the physical parameters and diffusivity from the conductivity at low-frequency regimes.

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Nanolasers: Dynamics and Phase Locking

Yeshaiahu (Shaya) Fainman

Department of Electrical and Computer Engineering, University of California San Diego, La Jolla, CA, 92093-0407 USA

We discuss nanoscale metal-dielectric-semiconductor resonant gain geometries to create a new type of light emitters focusing on three key aspects: second order intensity correlation characterizations, direct modulation and coupled nanolasers dynamics.

Ultrafast nonlinear phonon response of few-layer hexagonal boron nitride(h-BN)

Taehee Kang[(1)], Jia Zhang[(1)], Achintya Kundu[(1)], Klaus Reimann[(1)], Michael Woerner[(1)], Thomas Elsaesser[(1)], Bernard Gil[(2)], Guillaume Cassabois[(2)], Christos Flytzanis[(3)] (Presenter), Giorgia Fugallo[(4)], Michele Lazzeris[(4)], Ryan Page[(6)] and Debdeep Jena[(6)]

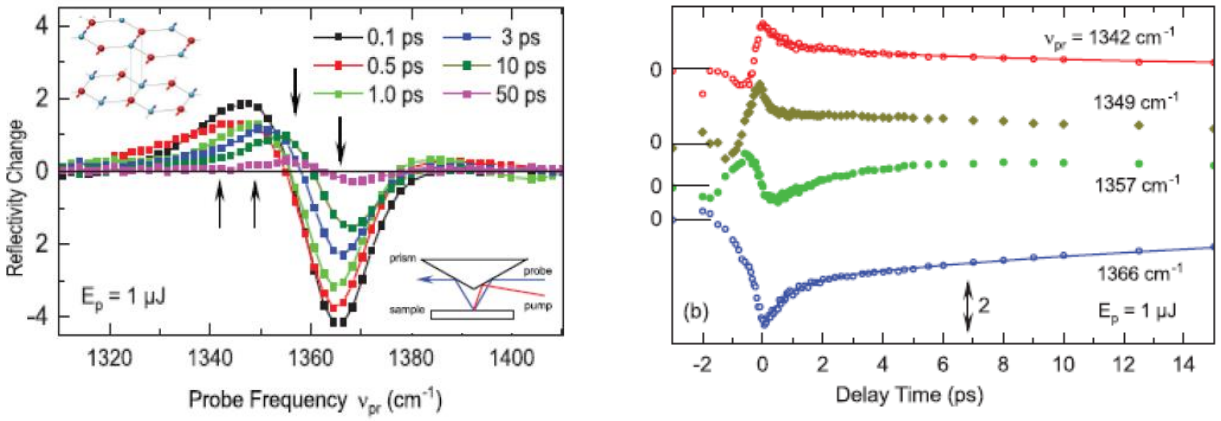
1. *Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, 12489 Berlin, Germany*
2. *Laboratoire Charles Coulomb (L2C), UMR 5221 CNRS-Université de Montpellier, F-34095 Montpellier, France*
3. *Laboratoire de Physique, Ecole Normale Supérieure, Université PSL, F-75231 Paris, France*
4. *CNRS, UMR 6607, Laboratoire de Thermique et Energie de Nantes (LTeN) Polytech Nantes, Université de Nantes, F-44306 Nantes, France*
5. *Sorbonne Université, CNRS UMR 7590, MNHN, IMPMC, F-75005 Paris, France*
6. *Cornell University, Department of Materials Science and Engineering, Ithaca, New York 14853,*

Two-dimensional nm-thickness crystal materials[1]are attracting widespread interest at both the fundamental and applied levels for a wide range of fields; because of their high surface area and possibility of interfacing with other 2D materials specific quantum features can be singled out, amplified and exploited for the conception of new functionality devices.

In this context the few layer hexagonal boron nitride (h-BN) with its specific structure has a high potential[1] for applications in particular in optoelectronics, nanophotonics and quantum opto-mechanics up to the visible optical range; it results by the formation of rigid flat 2D monolayers with B and N atoms alternating in hexagonal rings and each covalently σ-bonded in sp^2-configuration with three nearest neighbors of the other species resulting in a rigid 2D structure lacking space inversion symmetry (symmetry D_{2h}); these flat 2D layers are symmetrically entangled with van der Waals forces involving orbitals perpendicular to the monolayers much weaker than the covalent BN bonds in the planar sp^2 configuration resulting in a structure with highly anisotropic characteristics in particular opto-electro-mechanical; because of the high band gap, close to the 6 eV, these characteristics are strongly related to the state phonon configuration[2]and phonon-phonon couplings connected with distinct intraplane and interplane atomic motion and to their response to intense resonant EM fields. While phonon dynamics have been studied to some extent in bulk h-BN, a centrosymmetric crystal[3], this is not the case for the few layer thick h-BN.

Here we present the first fs pump-probe study[4,5] of the strong high frequency TO phonon excitations at 1360 cm^{-1} in few layer h-BN, revealing the TO phonon lifetime, the time-scale of energy redistribution between lattice modes and the coupling between TO and interlayer motion related to the sharing and breathing modes split into a multitude of phonon branches of frequency 1-2 orders of magnitude lower than that of the TO-phonon at 1360 cm^{-1} some of which are Raman active and are generated by impulsive Raman scattering within the pump bandwidth.

The ultrafast nonlinear TO phonon response of a few-layer h-BN sample of average thickness 2.5 nm corresponding to 8-9 h-BN layers, grown directly on a sapphire substrate is studied in temporally and spectrally resolved pump-probe measurements with femtosecond mid-infrared pulses. For the purpose independently tunable pump and probe pulses were generated in two home-



built optical parametric amplifiers driven by a Ti:sapphire oscillator/amplifier system. The energy of the pump pulses was varied between 70 nJ and 1 µJ, the probe pulse had an energy of 10 nJ. The spectral resolution was 2 cm^{-1}. Both pump and probe pulses are linearly polarized and interact with the sample in s-polarization.

Nonequilibrium dynamics of transverse-optical (TO) phonons and low-frequency interlayer shear and breathing modes are mapped in femtosecond midinfrared pump-probe experiments[4,5]. In the two figures above the measurements of the reflectivity change and the time-resolved pump-probe evolution are shown with pump energy E_p = 1.0 µJ. Time-resolved changes of TO phonon absorption reveal a TO phonon lifetime of 1.2 ps, while low-frequency excitations decay with a time constant of 22 ps. The coupling of intralayer TO and interlayer motions manifests in a quasi-instantaneous redshift of the TO phonon resonance by some 10 cm^{-1}.

Theoretical calculations account [4,5] for the coupling scenario and underline the relevance of interphonon interactions for the nonlinear phonon response. Motions of stacked BN planes relative to each other give rise to rigid-plane shear and breathing/compression modes at low energy; with finite number of layers[2,4] the discretization of the k-vector perpendicular to the layers results in an increasing number of optical branches and the coupling of intralayer and interlayer modes plays a crucial role and gives rise to the biexponential relaxation regime and the TO mode redshift.

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Electrically tunable large aperture lenses using nematic liquid crystals

O. Sova, A. Zohrabyan, V. Presniakov, A. Bagramyan and T. Galstian

Université Laval,

2375 rue de la Terrasse, Québec, Canada

G1V0A6

galstian@phy.ulaval.ca

Abstract :

Liquid crystal (LC) displays and spatial light modulators are well-known examples of application of nematic LC (NLC) materials [1]. Much less is known about their applications in electrically tunable LC lenses (TLCL) [2]. These devices may be fabricated as flat gradient index (GRIN) elements by using currently available manufacturing lines.

In the present talk we shall present a design of electrodes [3] that allows us to create large aperture TLCLs with bipolar response, that is, providing both focusing and defocusing. The particularity of the proposed approach consists in the form of the electrode which is much easier for fabrication in contrast to traditional approaches [4, 5].

We shall briefly review the previous approaches, describe their advantages and drawbacks, and we shall then describe our design. After a short theoretical introduction of its geometry and driving method, we shall present the basic experimental data describing the obtained phase profiles (in various modes of its operation) as well as corresponding intensity distributions in space.

New development directions, for example for lenses with significantly larger diameters (up to 50 mm) will be mentioned and very briefly discussed.

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Plasmonic photochemical process for preparation of metallic nanopore arrays

German Lanzavecchia[1, 2], Joel Kuttruff[3], Andrea Doricchi[1,4], Alba Viejo Rodríguez[5], Nicolò Maccaferri[5,6]*, Roman Krahne[1], Denis Garoli[1]*

[1]Istituto Italiano di Tecnologia, via Morego 30, I-16163, Genova, Italy.
[2]Dipartimento di Fisica, Università di Genova, Via Dodecaneso 33, 16146 Genova, Italy.
[3]Department of Physics, University of Konstanz, Universitätsstrasse 10, 78464 Konstanz, Germany
[4]Dipartimento di Chimica e Chimica Industriale, Università di Genova, Via Dodecaneso 31, 16146, Genoa, Italy.
[5]Department of Physics and Materials Science, University of Luxembourg, 162a avenue de la Faincerie, 1511 Luxembourg, Luxembourg
[6]Department of Physics, Umeå University, Linnaeus väg 24, 901 87 Umeå, Sweden
**denis.garoli@iit.it, *nicolo.maccaferri@umu.se*

Abstract: We report a process for fabricating sub-10 nm nanopores via photocatalysis caused by electromagnetic field enhancement in plasmonic structures, which immersed in metallic salt solutions triggers hotspots for metallic deposition causing pore diameter shrinkage.

1. Introduction

Nanopore technology is the core of third generation sequencing, and solid-state nanopores are now one of the main topics in single molecule sensing [1-3]. Fabrication of sub-10 nm pores usually requires complex multi-steps processes. Common strategies for plasmonic nanopore fabrication lack reproducibility and are only suitable for the preparation of single pores. Other methods used until now increase the thickness of the pore significantly, which reduces the spatial resolution. Therefore, metal deposition processes that can be spatially controlled on the nanoscale are highly desirable in the nanofabrication of pores. Ai et al. [4] showed that the growth of Ag nanoparticles can be controlled by means of plasmonic modes in the areas of maximum field enhancement in gold nanohole arrays. Zhou et al. [5] reported a similar experiment where light was used to guide the growth of Ag nanoparticles on nanobowl arrays. Here, we demonstrate a new scheme to prepare arrays of plasmonic nanopores by using a plasmon-enhanced photochemical reaction to prepare Au-Ag and Au-Au nanorings with the initial inner diameter of the pore down to few nanometers. This process is reproducible and can be applied over large arrays in a controllable way. Numerical simulations are used to estimate both the EM-field enhancement and confinement inside the plasmonic nanopore. We characterized the nanopores by electrical measurements and surface-enhanced Raman scattering (SERS) detection of a double-stranded DNA. Our results show that they can find interesting application in single entities (molecule or nanoparticle) detection by means of electro-optical read-out.

2. Methods

Sample fabrication

Freestanding Si_3N_4 membrane chips were prepared, following standard membrane fabrication procedure. Hollow nanopillars were fabricated by using already reported procedure [6]. In particular, focused ion beam patterning using different ion currents allowed for the preparation of different diameters in the final pillar/Au ring. The Au top layer was removed with gold etchant with a following oxygen plasma treatment to clean the upper part of the resist layer. A development in acetone with a further oxygen plasma produced the final hollow dielectric structure. A thin layer of Ti(2nm)/Au(30 nm) was then deposited on top of nanopillars via electron beam evaporation.

Plasmonic photochemistry

Was immersed in 30mL 10mM $AgNO_3$/ 1.8 mL 6mM Sodium citrate solution, and then illuminated with white light (Xe lamp 50 W / 20X 0.95NA objective) or 638 nm laser light for different time durations, following a protocol similar to that reported in [1]. For gold deposition $HAuCl_4$ [7] or $AuBr_3$ solution was used. Samples were then rinsed in isopropyl alcohol and dried under N2 flow.

Electrical characterization

Electrical measurements were conducted in 10 mM Tris-HCl/ 1 mM EDTA buffer solution, under 650 nm, and 460 nm LED light and no light conditions inside a nanopore reader [8] using Ag/AgCl electrodes. The reader and its computer controlled-software were developed by Elements SRL (Cesena, FC, Italy). Pore diameter was calculated from standard I-V electrical characterizations [9].

3. Results

The plasmon-enhanced photochemical reaction drives the seeding and growth of metallic structures with different efficiencies depending on the electromagnetic (EM) field confinement and enhancement that can be achieved in the ring structure used as starting point. Exposition times of up to 60 min under white light were performed in order to study the velocity of growth. Exposition under laser light resulted in the destruction of the samples. Both Au and Ag nanostructures can be grown, even if clear differences exist between the two metals. SEM and EDS analyses have been performed in order to confirm the local deposition. In particular, EDS analyses confirmed that the Ag growth is localized on the pillar and negligible deposition was observed on the metallic substrate. The prepared structures can then be annealed (200°C, 20 min) in order to obtain smooth and narrow nanopores with diameter down to 4 nm as demonstrated by electrical and SEM characterizations. Thermal annealing also modified the shape of the ring producing a curvature in the inner part that can affect the field confinement. To support the latter claim, numerical simulations were performed to evaluate the EM-field confinement and enhancement that can be achieved with the proposed structures, with a value in EM-field intensity enhancement exceeding 100. Noteworthy, this enhanced EM-field can be used to perform optical spectroscopies such as fluorescence, FRET and SERS. As proof of concept, we performed SERS measurements of double-stranded DNA. Finally, we measured the I-V curve of the single plasmonic nanopores illuminated with LEDs emitting at different wavelengths (460 nm and 650 nm), respectively, on and off resonance with the plasmonic modes of the pore. We observe an increasing of the pore conductivity for illumination on resonance, in agreement with the simulated EM-field enhancement in the Ag ring. This effect results also in local plasmonic heating of the pore, which can be used to perform thermoplasmonic trapping of single molecular entities.

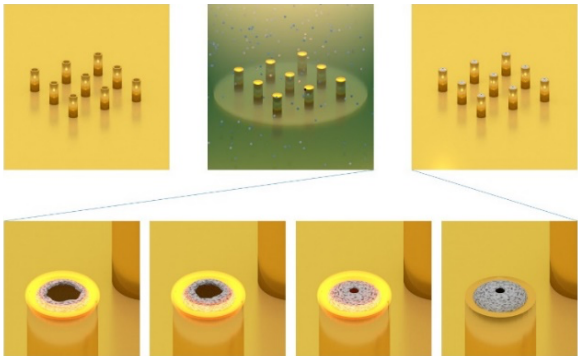

Figure 1. Illustration of the plasmonic photochemical process to fabricate metallic nanopore arrays. An array of metallic rings is illuminated with a proper light source and immersed in metallic salt solutions.

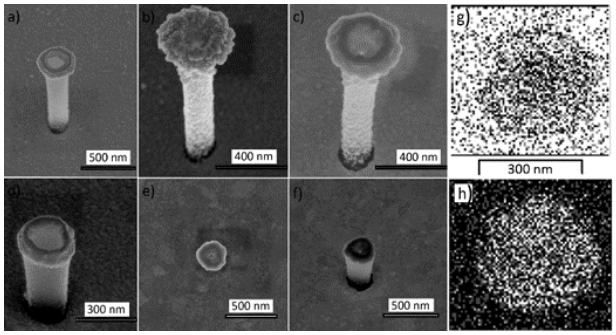

Figure 2. (a),(d) Examples of Au ring on top of dielectric pillars prepared at 24 and 80 pA, respectively. (b) Morphology of the ring after 40 minutes of Ag seeding. (c),(e),(f) Examples of Ag nanopore morphology after thermal annealing. (g) EDS map of the ring – Au channel; (h) EDS map of the ring – Ag channel.

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A new dynamic holographic light sculpting modality

Jesper Glückstad
SDU Centre for Photonics Engineering
Univ. of Southern Denmark
DK-5230 Odense, Denmark

j.gluckstad@gmail.com

The ability to dynamically sculpt coherent or semi-coherent light in 2D and 3D has paved the way for many studies and applications and can be considered a key enabling tool in modern science. Dynamic light sculpting can serve as generic technology for volumetric controlled light-matter interaction that can benefit various novel applications such as microbiology, neuroscience [1,2], optical manipulation at microscopic scales [3–5], non-invasive cell sorting [6], materials processing [7], microfabrication [8,9], controlled photo-stimulation [1,10], cell surgery [11], advanced light microscopy [12,13], to name just a few. Hence, new and disruptive light sculpting modalities that can offer promising enhancements are always being explored and developed.

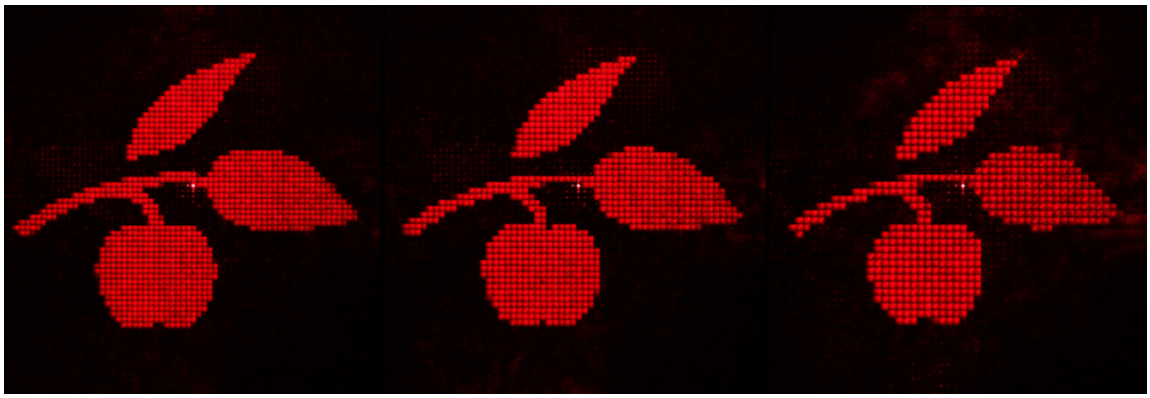

Fig. 1: Speckle-free experimental reconstructions of the SDU university-logo by HoloTile on a phase-only Spatial Light Modulator (SLM) for various output diffraction pattern resolutions.

HoloTile - experimentally shown in Figure 1 above for +90 % photon efficient phase-only projected diffraction patterns - aims to solve the challenge of rapid and speckle-free light sculpting without the need for time-averaging techniques - a challenge that exists in several fields of optics, biophotonics, additive manufacturing, display technology and others. HoloTile is our novel and recently patent-filed approach [13, 14] to very rapid and speckle-reduced digital holography and works by multiplexing the phase-shaped Point Spread Function (PSF) of the holographic system to match the inter spatio-spectral spacing in the far field reconstruction, that occurs due to tiling on a high resolution SLM or Diffractive Optical Element (DOE). In particular, HoloTile provides four new unique key features as Computer Generated Holography (CGH) modality for high resolution phase-only SLMs, reconfigurable DOEs or new meta-surface MOEs:

- A 100x speed improvement over standard CGH-modalities
- Substantial speckle reduction by matched tiling and PSF-shaping
- Real-time dynamic and output 'pixel' discretized digital holograms
- Lens-free scaling or zoom by software adapted HoloTile phase-encoding

Very fast camera-in-the-loop in-situ optimisation is made possible by the 100x speed-improvement over standard CGH-modalities and thereby makes HoloTile potentially very attractive for a variety of applications including:

- Ultrafast additive manufacturing
- Laser material processing in parallel
- Volumetric bioprinting
- Rapid laser engraving, welding, machining
- Two-photon excitation in optogenetics and voltage imaging
- Multi-color and multi-plane diffraction
- Photon-efficient phase-only display technology
- Real-time adaptive optics embodiments including aberration correction
- Temporal focusing HoloTile for parallel two-photon excitation
- Digital quantum holography

In future research and development, we aim to demonstrate some of these potential advantages of HoloTile in one or more of the above dynamic or static light diffraction applications. Our ultimate aim is to offer HoloTile as a stand-alone light engine that can be integrated with ease both hardware- and software-wise [15, 16] in existing optics and photonics configurations for both industry and academia.

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Ultra-High-Speed X-ray Imaging of Laser-Driven Processes

J. Grenzer[1], A. Rack[2], M. P. Olbinado[2], T. De Resseguier[3], A. Danilewsky[4], D. Kraus[5] and T. Cowan[1]

[1] Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
[2] ESRF – The European Synchrotron, Grenoble, France
[3] Institut Pprime, CNRS - Universit de Poitiers, Futurosscope Chasseneuil, France
[4] Crystallography, University Freiburg, Freiburg, Germany
[5] Institut für Physik, University Rostock, Rostock, Germany

Time-resolved in-situ or/and in-operando X-ray experiments open a very direct and a natural way to study the formation and transformation of materials during relevant technological processes. Synchrotron light sources produce X-ray pulses with high temporal resolution (ESRF: ~100 ps pulses up to 5.6 MHz in the 16 bunch mode) and are able to reach high X-ray energies (>25 keV). Hard X-rays are perfectly suitable for visualization of transient processes in optically opaque materials even for objects of several mm in size. The MHz pulsed time structure, tunable energy bandwidth, high brilliance, and the high degree of spatial coherence of hard X-rays allow transient processes to be tracked directly by ultra-high-speed image acquisition techniques [1].

Here, we report on an in-situ real time investigation of high-power (>1 J), nano seconds single-pulsed laser-driven irradiation processes leading either to surface ablation, crack propagation or shock generation [2]. While macroscopic changes (i.e. density changes or cracks) in bulk materials can be quite easily deduced from X-ray phase contrast imaging, diffraction imaging is used to probe changes of the crystal lattice structure.

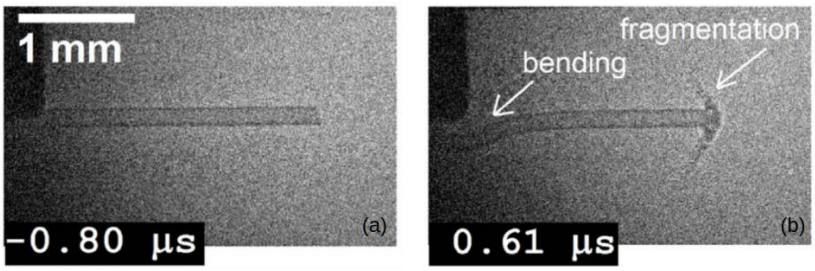

Figure 1: X-ray phase-contrast images of a graphite rod (125 µm × 125 µm × 2 mm) subjected to shock applied on the right surface parallel to the rod axis, directly impacting the free face of the rod to generate shock compression. (a) shows the rod before impact and (b) after the shock wave reached the solid support on the left. The energy of Nd:YAG laser (at 532 nm; pulse length ~10 ns) was 4 J at a spot diameter 100 µm.

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New optical features of designer 2D materials and machine-learning assisted characterization

Shengxi Huang[1]

1 Rice University, USA

2D materials offer enormous opportunities to build designer structures with widely tunable properties. The precise atomic engineering and quick characterization approach are critical to advance the application of designer 2D materials. This talk will introduce new optical features of designer 2D materials [1-4] with a focus on atomic substitution in monolayer WS_2 [1]. The engineering of 2D materials presents unique opportunities for optoelectronic device and quantum information platform. When designing optoelectronic devices of 2D materials, spectroscopic permittivity of 2D material is a key parameter. While ellipsometry has been used to measure permittivity, it requires simple device structure, non-trivial parameter fitting, and special setup. This talk will also present a new machine-learning assisted approach to measure permittivity of 2D materials embedded in complex device structures without model fitting, which can facilitate a quick, accurate, and in-situ characterization of 2D and other thin film materials [5].

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Towards Nonlinear Hybrid Lattice–Waveguide Structures

Mikko J. Huttunen, J. Kelavuori, and Ali Panahpour

Photonics Laboratory, Physics Unit, Tampere University, FI-33014 Tampere, Finland

An important trend in nonlinear photonics is to improve the energy-efficiencies of devices by moving towards small-scale and integrated components. This challenge is difficult to solve by conventional nonlinear material platforms, motivating to search for alternatives. Nonlinear metasurfaces have recently emerged as a promising candidate to enable nanoscale/flat nonlinear optics [1,2]. Here, we discuss our work to develop more efficient nonlinear metamaterials by using high-Q-factor collective lattice excitations known as surface lattice resonances (SLRs) [2].

The SLRs are associated with very narrow spectral features (Q~1000), while their properties can be intuitively understood by using the lattice-sum approach (LSA). Here, we show how the conventional LSA formalism can be extended to multipartite arrays, arbitrary angles of incidence, and hybrid lattice–waveguide structures. We will also show how by placing metasurfaces inside waveguiding structures, the coupling between nanoparticles can be dramatically increased providing a clear route towards higher Q-factors. In addition, the associated waveguide modes become strongly dispersive near their cut-off frequencies (Fig. 1a), providing a novel mechanism to further increase the attainable Q-factors (Fig. 1c). This is particularly interesting, since it may enable to experimentally realize ultrahigh-Q-factor metasurfaces (Q > 23 000, see Fig. 1b) with smaller number of nanoparticles.

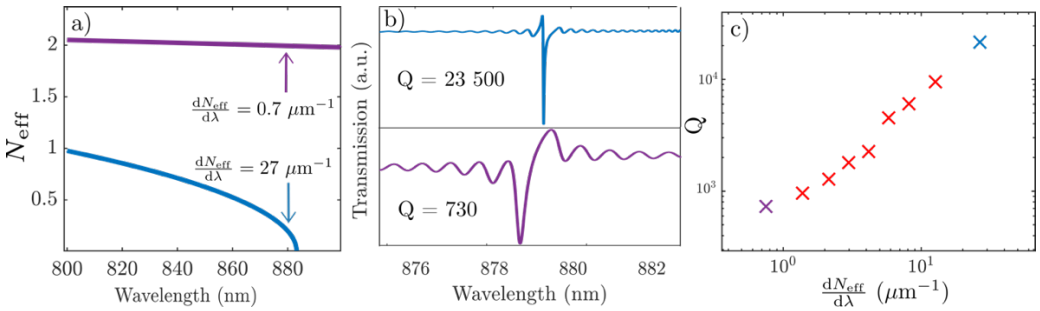

Figure 1. **a)** Effective indices associated with rectangular metal–insulator–metal waveguide modes [waveguide dimensions are 300x500nm^2 (blue), 600x1000nm^2 (violet)]. By waveguide and metasurface design (aluminum spherical nanoparticles, radius 37 nm, lattice period 4000 nm), the SLR can be made to coincide with the cut-off frequency of the waveguide near 880 nm (blue), considerably increasing the mode dispersion of the associated mode and the Q-factor of the SLR. **b)** The estimated Q-factors of the SLRs clearly increase near the vicinity of the cut-off frequency, reaching ultra-high values >23 000. **c)** The dependence of the Q-factor on the mode dispersion for the studied SLRs. Here, in total nine SLRs of increasing order was studied (violet: 1st-order, blue: 9th-order).

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Nonlinear Chiro-optics. Chiro-optical Parametric Amplification and Oscillation

F. Jonsson[(1)], G. Agrawal[(2)] and C. Flytzanis[(3)]

1a Mycronic AB, SE-183 03 Täby, Sweden, 1b Division of Electricity, Dept of Electrical Engineering, University of Uppsala, SE-751 03 Uppsala, Sweden
2 The Institute of Optics, University of Rochester, Goergen 515, Rochester, NY 14627-0186, USA
3 Laboratoire de Physique, Ecole Normale Supérieure, Paris 75231 Paris Cedex 05, France

Chiral media are involved and studied in many disciplines including optics and photonics. The optical chirality endows a chiral medium with intriguing properties resulting from specific nonlocal features of its interaction with an electromagnetic field and nonlocal quantum optical aspects. Their real impact on transverse features of the propagation modes results in phenomena such as optical activity, rotatory dispersion, polarization state changes and issues related to reciprocity and the breakdown of spatial inversion symmetry allowing for outstanding discrimination from the background and having strong impact on their couplings and with the environment. The nonlinear optical effects are very sensitive to these issues and are attracting growing interest at both the fundamental and applied levels.

Here we present an analysis of the chiro-optical parametric amplification and oscillator operation involving interaction of three light fields of frequencies ω_p, ω_s and ω_c , the pump, signal and idler respectively with $\omega_p=\omega_s+\omega_c$. The equations governing the propagation and evolution of the three fields in the transparency region of an optical active crystal are derived extending the analysis of Armstrong et al. [1] to include effects of optical activity [2]: this splits each plane wave mode into two left and right circularly polarized modes with different k-vectors, their difference resulting from the gyrotropy leading to double phase matching requirements[3][4].

The analysis is carried out for the case of waves propagating along the optic axis of a crystal of point symmetry 32, specifically[4] $NaClO_3$ and $NaBrO_3$, with particular attention to the phase mismatch issue, a quintessential nonlocal feature in nonlinear optics, that has crucial impact on the efficiency of nonlinear optical processes. We have analyzed the case of a singly resonant chiroptical parametric oscillator which involves a cavity and accordingly intracavity feedback interactions [5] and evaluated the impact of the doubling of the phase mismatch. The case of the backward chiro-optical parametric oscillator presents interesting features with a double configuration for a chiral crystal, but its realization is hampered by serious problems as in the case of achiral crystals [6]. The parametric fluorescence [5] too shows interesting aspects in the context of quantum chiro-optics.

It is clear from above considerations that nonlocality is an essential feature in chiro-optics and its impact is enhanced in nonlinear chiroptical effects, with increasing complexity for higher order effects such as those involving the optical Kerr effect, degenerate four wave mixing, chiro-optical solitons and emitters with new applications combined with chiral quantum optical and optomechanical aspects.

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Strategies for enabling optical tweezers as a tool for environmental monitoring and biomedical applications.

Pedro A. S. Jorge,[1,2], *Joana Teixeira*[1,2], *Vicente Rocha*[1,2], *Felipe Coutinho*[1,2], *José A. Ribeiro*[3], *Nuno A. Silva*[1,2]

1 Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto, Portugal. 2 INESC TEC, Centre for Applied Photonics, Porto, Portugal. 3 CIQUP/IMS, Department of Chemistry and Biochemistry, Faculty of Sciences, University of Porto, Rua do Campo Alegre 687, 4169-007, Porto, Portugal.

The ability to select, separate, manipulate and identify single cells or other type of microparticles is a critical ability for modern biotechnology. In the biomedical field, for instance, sensing at the single cell level can provide insights into its dynamics and heterogeneity, yielding information otherwise unattainable with traditional biological methods where average population behavior is observed. When analyzing environmental samples, on the other hand, identifying and discriminating different types of living cells such as algae or different types of microplastics, can be an asset for better understanding ecosystem dynamics at the microscale.

To attain such capabilities, minimum invasive techniques are required and trapping and accurate manipulation without physical contact is an important requirement. Presently some of the most attractive solutions available rely on the use of optical trapping techniques using single beam optical tweezers [1]. While many different approaches have been reported and successfully applied for in vitro, and even some in vivo assays, there are still many challenges to overcome before this can be considered a standard tool.

In this work the combination of several instrumental and processing technologies for the implementation of intelligent optical tweezers, are described. Different strategies, including interferometry, automation and machine learning, are used in synergy, enabling a more robust manipulation, and identification of different type of microparticles and cells. Validation results will be presented with different types of targets, including microalgae, molecularly imprinted polymers and biofunctionalized nanoparticles.

Acknowledgements

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Photovoltaic-Liquid Crystal Spatial Light Modulators and their Non-Invasive Characterisation

Malgosia Kaczmarek[1]
Denitsa Bankova[1], Nicolas Brouckaert[1], Oleksandr Buchnev[1], Nina Podoliak[1],
Giampaolo D'Alessandro2, Thomas Heiser[3]a
[1]*School of Physics and Astronomy,* [2]*School of Mathematical Sciences,*
University of Southampton, Southampton, UK,
[3]*ICube Research Institute, Université de Strasbourg, Strasbourg, France*

Liquid crystals are essential components of many optoelectronic devices, from large displays to flexible thin screens, waveplates, smart glasses and AR/VR systems. When developing new applications or extending the functionalities of the existing liquid crystal devices, an important aspect to consider is that the modification of a specific property can impact other, so that the overall performance of a device is, therefore, determined by the interplay of a large number of parameters, such as voltage threshold, voltage holding ratio, elastic constants, viscosity or optical quality. Some parameters, such as anchoring energy or pretilt angle particularly important in devices with active alignment materials as photosensitive layers or structured substrates that can change their electrical or alignment properties as a function of the incident light intensity or frequency. In addition, capturing such static and dynamic properties is most useful when carried on an actual, final working cell or modulator, and done in a non-invasive way.

We present a versatile method that successfully captures static and dynamical properties of either pure or doped liquid crystals, including those in optically thin cells, and modulators driven by a photovoltaic unit. The underpinning measurement methodology is based on cross-polarised intensity (CPI) measurement, coupled to an Ericksen-Leslie model of the liquid crystal alignment [1-2]. The measurement process consists of detecting the intensity of a monochromatic light that propagates through a cell sandwiched between two cross-polarisers as a function of the amplitude

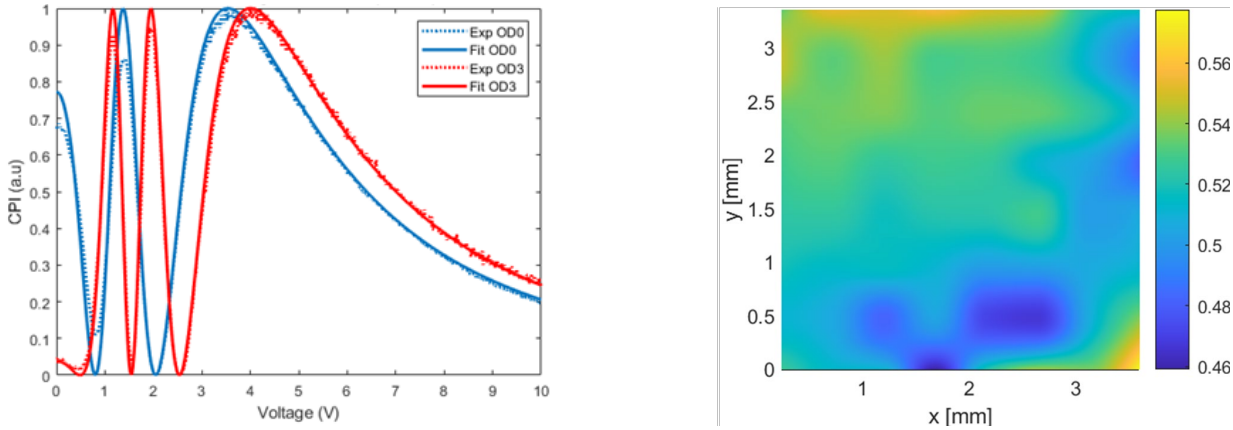

Figure 1: CPI measurements (dotted lines) and corresponding fitted line (solid lines) at 532nm of PM6:ICBA PSLMs filled with E7 (left panel performed at different optical densities (OD). The strong shift of the CPI from OD3 to OD0 conditions is due to the additional DC voltage generated by the PVU upon illumination in OD0 conditions (left panel). OD0 corresponds to full light intensity (2.2mW over a 6mm^2 area) and OD3 is in the dark, corresponding to 0.1% of the previous intensity. Photovoltage distribution of a PSLM over a 3.5mm^2 area (right panel)

and frequency of the voltage applied to the cell. The experimental trace is then fitted to the prediction of the model, estimating a range of liquid crystal and device parameters: the three liquid crystal elastic constants, bend, twist and splay [2], the liquid crystal rotational viscosity [1], the polar alignment angle and anchoring energy at the surface and the cell thickness. The method is applicable to doped liquid crystals [3] and cells with optical thickness as small as π [4].

Photovoltaic spatial-light modulators (PSLMs) use an organic photovoltaic unit as an integrated power source to drive and control light transmission in liquid crystal modulators [5] and can operate as self-powered devices. The structure of the modulators includes a twisted nematic liquid crystal layer and an organic donor-acceptor bulk heterojunction, the latter being in contact with the liquid crystal and also acting as a molecular alignment layer. Under illumination, the photovoltage can be sufficiently strong to partially reorient the liquid crystals and thus change the optical transmittance of the modulator, without requiring an external power source.

The optical method presented here was successfully extended to determine the core parameters of such PSLMs: apart from characterising the main liquid crystal parameters, it is also capable of capturing the photovoltaic properties, such as the photovoltage generated and photoconductivity (figure 1 left panel). The analyser also proved invaluable in monitoring of aging of PSLMs. In addition, it can probe either a single spot or a large area of the PSLMs. This allows us to map spatial changes in pre-tilt, anchoring, and uniformity of the alignment across the whole panel of the modulator (figure 1 right panel).

While this optical method is ideal for the characterisation and monitoring of performance of devices with nematic liquid crystals, different approach is needed for the cases of structured liquid crystals. For example, liquid crystals with complex gratings, patterns or with dispersed azo-functionalised gold nanoparticles, assembled using layer structure or defect points and lines. The analysis of such complex patterns was successfully achieved [6] using a mathematical method, based on topological data analysis and learning, to detect the stability, characterise complex, dynamic processes and quantify their dimensional and structural characteristics.

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Optical manipulation of resonant nanoparticles for thermal and rheological measurements

Pawel Karpinski

Faculty of Chemistry, Wroclaw University of Science and Technology,
Wyb. Wyspianskiego 27, 50-370 Wroclaw, Poland,
pawel.karpinski@pwr.edu.pl

Optical trapping is a widely used technique allowing for remote and precise manipulation of particles and measurement of the forces acting on them. Optical forces can be enhanced when particle resonantly interact with light, like in case of e.g. plasmonic and high-index dielectric nanoparticles. These particles have the cross section for the light-matter interaction much larger than their physical size. This makes them perfect nanoantennas for bio-sensing, SERS, local temperature measurements, and heat-therapy. It also allows for efficient transfer of spin and orbital angular momentum of light for realization of fast nanorotors. We show that the circularly polarized Laguerre-Gaussian beam allows to simultaneously rotate a gold nanorod about its symmetry axis while revolve it around the beam's symmetry axis. [1] We also show that the trapped Silicon nanorods can be rotated at high frequencies comparable to plasmonic particles. Analysis of strong Raman scattering of Si and rotation motion of Si nanorod allows to estimate the temperature increase of the trapped particle and its surrounding. [2]

From the other hand, strong interaction of resonant nanoparticles with light makes their optical trapping in 3D challenging and limited to a narrow size range due to the strong radiation pressure. We developed a novel optical trapping configuration based on counter-propagating laser beams generated through focus splitting in a uniaxial birefringent crystal and reflection from a mirror. We demonstrate this application by trapping and rapid rotation of gold nanorods that are impossible to trap in 3D using conventional laser tweezers. We also show that the counter-propagating laser beams interfere and form standing wave pattern, which allows to trap nanoparticles in different fringes. [3]

Presented studies can be connected in a platform, which allows one to investigate micro-rheological properties of complex fluids in different spatial arrangements and at different temperatures. One of the interesting complex fluid is a polymer network with azo-benzene groups attached to its chain or chrominic liquid crystals with addition of azo-benzene dye.

Acknowledgements

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Super-high grating period chiral photonic crystals for ultrafast laser vector fields manipulations

[1]I. C. Khoo, [2]C.-W. Chen, [3]T.-M Feng and [3]T.-H Lin

1.Electrical Engineering, Pennsylvania State University, University Park, PA 16802 USA
2. Department of Applied Physics, Yale University, New Haven, CT 06520, USA
3. Department of Photonics, National Sun Yat-sen University, Kaoshiung, Taiwan

Abstract

We present a detailed study of the dynamical evolution of cholesteric helical self-assembly and defect formation in the bulk of extraordinarily thick cholesteric liquid crystals under various applied electric field conditions, and a thorough exploration of how applying fields of vastly different frequencies can eliminate and/or prevent formation of unremovable defects and to control the alignment of cholesteric helices in the entire bulk. We have developed a room-temperature dual-frequency field assembly technique that enables robust room-temperature fabrication of stable well-aligned cholesteric liquid crystals to unprecedented thickness (over 2 mm thick containing nearly10000s of grating periods). The method entails first a low-frequency field to create hydrodynamical instabilities and mesh the CLC mixture to a state with completely randomized orientation of the cholesteric helices, and then a high- frequency electric field to reorient all the helices into uniform standing helices.

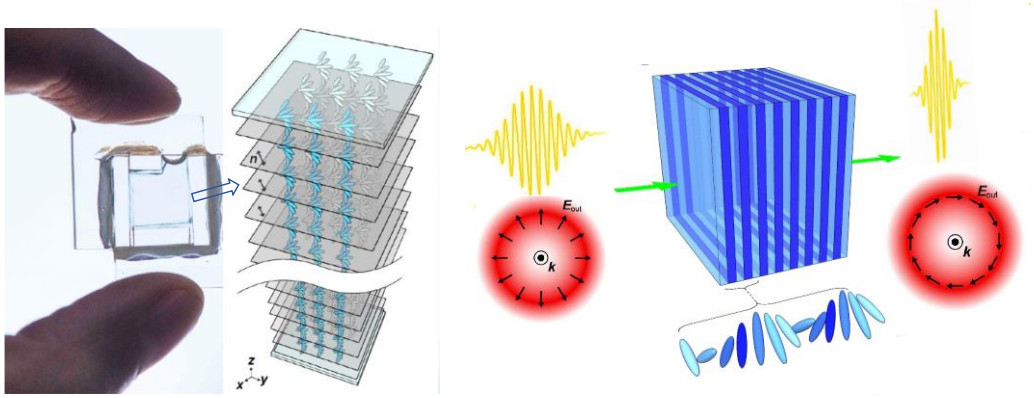

Figure 1. (a) Photograph of a SN-CPC made with cholesteric liquid crystals; (b) schematic depiction of orthogonal polarization states switching and ultrafast [femtoseconds] laser pulse self-compression with SN-CPC.

Optical properties of a photonic crystal depend strongly on the period number N [thickness/pitch of the spiral]. With a very high N (usually, thousands), a photonic crystal exhibit properties *approaching* one with *infinite* periods. These super-high N chiral photonic crystals (*SN-CPC*) with maximal density of states open up new and broad spectral bands where the transmission can be near unity while the optical responses are highly efficient, contrasting greatly with the less desirable operation regime near the

photonic band-edge with low transmission and high optical dispersions. They thus offer many new possibilities for fundamental pursuits and applications impossible with their thinner counterparts [1-4]. For example, in ultrafast (nonlinear) all-optical modulation/switching with picosecond – femtoseconds pulsed lasers, one can expect to realize polarization switching, pulse shaping, and other processes with much lower activation thresholds than using inorganic photonic crystals or metasurfaces; in conjunction with the circular birefringence, SN-CPC's enable rotation/switching of the polarization states of complex laser vector fields to their orthogonal states, c.f. Fig. 1. The operation spectral regime can be extended from the visible to the mid-infrared regime that is beyond the reach of existing or developing CPC.

As a single mm-thick planar optical element that is highly transmissive and requires no additional optical/electronic accessories, SN-CPC are highly promising compact alternatives to bulky optics used in conventional free-space ultrafast pulse modulation systems.

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What power does it take to modulate refractive index today

and in the foreseeable future?

Jacob B Khurgin

Johns Hopkins University

Baltimore MD 21218 USA

Whether one likes it or not, but there has been a rising wave of renewed interest to time modulated optics (previously known and understood as parametric processes) where strong modulation of permittivity begets such appealing concepts as nonreciprocity, synthetic dimensions, time reflection and time crystals and so on. Many of these concepts have been successfully demonstrated in the low frequency, RF domain, while in the optical domain the progress has been less spectacular, which is no wonder, given that modulation of refractive index in time domain (unlike in space domain)does not conserve energy, i.e., one needs to introduce a certain amount of energy per unit volume to change the refractive index[1]. There exist many methods of index modulation, starting with Pockels and Kerr electro-optic effects, acousto-optic and opto-mechanical effect, optical nonlinearities, thermal, carrier injection/depletion, etc. and virtually all of them had been invoked in the quest for efficient time modulated photonics. While the methods differ in terms of speed, required footprint and many other important characteristics, to the best of my admittedly limited knowledge, no rigorous comparison of energy requirements has been performed in the literature. In my talk I will try to fill this gap and provide a comprehensive analysis that will show that *independent of the modulation technique, one must supply and maintain (but not necessarily dissipate) anywhere between few times 10^3 and 10^5 J/cm^3 of energy in order to achieve relative index change on the order of 50-100% (with energy requirements increasing in sync with the increase of operating frequency).* The power requirements for most time modulated schemes can be derived from the energy requirements, as power demand differ greatly as functions of frequency of modulation, footprint, and whether various resonant enhancement schemes can be employed. The general conclusion is that unless radically new material systems are developed, the improvement of the performance of existing modulation techniques will have evolutionary rather than evolutionary character with no order of magnitude improvement in sight. I will try to argue for using collective effects and fast phase transitions to achieve future breakthroughs and hope that I will be heard.

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White Light Emission and Exciton-phonon coupling inTwo-Dimensional Metal Halide Perovskites

Balaji Dhanabalan[1], Beatriz Martin-Garcia[2], Davide Spirito[3], Sergey Artyukhin[1], Miao-Ling Lin[4], Yu-Chen Leng[4], Ping-Heng Tan[4], Seda Kutkan[1], Milena Arciniegas[1] and Roman Krahne[1]

1. Istituto Italiano di Tecnologia, Genova, Italy

2. CIC nanoGUNE, Donostia-San Sebastian, Spain

3. IHP–Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder), Germany

4. State Key Laboratory of Superlattices and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China

Metal-halide perovskite nanomaterials are highly promising for in solar cells and light emission in recent years, and their layered low-dimensional counterparts demonstrated increased stability and even greater tunability due to the huge variety of molecules available for the organic phase.[1] The band gap and emission wavelength is mainly determined by the choice of the halides and exciton confinement in the inorganic layers, and single or double octahedra-layer structures show strong confinement and large exciton binding energies. However, the band gap and exciton recombination dynamics depend also sensitively on the choice of the organic cations in the layered architecture,[2, 3] since the binding of the organic cations can induce lattice distortions that modify the band gap, and also affect the electron-phonon coupling in carrier relaxation to the band edge states.[4]

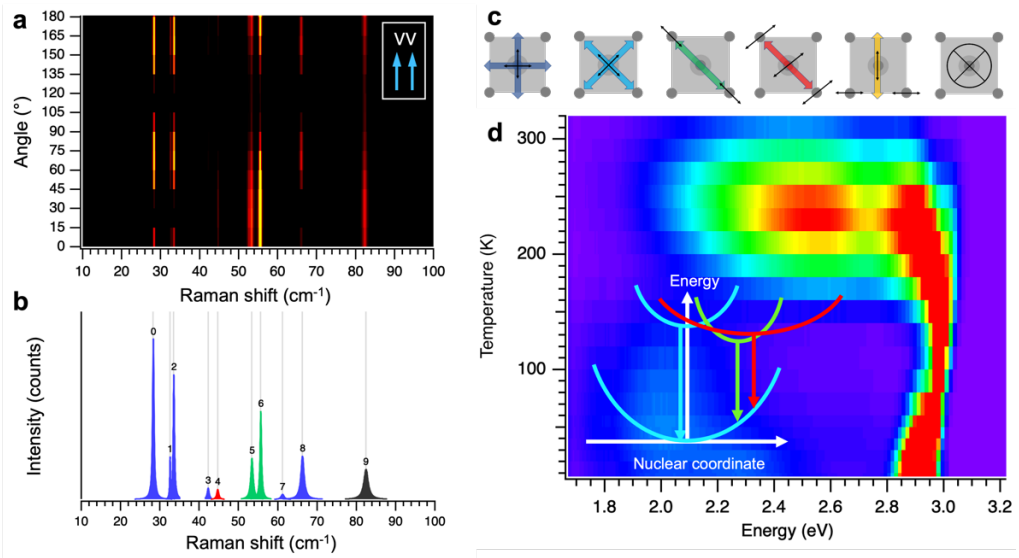

Fig. 1 (a,b) Angle- and polarization-dependent phonon modes in two-dimensional perovskites. (c) Vibrational schemes and their directionality. (d) Temperature-dependence of band-edge and broadband emission. [4]

In this talk we present a detailed study of the emission properties of metal halide perovskites in the strong confinement regime. We investigate the symmetries and directionality of the fundamental phonon modes of the inorganic lattice in single- and

double-layer metal halide perovskites, and relate our results to the structure, band gap and light emission of these materials.[2, 5, 6] We show that angle-dependent polarized Raman spectroscopy in the ultralow-frequency range (from 10 to 200 cm^{-1}) provides detailed insights on the nature of the vibrational modes, and analyse the observed symmetries by group theory and density functional theory modeling. We chose lead-bromide single layer Ruddlesden-Popper perovskites with different organic spacer molecules,[2] and low-dimensional silver-bismuth double perovskites[7] for our study, and discuss modes with isotropic, dipolar, and quadrupolar behavior, their temperature dependence, and relation to crystal phase transitions. Understanding the vibrational modes in these materials elucidates the dynamics of their light emission, and provides crucial information to control their emission color and efficiency.

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Domain Walls in Ferronematics and Geometrical Optics

Oleg D. Lavrentovich[1,2,3], *P. Kumari*[1,2], *B. Basnet*[1,2], *M. Rajabi*[1,3]

1 Advanced Materials and Liquid Crystal Institute, Kent State University, Kent, OH 44242, USA
2 Materials Science Graduate Program, Kent State University, Kent, OH 44242, USA
3 Department of Physics, Kent State University, Kent, OH 44242, USA

Spontaneous electric polarization **P** of solid ferroelectrics follows the direction of crystallographic axes. Domains of differently oriented polarization are divided by boundary defects, called domain walls (DWs), which are predominantly flat. Here we demonstrate that DWs in a ferroelectric nematic (N_F) liquid crystal, which is a fluid with no crystallographic axes, are shaped either as 2π solitons [1] or as conic sections (parabolas, hyperbolas and ellipses), depending on the surface anchoring [2]. The conics bisect the angle between two neighboring polarization fields to avoid electric charges. The remarkable bisecting properties of conic sections, known for millennia and exploited in geometrical optics, find their material realization as intrinsic features of fluid ferroelectrics. Switching of DWs by the electric field leads to new propulsive modes of ferroelectric nematics. The findings could be helpful in designing patterns of electric polarization and space charge. The work is supported by NSF grant ECCS-2122399.

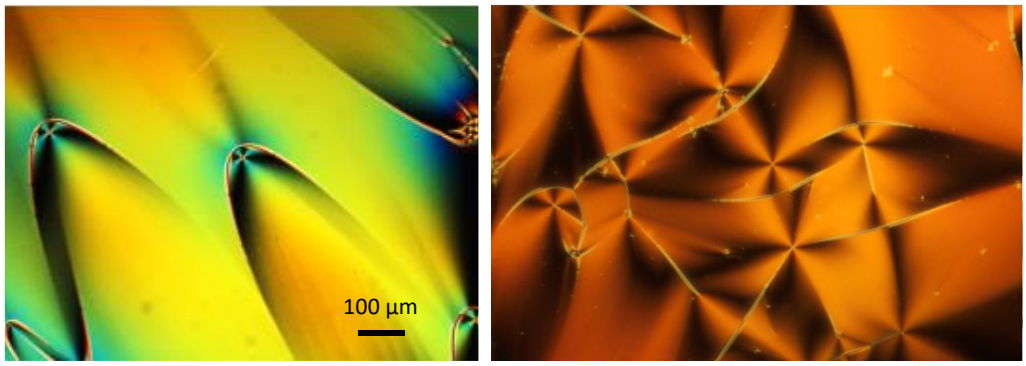

Fig.1. Parabolic (left) and hyperbolic (right) domain walls in a ferroelectric nematic.

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Nonlinear plasmonic nanostructures for quadratic nonlinear optics

H.M. Ngo, E. Drobnyh, M. Sukharev[2,3], Q.K Vo[1], J. Zyss[1] and I. Ledoux-Rak[1]

1 - Laboratoire Lumière, Matière et Interfaces, UMR 8537, Ecole Normale Supérieure Paris-Saclay, CentraleSupélec, CNRS, Université Paris-Saclay, 91190 Gif-sur-Yvette, France

2 - College of Integrative Science and Arts, Arizona State University, Mesa, Arizona 85212, USA

3 - Department of Physics, Arizona State University, Tempe, Arizona 85287, USA

4 - Faculty of Chemistry, Ho Chi Minh City University of Science, Vietnam National University , 227 Nguyen Van Cu Street, Ward 4, District 5, Ho Chi Minh City 70000, Vietnam

The increasing interest in metallic nanoparticles (NP) is motivated by their potential applications in photonics, information storage, detection systems, therapeutics, diagnostics, photovoltaic and catalysis. Their size and shape (nanospheres, nanorods, nanostars…) affect significantly their physical and chemical properties, especially their optical response. These nano-objects display high quadratic nonlinear optical responses, which strongly depend on nanoparticle geometry and surface state. We report here a systematic investigation of the influence of nanoparticle surface area and symmetry on hyperpolarizability β values, as measured via the Harmonic Light Scattering technique[1] in colloidal NP solutions. Here we use a fundamental laser source at 1.064 nm, the second harmonic wavelength at 532 nm coming close to plasmonic resonances of Au and Ag nanoparticles.

First we investigate the influence of surface area of noble metal nanospheres and nanorods on their β values. Gold and silver nanospheres, with diameters ranging from 3 to 80 nm have been characterized in order to explore the limits of validity of the purely dipolar origin of β values. Moreover, by studying gold and silver nanorods (Fig. 1a) with different surface areas, we will evidence the predominance of these surface effects over shape factors, leading us to revisit previous studies on the NLO properties of these nanorods [2].

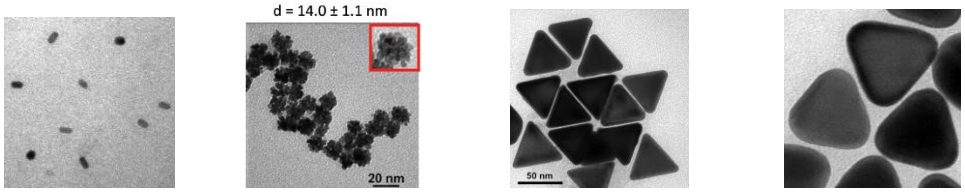

Figure 1: TEM images of Au nanorods (a), Pt nanoflowers (b), sharp (c) and smooth (d) Au nanotriangles

Second, we have synthesized and characterized platinum “nanoflowers” (PtNFs (Fig. 1b) with different controlled sizes. These PtNFs display exceptionally strong first hyperpolarisabilities, higher than those of gold nanoparticles of similar size. Particle surface corrugation is shown to be the dominant factor governing these exceptionally high β values, with a very limited contribution from plasmonic effects that are negligible in the visible range [3].

In a third part, a single – step growth of gold nanoprisms (GNPs) was achieved by seedless growth. Their second harmonic response has been investigated experimentally and theoretically with edge length ranging from 40 to 116 nm and for different curvature radii at corners [4]. Their experimental β values are found to display a linear dependence with the surface area as reported for other metallic nanoparticle shapes, and also a strong influence of their corner sharpness on the corresponding nonlinearities. For this purpose, we have defined a quantitative sharpness factor depending on the external triangle side length L_{ext} and the triangle corner curvature radius R according to : $SF = (L_{ext} - 2R)/L_{ext}$.

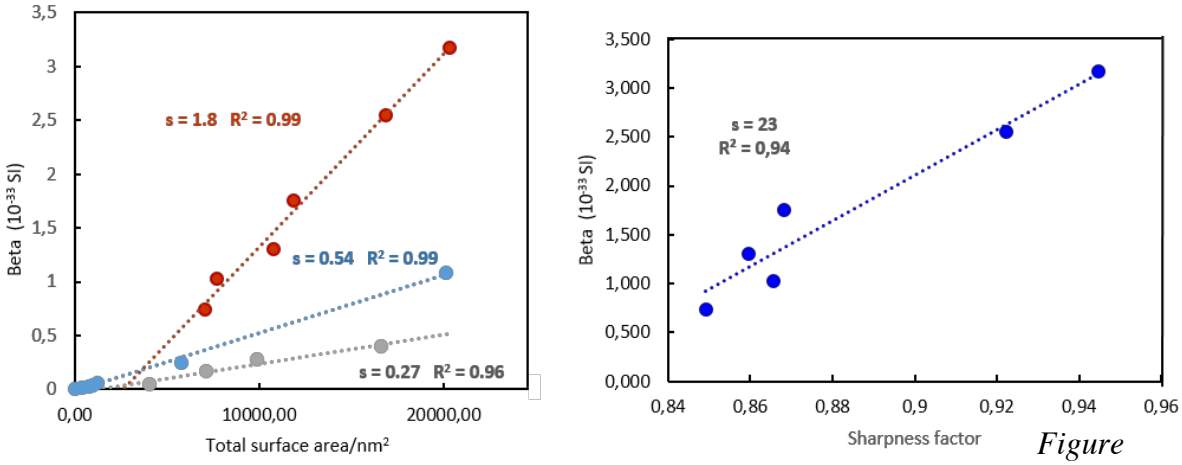

Figure 2 : (Left) : Values of the first hyperpolarizability (β) for sharp" (resp. "smooth") Au triangles (orange (resp. grey) disks) and for Au nanospheres (blue disks, nanospheres of ref [2]) in water solution, plotted as a function of the surface area of nanoparticles. (Right) Plot of β values as a function of the prism sharpness factor. Dotted lines are least-square linear fits of β values with respect to surface area or sharpness factor. The correlation factors (R^2) and slopes s of each linear plot are displayed with the corresponding color. The average curvature radius of "sharp" nanoparticles is 4.4 nm, ranging from 3.2 to 5.4 nm. The curvature radii of smooth nano-prisms vary from 8.9 nm to 24 nm.

Systematic calculations performed on gold nanoprisms with various edge lengths and corner radii do confirm this trend. Therefore, the influence of corner sharpness seems to dominate over centrosymmetry breaking. These results shed new light on the SHG properties of acentric, sharp corner gold nanoparticles, and open the way to the investigation of various noble metal nanopolyhedra (e.g. nanocubes) to develop new families of highly nonlinear metallic nanostructures making use of an increased number of facets and of the sharpness of related geometric singularities

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Electrically Tunable Liquid Crystal Lenses with Seamless Progression of Lens Power via Nematic Liquid Crystals

Y.H. Lin[1], W. C. Cheng[1], Y. J. Wang[1],and V. Reshetnyak[2,3]

1 Department of Photonics, National Yang Ming Chiao Tung University, Hsinchu, Taiwan
2 Theoretical Physics Department, Taras Shevchenko National University of Kyiv, Kyiv 01601, Ukraine
3 Department of Physics, University of Warwick, Coventry, CV4 7AL,UK
yilin@nycu.edu.tw

An electrically tunable liquid crystal lens with seamless progression of lens power based on nematic liquid crystals(LC) is investigated and demonstrated. The general concept of the structure is depicted in Fig. 1. The phase profile is connected by many segments from LC layers. The proposed lens with seamless progression of lens power, or so-called progressive LC lens, could be a positive or a negative lens with a continuously tunable focal length. The progressive LC lens shows the spatially distribution in lens power ranging from +4D to -4D even though the lens power of the LC lens seems only -0.87D ~ +0.87 D calculated under parabolic wavefront approximation. The experimental results are shown in Fig. 2. The surprising results we present in this paper give LC lenses an insightful aspect and overrule the traditional statement of the limitation of lens power set by the optical phase difference in gradient-index LC lenses. It also paves a way in ophthalmic applications.

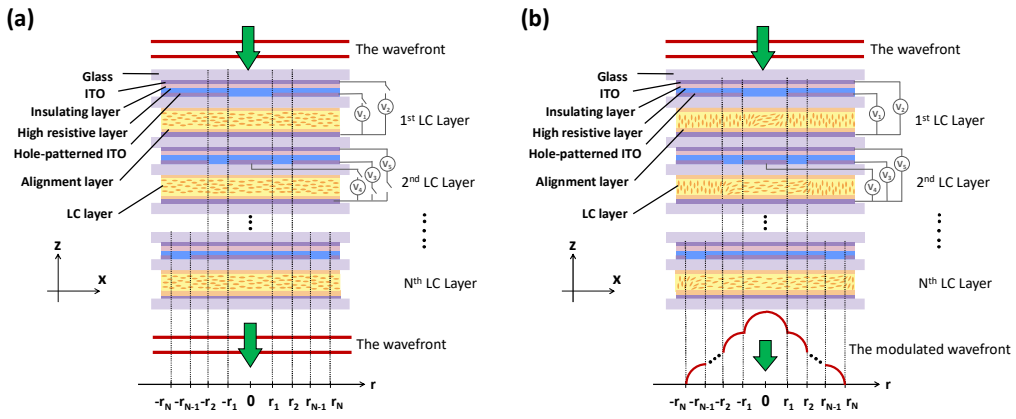

Fig. 1 General concept of the LC lens with a method of a spatially extended phase distribution. (a) Without applied voltage, the LC molecules in LC layer are parallel to x-axis. The plane wave of entering x-linearly-polarized light remains unmodulated. (b)When applied voltages exceed the threshold voltages, the plane wave of entering x-linearly-polarized light is modulated by a gradient distribution of optical path difference contributed from all LC layers. The red lines represent the wavefronts.

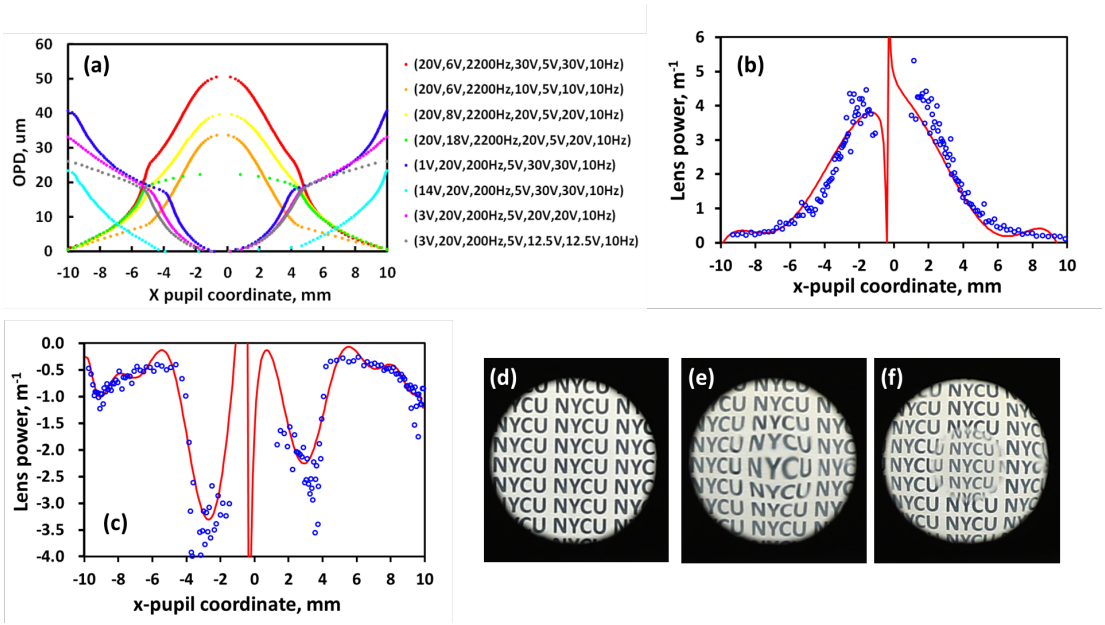

Fig. 2 The LC lens with a method of a spatially extended phase distribution (two layers, aperture size: 20 mm).(a) Optical path difference of the LC lens. The lens power, an inverse of the focal length, as a function of x-pupil coordinate at (b)(20V_{rms}, 6 V_{rms}, 2200Hz,15 V_{rms}, 5 V_{rms}, 15 V_{rms}, 10Hz) and (c) (1 V_{rms}, 20 V_{rms}, 200Hz, 5 V_{rms}, 30 V_{rms}, 30 V_{rms},10Hz). Image performance at (d) voltage off, (e) the electronic condition of (b), and (f) the electronic condition of (c).

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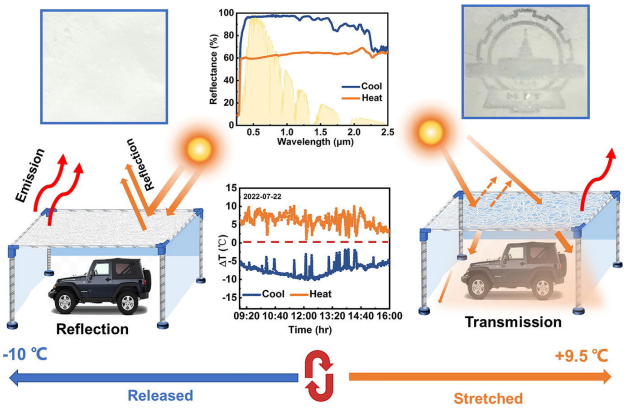
Strain-adjustable reflectivity of polyurethane nanofiber membrane for thermal management applications

*Xin Li[1], Zhenmin Ding[1], **Giuseppe Emanuele Lio**[2,3], Jiupeng Zhao[1], Hongbo Xu[1], Lorenzo Pattelli[2,4], Lei Pan[1], Yao Li[5]*

1 School of Chemistry and Chemical Engineering, Harbin Institute of Technology, Harbin 150001, China
2 European Laboratory for Non-Linear Spectroscopy (LENS), Sesto Fiorentino, 50019, Italy.
3 Department of Physics and Astronomy, University of Florence, Sesto Fiorentino 50019, Italy
4 Istituto Nazionale di Ricerca Metrologica (INRiM), Turin 10135, Italy
5 Center for Composite Materials and Structure, Harbin Institute of Technology, Harbin 150001, China



Passive radiative cooling technologies are highly attractive in pursuing sustainable development. However, current cooling materials are often static, which makes it difficult to manage thermal comfort in all weather conditions. To overcome this limitations, a different strategy was adopted to design flexible membranes made of thermoplastic polyurethane nanofibers (Es-TPU) by electrospinning, realizing in-situ, solvent-free reversible switching between radiative cooling and solar heating via mechanical actuation. In its radiative cooling state (0% strain), the Es-TPU membrane shows a high and angular-independent reflectance of 95.6% in the 0.25–2.5 μm wavelength range and an infrared emissivity of 93.3% in the atmospheric transparency window (8–13 μm), reaching a temperature drop of 10 °C during the day, with a corresponding cooling power of 118 W/m^2. The excellent mechanical properties of the Es-TPU membrane allow continuous adjustment of reflectivity by reversible elongation, reaching a minimum reflectivity of 61.1% at an elongation of 80%. In this heating state a net temperature increase of 9.5 °C above ambient of an absorbing substrate and an equivalent power of 220 W/m^2 are observed. The strong haze, hydrophobicity, and outstanding aging resistance exhibited by this scalable membrane are promising for achieving uniform illumination with adjustable strength and efficient thermal management in practical applications.

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Li, X.; Ding, Z.; **Lio, G. E.**; Zhao, J.; Xu, H.; Pattelli, L.; Pan, L.; Li, Y. Strain Adjustable Reflectivity of Polyurethane Nanofiber Membrane for Thermal Management Applications. *Chem. Eng. J.* **2023**, *461*, 142095. https://doi.org/10.1016/j.cej.2023.142095.

Imaging with random encodings

Zhiwen Liu, Chen Zhou, Cheng-Yu Wang, Jennifer Miller, Lidan Zhang, Tunan Xia, Christine Keating, and Xingjie Ni

The Pennsylvania State University, University Park, PA 16802

Abstract: Random masks including random spatial masks and random spatiotemporal masks allow for encoding and decoding of image information that is challenging to retrieve using conventional approaches. Several examples are discussed. The use of dynamic particle assemblies as encoding masks is presented. It is shown that a multi-shot approach implemented by using reconfigurable particle assemblies can significantly improve the reconstruction quality. Ultrafast imaging using random spatiotemporal masks is also discussed. It is shown that a single-shot capture of a time-integrated signal can be decoded to reconstruct several frames of an ultrafast event. Additionally, non-line-of-sight imaging off a scattering surface is investigated. Both experimental results and simulations are presented. ADMM and machine learning based reconstructions are discussed.

Exploring Light-Induced Rotational Speed Changes in Thin Photomobile Films: Insights from Acoustic Levitation

D. E. Lucchetta[1], A. Di Donato[2], R. Castagna[3]

1, Dip. SIMAU, Università Politecnica delle Marche, Via Brecce Bianche, 60131 Ancona, Italy. 2, Dip. DII, Università Politecnica delle Marche, Via Brecce Bianche, 60131 Ancona, Italy. 3, URT-CNR, Università di Camerino (UNICAM), Polo di Chimica, Via Sant'Agostino, 1, 62032 Camerino (MC), Italy.

In this study, we investigate how light affects the rotational speed of a thin photomobile film [1]. Our experiments are conducted using a single-axis acoustic levitator operating at 40 kHz, where a 50 μm thick photomobile polymer film (PMP) is suspended in air at one of the nodes of a stationary acoustic field. By perturbing this equilibrium, the film starts rotating at its natural frequency, which is detected in real time by monitoring the light from a low power He-Ne laser that impinges on and reflects off the film. To induce changes in the rotational motion, we use an external laser source to illuminate the PMP film, causing it to bend and the rotational speed to change by approximately 20 Hz [2]. This non-contact, long-distance interaction provided by the acoustic levitator is an ideal platform for developing and studying electro-optic devices under microgravity and low-friction conditions. We believe that this technology has potential applications in fields such as 3D dynamic displays and aerospace applications [3-5].

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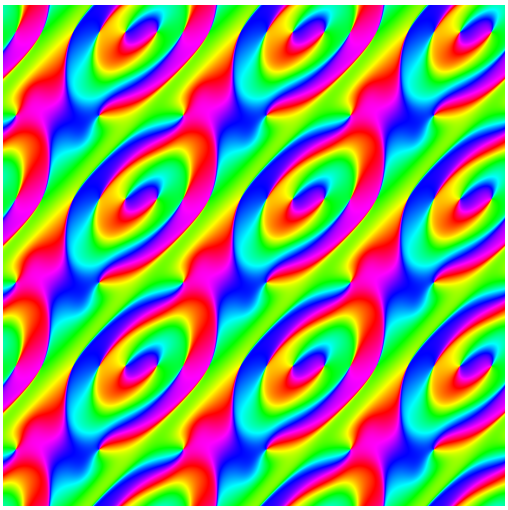
Ultralong photonic quantum walks in a single optical beam

Lorenzo Marrucci[1]

[1] *Università di Napoli Federico II, Napoli, Italy*



Pattern of liquid crystal cell used to optically reproduce the overall evolution of a 5 steps 2D quantum walk. The colors correspond to azimuthal angles of the molecular director in the plane.

Quantum walks are simple quantum-evolution processes that can reproduce the key qualitative features of many interesting complex real systems. Hence, these processes are at the root of many quantum simulations. A quantum walk can be for example carried out using photons in a variety of possible experimental architectures. The most straightforward and versatile concept is using "real space" for the walk degree of freedom, as in waveguide networks of integrated optics. However, in the last few years my coworkers and I have demonstrated an interesting alternative approach for which the walk degree of freedom is encoded in the internal mode structure of a single light beam [1]. The walk is then physically realized by letting the light beam propagate through a sequence of suitable optical elements exploiting Pancharatnam-Berry phases to couple modes and polarization [1]. An important practical advantage of this approach is that no interferometric stability is needed. Moreover, the required resources scale linearly with the number of steps, and it is particularly easy to introduce time-varying actions and external parameters [1].

Initially, we used the orbital angular momentum (OAM) of the light beam, a naturally discrete variable, to give rise to a discrete-time quantum walk on a 1D lattice. This has allowed us, for example, to explore experimentally the topological features of certain 1D single-particle systems [2,3]. Next, we moved to a different approach that enabled us to simulate 2D lattice systems and their fascinating physics: a discrete set of slightly tilted overlapping Gaussian waves [4]. We then tested this setup in a truly quantum regime, involving single photons and photon pairs [5]. Most recently, we developed a new method to simulate the effect of very long quantum walks with only few optical elements [6], which allowed us to break all previously existing records of number of steps for a quantum walk simulation. In this presentation, I will review these progresses on photonic quantum walk simulations, mainly focusing on the latest results.

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Studies of luminescent carbon nanodots as myelin dopants

Katarzyna Matczyszyn[1], Dominika Benkowska-Biernacka[1], Sebastian Mucha[2]

[1] *Institute of Advanced Materials, Wroclaw University of Science and Technology, Poland*
[2] *Laboratoire Charles Coulomb, Universite de Montpellier, France*

Carbon nanodots (CNDs) are the nanostructures of multiple possible applications ranging from optoelectronics to bioimaging. In the frame of our studies we explore the non-linear optical properties of CNDs and their effective use in doping to the myelin structures.

Myelin sheath, exhibiting liquid crystalline properties, plays a crucial role in the propagation of action potential [1-2] . Many studies have focused on the importance of relevant model systems to better understand the behavior of biological membranes [3]. Therefore, the combination of luminescent nanomaterials with diverse biological components, such as phospholipids [4] , gains considerable attention for their potential applications in bioimaging.

In this work, we discuss the formation of synthetic myelin figures (MFs) made of phosphatidylcholines and doped with blue- and green-emitting carbon nanodots. To get insight into the details on the morphology of the multilamellar structures, we used the combination of polarized light and fluorescence microscopy techniques. Moreover, our studies indicate two-photon excited fluorescence microscopy (2PEFM) as a powerful method to study a three-dimensional view of the distribution of CNDs within MFs. Taking advantage of 2PEFM, we showed that the multilamellar tubes with dopants can be excited by wavelengths lying in the near-infrared region that corresponds to the first biological window, thereby providing deeper penetration depth and preventing strong photobleaching [5].

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Keywords : myline, carbon nanodots, two-photon microscopy, lyotropic liquid crystals, bioimaging

*contact : katrzyna.matczyszyn@pwr.edu.pl

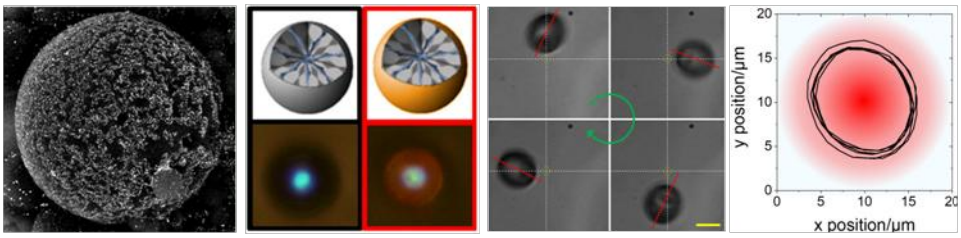
Core-shell mesogenic-metallic particles: photonics and optomechanics applications

A. Mazzulla[1], *N. Pellizzi*[2], *P. Pagliusi*[1,3], *G. Cipparrone*[3]

1 CNR Nanotec - Institute of Nanotechnology, S.S. Cosenza, 87036 Rende (CS), Italy,
2 Department of Physics, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133, Milano, Italy,
3 Department of Physics, University of Calabria, Ponte P. Bucci 31B, 87036 Rende (CS), Italy

Core-shell architecture provides unique features to microparticles (MPs) by accurately selecting the employed materials. MPs with a mesogenic core and a metallic shell of gold nanoparticles (NPs) have been realized. The core is obtained by UV induced polymerization of reactive mesogens droplets in a chloroauric acid aqueous solution, whilst gold nanoparticles precipitation happens at the same time, covering the MPs surface. The MPs optical properties are modified by the gold shell, in the Bragg onion resonator condition when a chiral core is utilized, improving the laser emission stability compared to the MPs without shell. The proposed strategy, due to both the method and the versatility of the materials, suggests a new route to realize microdevices with wide control in term of intensity, polarization, generation [1].

The development of efficient micromachines is a challenge for applied and fundamental research. Light is a worthy mean to remotely displace micro-objects by inducing forces and torques. Rotational dynamics of core-shell MPs having ellipsoidal shape and nematic core is studied, and in particular a peculiar synchronous spin-orbital motion when the MPs are irradiated by a simple Gaussian beam. The observed effects originate from the coupling of the metallic NPs' optical response and the core anisotropies. The rotation performances strongly improve when trapping wavelength lie inside the plasmonic resonance range. In that case, spin kinetic energy achieves values two orders of magnitude larger than the one obtained from the bare MPs. The proposed approach bears important insights for design optimization in the MPs light driven motion, giving benefits to applications in microfluidics, microrheology, and micromachining that imply rotational dynamics [2].



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Marangoni Bursting Mystery in Growth of DCNP Nonlinear Optical Nanocrystals

A. Miniewicz [1], M. Ślemp [2], R. Zaleśny [3] and P. F. Brevet [2]

[1]Institute of Advanced Materials, Faculty of Chemistry, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

[2]Non-Linear Optical and Interfaces Group, Institut Lumiere Matiere, UMR 5306, Uinveriste Claude Bernard Lyon 1, 69622 cedex, Villeurbane, France

[3]Faculty of Chemistry, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland.

Marangoni bursting results from spontaneous spread of an alcohol/water drop over oil surface. This is accompanied by fingering instability that generates the thousands of "daughter" droplets making spectacular dynamic flower-like phenomenon, firstly described in Phys.Rev.Lett. (2017) by Keiser et al.[1]. To improve the visibility of this emulsification process, the small amount of methylene blue dye is added to the mixture. Alcohol evaporation followed by water evaporation leaves on the oil surface the remnants of the dye. Fast formation of "daughter" droplets opens a possibility to grow nanocrystals or nanoparticles of some organic substances that are well soluble in alcohols and insoluble in water and oil. In order to explore this possibility we chose the well-known organic nonlinear optical dye (3-(1,1-dicyanoethenyl)-1-phenyl-4,5-dihydro-1H-pyrazole) [2], abbreviated as DCNP, which is soluble in isopropanol (IPA) and insoluble in water.

The crystals of DCNP are quite unusual, showing interesting luminescent properties that come from trapping states and in parallel they are noncentrosymmetric, showing large second order nonlinear optical properties [3], like second harmonic generation (SHG) of light or Pockels effect. We will describe spectroscopic properties of DCNP, SHG effect and a newly developed technique of photofragmentation of micrometer size DCNP crystallites using resonant SHG [4]. Nd:YAG laser (λ = 1064 nm) frequency doubling produces harmonic light at 532 nm that is reabsorbed producing 10 ns short thermal stresses that lead to microcrystals fragmentation into nanocrystals. Nanocrystals remain to show SHG light but their luminescence was attenuated [4].

This result prompted us to use Marangoni bursting phenomenon for producing DCNP nanocrystals in a different procedure, e.g., due to fast crystallization of nanograms of this compound left in each daughter droplet on the oil surface. Surprisingly, a few days after Marangoni bursting process in oil bath we have noticed, using microscope, elongated fibrils (up to 1.5 cm long and 20 -30 μm wide). When Marangoni bursting took place on solid substrate we observed DCNP crystallization into small nanometric branched structures. Investigation of fibrils extracted from oil was performed using two-photon excitation technique with pulsed fs laser with a center wavelength λ = 780 nm. These fibrils generally showed red luminescence characteristic for micrometer size DCNP crystals but also a blue luminescence, the latter appeared at some places of these fibrils. The luminescence band centered at 430 nm was never observed in DCNP crystals, however

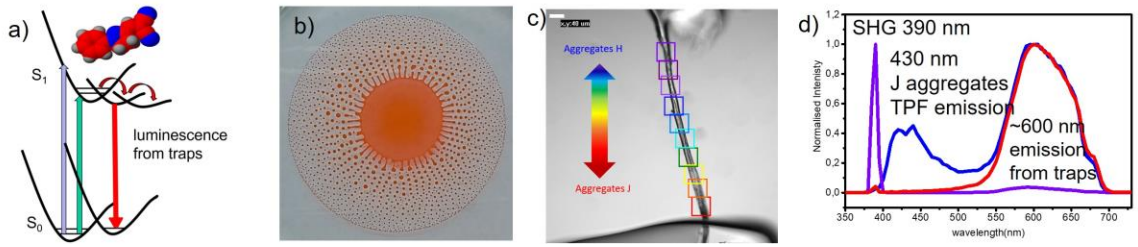

Fig. 1. a) Jablonski diagram for DCNP molecule showing mechanism of red luminescence from the structural traps. b) Photograph captured from movie of Marangoni bursting of isopropanol/water binary mixture with small amount of dye and about 1600 small separated droplets moving on the oil surface. c) and d) A single DCNP fibril when illuminated by fs pulses at 790 nm wavelength shows both second harmonic of incident light at 395 nm, fluorescence emission from J aggregates at 430 nm and red fluorescence emission characteristic for DCNP bulky crystals. The blue and red luminescence are located at the opposite ends of the fibril which suggests that rapid solution evaporation favors small aggregate formation and slower favors formation of crystals.

quantum chemical calculations predicted that molecular J aggregates of DCNP may exhibit luminescence in this spectral region [3,5]. Aggregation-induced emission (AIE) is an intriguing phenomenon in which molecular aggregates exhibit stronger fluorescence than isolated molecules. Ab initio quantum chemical calculations demonstrate that cross section for two photon absorption in DCNP dimer can be quite large and reach around 100 GM [6]. Therefore, one can conclude that DCNP fibrils are built from crystalline parts and molecular aggregates. The formation of DCNP aggregates takes place probably due to dipole-dipole interactions of DCNP molecules in oil phase and the tendency to growth into polar structure known from single crystals [7] in which molecules having permanent dipole moments are parallel to each other.

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Volumetric Bioprinting: a new light-based tool for producing artificial tissue models

Jorge Madrid-Wolff[1], Antoine Boniface[1], Damien Loterie, Paul Delrot[3], Paulina Bernal[2], Riccardo Levato[2], Christophe Moser [1]

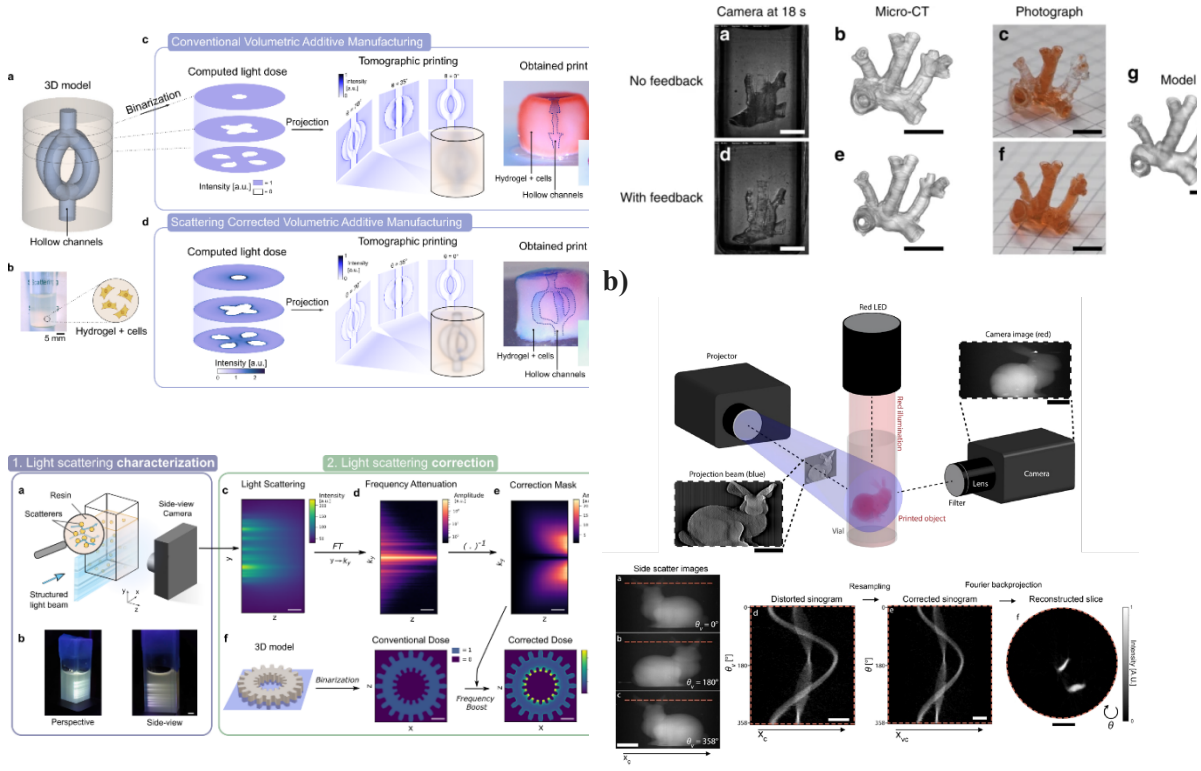
[1] Laboratory of Applied Photonics Devices, Institute of Electrical and MicroEngineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
[2] Department of Orthopaedics University Medical Center UtrechtUtrecht University
[3] Readily3D, Innovation Park, EPFL, Switzerland

Three-dimensional (3D) Additive Manufacturing (AM), better known as 3D printing, has been a breakthrough in many fields such as tissue engineering, regenerative medicine, aerospace, optical components, and many others. 3D printing technologies consist of selectively adding material point-by-point or layer-by-layer to build three-dimensional objects. Various AM methods have been developed, using different materials, such as Stereolithography (SLA) based on liquid photopolymers proposed by Charles Hull in 1986, direct laser writing (DLW), heating or melting powders as in selective laser sintering (SLS) or selective laser melting (SLM), extruding liquid material as direct ink writing (DIW), or extruding thermoplastic filaments such as fused filament fabrication (FFF) .

Conventional 3D printing works by printing an object in layers, which means that a three-dimensional object is obtained by a 2D extended process (2D + 1D). In contrast, layer free 3D technologies do not rely on a layer after layer deposition. Such technologies are termed volumetric additive manufacturing (VAM). Two-photon Polymerization is such a VAM method that relies on 2 photon absorption. Recently VAM methods relying on single photon absorption have been developed: rotation-based via reverse tomography [1,2], where an entire three-dimensional object is simultaneously solidified, Xolography[3]. Light-Sheet 3D Printing[4].

Inspired by computerized tomography (CT) scanners, a series of images are taken from different angles around the body and are then used to reconstruct a 3D image by digital processing. The reverse process has been implemented for constructing a 3D object. Here, 2D light patterns are computed from a desired 3D object using the Radon Transform and then sequentially projected in a container of photocurable resin from different angles, as shown in Figure 2a.
The cumulative projections generate a 3D dose distribution. Once the light dose exceeds the gelation threshold, the resin solidifies. In this approach, a one-photon absorption (1PA) process is sufficient to cure all the voxels in parallel to create the entire object simultaneously without the need for supports.

In tomographic printing, the Radon transform is digitally computed to produce angular projections followed by computing the Filtered back-projections (FBP). The FBP produces positives and negative values for the intensities. The projection patterns are thresholded to keep only positive values for the actual physically projected patterns, which means that we are producing an approximation of the target object.



a) *b)* *c)*

Figure 1. Volumetric Additive Manufacturing by reverse tomography assisted by feedback from scattered light. a) *correction in a scattering resin [5].* ***b)*** *The improvement in printing accuracy is shown by integrating a feedback system. The featureless printed part is shown in c and the improvement in features and resolution is shown in f. The scale bars are 5mm.* ***Reproduced from [2],*** ***c)*** *Feedback using optical scattering imaging. Reproduced from [5].*

However, these new approaches only work with homogeneous and relatively transparent resins so that the light patterns used for photo-polymerization are not scrambled along with their propagation. We will illustrate a method that considers light scattering in the resin prior to computing projection patterns. Light scattering in resins having a high cell density (> 4 million cells /mL) is severe and we will show that scattering correction method allows to print high-resolution structures (figure 1a).

We will show that this printing technology is well suited to print convoluted structure in which living cells are directly embedded. Several examples of complex 3D tissue models including bone, liver and a pancreatic cancer tissue. This scattering correction extends the capabilities of conventional light-based volumetric printing which opens up promising perspectives for bioprinting cell-laden constructs.

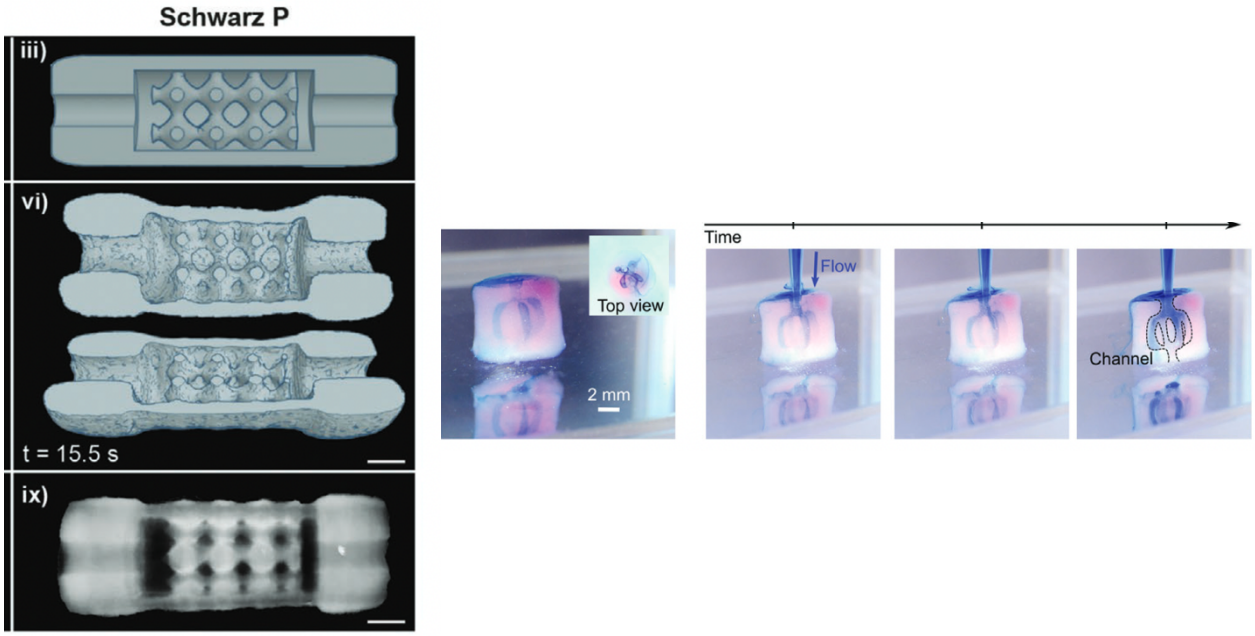


Figure 2: (left) Printed perfusion 3D construct that contain functional liver organoids [6] (Right) Demonstration of 3D printable lumen (colored part) in a highly scattering cell loaded construct (right) [7]

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Scalable metasurface fabrication and integration for flat optics devices

Xingjie Ni,[1,2] *Lidan Zhang,*[1] *Xuexue Guo,*[1] *Yimin Ding,*[1] *Shengyuan Chang,*[1] *Xi Chen,*[1] *Md Tarek Rahman,*[1] *Haiyang Huang*[1]

1 Department of Electrical Engineering, The Pennsylvania State University, University Park, PA 16802, USA
2 Materials Research Institute, The Pennsylvania State University, University Park, PA 16802, USA

Metasurfaces, ultrathin subwavelength nanostructures with exceptional light manipulation capabilities, have the potential to revolutionize traditional optics. Our group has previously demonstrated various metasurface devices, such as invisibility cloaks and space-time-modulated one-way mirrors. However, standard fabrication methods for metasurfaces, like electron beam lithography and focused ion beam milling, are slow, expensive, and lack scalability. To address these challenges, we have developed a cost-effective, scalable design and fabrication approach for large-scale meta-optical devices, as demonstrated by our construction of a single-lens telescope using a wafer-scale metasurface lens. Furthermore, although metasurfaces are ultrathin, their reliance on free-space light excitation has limited the compactness of optical systems. We have resolved this issue by creating a hybrid architecture that combines subwavelength metaphotonic structures with photonic-integrated waveguide platforms, leading to a fully integrated platform with a range of functionalities. These capabilities encompass steering and focusing guided waves into free space, projecting holograms with controlled phase and amplitude, and generating laser emission with orbital angular momentum. Our research lays the groundwork for comprehensive light control across integrated photonics and free-space platforms, opening new avenues for the development of agile, multifunctional flat optics devices.

Photophysics, Photochemistry, and Optoelectronics of Organic Semiconductors in Microcavities

W. Goldthwaite,[1] R. Lamug,[1] A. Ullah,[2] M. Chase,[1] J. E. Anthony,[3] L. -J. Cheng,[2] O. Ostroverkhova[1]

[1]Department of Physics, Oregon State University, Corvallis, OR 97331
[2]School of EECS, Oregon State University, Corvallis, OR 97331
[3]Department of Chemistry, University of Kentucky, Lexington, KY 40511

Organic (opto)electronic materials have been explored in a variety of applications in electronics and photonics, driven by several advantages over traditional silicon technology, including low-cost processing, fabrication of large-area flexible devices, and widely tunable properties through functionalization of the molecules. Over the past decade, remarkable progress has been achieved in understanding physical mechanisms and in developing guidelines for the material design, which boosted the performance of organic devices that rely on photophysics and/or (photo)conductive properties of the material [1]. However, further improvements in device performance are desirable, and challenges related to (photo)stability of organic devices need addressing.

One of the major thrusts in developing new organic materials and device concepts has focused on materials exhibiting singlet fission, which is a process where one photon can generate two pairs of charge carriers and enable, for example, enhanced power conversion efficiencies in solar cells. Nevertheless, fundamental questions pertaining to exciton physics in singlet fission materials, and how it can be manipulated by material design and external parameters, remain [2].

Strong exciton-photon coupling that occurs when an organic film is placed in a microcavity, enabling formation of a light-matter hybrid state (polariton), represents a largely unexplored potential to control photophysics, photochemistry, and optoelectronic characteristics in singlet fission materials and devices using polaritons [3-4]. In this presentation, we summarize our efforts aiming to understand and tune exciton and polariton properties in model singlet fission organic materials, towards exploiting these properties in optoelectronic devices and controlling photochemical reactions responsible for photostability.

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Self-Assembled Meta-Atoms And Metasurfaces

Maeva Lafitte[1], Rajam Elancheliyan[1], Cian Cummins[1,2], Ranjeet Diwedi[1,3], Philippe Barois[1], Alexandre Baron[1], Olivier Mondain-Monval[1], Guillaume Fleury[2], and Virginie Ponsinet[1]

1 Univ. Bordeaux, CNRS, Centre de Recherche Paul Pascal, UMR 5031, Pessac, France
2 Univ. Bordeaux, CNRS, Bordeaux INP, LCPO, UMR 5629, F-33600, Pessac, France
3 ENSEMBLE3 Centre of Excellence, Wolczynska 133, 01-919 Warsaw, Poland

Since the emergence of the metamaterial field in the 2000s', nano-optics has relied on assembled sub-wavelength artificial optical resonators, which interact strongly with light. This presentation aims at pointing out how colloid- and polymer-based chemical engineering offers exciting routes to tailor the optical response, including polarizabilities, frequency bandwidth and scattering diagram of such resonators; and transmission and absorption of their planar assemblies. We will discuss examples where bottom-up synthesis and assembly of tailored metallic nanoresonators leads to promising optical properties, specifically using self-assembled soft matter systems such as emulsions and copolymers.

Densely-packed spherical colloidal clusters of metallic nanoparticles have garnered a lot of interest recently, because they involve localized resonant inclusions that are assembled into a Mie resonator. We show that the multiscale resonant nature of these colloidal resonators provides specific spectral and angular scattering characteristics. In particular, they present strong magnetic resonances, outperforming previously obtained complex colloidal nanoresonators [1,2].

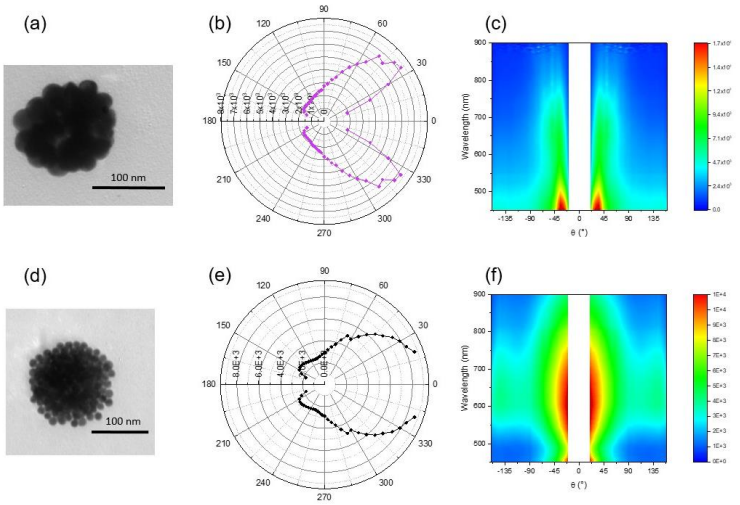

Fig 1. TEM images of a representative (a) Ag-cluster and (c) Au-cluster. Scale bars are 100 nm. Logarithmic polar plot of the experimental differential scattering cross-section for (b) Ag-clusters at wavelength 662 nm and (d) Au-clusters at wavelength 751 nm. Lines are guides for the eye. Experimental scattering color pattern representing the differential scattering cross-section values of (c) Ag-PVP clusters and (e) Au-clusters as a function of the scattering angle θ and of the wavelength λ. Measures were only made for positive values of θ but we assumed that differential cross-section values are identical for θ and -θ. All differential scattering cross-section values are represented in nm^2 per steradian units.

We synthesized clusters of gold or silver nanoparticles using an emulsion-based formulation approach. Each cluster comprises a few hundreds or thousands of nanoparticles, depending on the formulation parameters. Using polarization-resolved multi-angle light scattering measurements, we conducted a comprehensive angular and spectroscopic determination of the complex colloid optical resonant scattering in the visible wavelength range [3]. We report and discuss experimental evidence of strong optical magnetic resonances and directional anisotropic scattering patterns (see Fig. 1).

In a second example, we aimed at producing thin light absorber layers, using bottom-up technologies. To this end, Au nanoresonators possessing heights from 5 - 15 nm with sub-50 nm diameters were engineered by block copolymer (BCP) templating. The Au nanoresonators were fabricated on an alumina spacer layer and a reflecting Au mirror, in a film-coupled nanoparticle design. The BCP nanopatterning strategy was tailored to achieve near-perfect absorption at ≈ 600 nm [4].

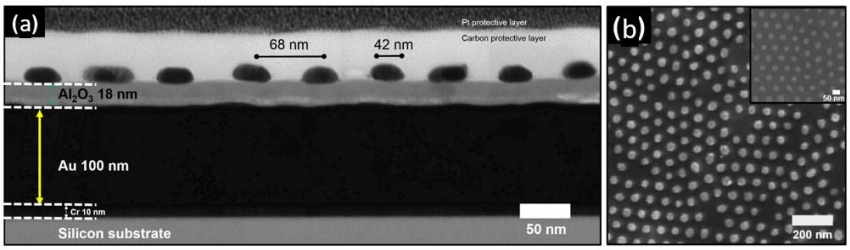

Fig 2. Electron microscopy images of the gold metasurface. (a) STEM image of the Au metasurface revealing the cross-sectional profile of the fabricated bilayer absorber comprised of an Au reflector layer, Al2O3 spacer layer and the rounded Au dots. (b) Top-view SEM image of the Au nanoresonators (15 nm height).

These experimental approaches allow for the large scale production of nanoresonators and resonant thin films with potential uses for optical metasurfaces.

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Optical Diffraction Tomography Using MaxwellNet

Demetri Psaltis

Ecole Polytechnique Federale de Lausanne Lausanne, Switzerland

We will discuss how iterative reconstruction methods can benefit from the use of physics constraints. We use a machine learning approach which is trained with a loss function that is designed to satisfy Maxwell's equations. We will present experimental results demonstrating the method.

Reconfigurable physical unclonable functions made with light responsive materials

S. Nocentini[1,2], *U. Rührmair*[3,4], *M. Barni*[5], *D. S. Wiersma*[1,2,6] *F. Riboli*[2,7]

[1] Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Torino, Italy
[2] LENS, Via Nello Carrara 1, 50019 Sesto Fiorentino (FI), Italy
[3] Physics Dept. LMU Munchen, Schellingstraße 4/III D-80799 Munchen, Germany
[4] Electrical and Computer Eng. Dept., University of Connecticut, Storrs, CT, USA
[5] Dip. di Ing. dell'Inf. e SM, Università di Siena, via Roma 56, 53100 Siena
[6] Dip. di Fisica, Università di Firenze, Via Sansone 1, 50019, Sesto Fiorentino, Italia
[7] CNR-INO, Via N. Carrara 1 Sesto Fiorentino, 50019, Italy

A physical unclonable function or PUF, is a physical object that for a given input and conditions (challenge), provides a physically defined output (response) that serves as a unique identifier. The most promising application is in the field of cyber physical security for authentication or anticonterfeiting. PUFs are characterized by the uniqueness of their microstructure that depends on random physical factors that are present in any natural or manufactured system. These factors are unpredictable and uncontrollable, which makes it practically impossible to duplicate or clone the structure.
Optical PUFs rely on a random optical multiple-scattering medium, which serves as a token [1]. Due to their unmatched entropy, complexity, and security level, optical physical unclonable functions (PUFs) currently receive a lot of interest in the literature. One PUF limitation, so far, has been that their physical configuration is either fixed or can only be permanently modified, and hence allowing only one token per device. We show that it is possible to overcome this limitation by creating a reconfigurable structure made by light transformable polymers, in which the physical structure of the unclonable function itself can be reversibly reconfigured, allowing a large number of PUFs to co-exist simultaneously within one and the same device [2]. The physical transformation of the structure is done all optically in a reversible and spatially controlled fashion. Our novel technology provides a massive enhancement in security generating more complex keys containing a larger amount of information. At the same time, it allows for new applications, for example serving multiple clients on a single encryption device and the practical implementation of quantum secure authentication of data.

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Multiscale Modeling of Molecular Nanophotonic Materials

C. Rockstuhl[1,2], *D. Beutel*[1], *B. Zerulla*[2], *L. Rebholz*[1], *M. Nyman*[2], *C. Holzer*[1], *M. Krstić*[1], *and I. Fernandez-Corbaton*[2]

1 Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany
2 Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe, Germany

To capture the properties of photonic devices from first principles, any consideration must start with analyzing the materials from which these devices are made. For molecular materials that we aim to consider in this presentation, this requires to use time-dependent density functional theory to study the response of an individual molecule to an external illumination on the grounds of quantum chemistry. Then, a multi-scale modeling approach needs to be put in place that allows for coarse-graining, meaning that the output from these quantum chemical simulations needs to be converted so that they can be considered in macroscopic optical simulations. In these simulations, we face the challenge of solving Maxwell's equations for spatially structured molecular materials.

In this presentation, we outline our contributions along these lines of research. By calculating a transition (T-) matrix for an individual molecule in linear response theory, we can consider it subsequently in photonic simulations in the framework of scattering theory [1]. In this T-matrix based technique, disordered and periodically arranged scatterers can be considered to describe the optical response from many photonic materials [2]. Also, an explicit homogenization is possible where we can assign actual material properties to the molecular medium [3]. Currently, we consider a description of the molecular materials up to bi-anisotropic constitutive relation, but also non-local extensions are possible.

Then, we can consider the molecular materials to design complex photonic devices. Examples that we discuss at the conference concern molecular materials integrated into photonic cavities for the purpose of observing strong coupling or structured photonic materials made from chiral molecules that intrinsically enhance the circular dichroism.

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Imaging, measuring and modelling using optical tweezers.

Mark Watson[1], Itia Favre-Bulle[1,2] , Patrick Grant[1], , Timo Nieminen[1], Alexander Stilgoe[1] and Halina Rubinsztein-Dunlop[1]

1, ARC CoE for Engineered Quantum Systems, School of Mathematics and Physics, The University of Queensland, St. Lucia, Brisbane, Queensland 4072, Australia, 2, Queensland Brain Institute, The University of Queensland, St. Lucia, Brisbane, Queensland 4072, Australia.

The way light can apply forces to a microscopic object is easily understood as an exchange of momentum between the light beam and the object. This applies both to linear momentum and to angular momentum exchange and constitutes basis of optical tweezers. Methods based on these phenomena promise high flexibility and an opportunity for using this technology for super-resolution imaging, quantitative and extremely precise measurements of forces, torques and positions as well as modelling of the trapped objects in biological cell, polymer based optically driven micro and nanomachine, or chemical emulsions or being used for stimulation of nervous system in mammalian models. A combination of the optical tweezers with other techniques such as fluorescence imaging, fluorescence resonance energy transfer spectroscopy, selective plane illumination microscopy and correlation spectroscopy provide unprecedented tool for sophisticated studies of complex out of equilibrium systems.

In this talk we will present an overview of the field and outline the latest exciting results.

Approaches to Electrically Driven Organic Semiconductor Lasers

K. Yoshida, J. Gong, G.A. Turnbull and I.D.W. Samuel
Organic Semiconductor Centre, SUPA, School of Physics and Astronomy
University of St Andrews, St Andrews, UK

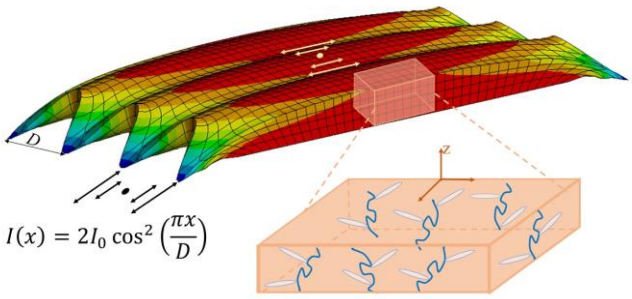
Organic semiconductors have the potential to be attractive laser materials. For example, in addition to simple processing, they have strong optical transitions enabling high gain, and broad spectra enabling tuneability. Many optically pumped lasers have been demonstrated. However, electrical excitation is very challenging because of the low mobility of the materials, together with losses to triplets, polarons and contacts. We will discuss and compare approaches to electrically driven lasing. Approaches that separate charges from the gain medium can potentially address the main challenges, though bring their own challenges. For example indirect electrical excitation by an organic LED would require an OLED with world-record light output. Recent advances in this direction will be presented.

Modeling of Photoinduced Grating Growth on Preoriented Azopolymer Films

N. Tverdokhleb, B. Yadav, M. Saphiannikova

Theory of Polymers, Leibniz Institute of Polymer Research Dresden, Germany

In modern engineering, a special interest is evoked by a unique opportunity to control the deformations of thin azopolymer films depending on the light irradiation pattern. The optical restructuring is used to produce the surfaces with tunable wettability, anisotropic templates for living cells, multiplexed gratings for photonic applications. Many theories are developed to explain the appearance of surface relief gratings (SRG), but only a few of them consider the features of underlying molecular architecture. We have also worked on this problem by pursuing the orientation approach, which establishes a clear relation between the light characteristics and the molecular properties of azopolymers. Recently we provided crucial evidence that reorientation of polymer backbones along the light polarization direction is the main reason of photoinduced deformations in azopolymer films [1].



In this talk, the viscoplastic modeling of SRG inscription under irradiation with intensity and polarization interference patterns will be presented. In particular, we explain the influence of initial orientation of polymer backbones on the SRG appearance [2]. The effects of photo-softening and self-induced polarization rotation [3] are also considered.

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Novel Health Applications of Bio-phonons

L. Savoia[1], M. Purnell [2]

1 Captain L. Savoia-McHugh, US Navy, Retired
629 Clubhouse Terrace, Pensacola, FL 32512
United States

2 Dr. M. Purnell
65 Cloudcrest Aliso Viejo CA 92656
United States

Bio-phonons are a frequency based treatment similar to bio-photons, in a different frequency range. Bio-phonons have been utilized to improve or heal many medical diseases, even medical problems believed to be DNA anomalies. Examples include multiple sclerosis[1], cystic fibrosis[2], Down's syndrome[2], and paralysis[2]. Organs have been regenerated utilizing a particular form of bio-phonon treatment termed Linguistic Wave Genetics[2]. Listening to personalized bio-phonon treatments created from pictures taken in childhood health can bring an organism back to health[3].

In the Acupuncture Five Phases system of medical treatment, one 'Phase' is dominant in most people; to treat illness, and needles are employed to bring the individual 'In-Phase' [4]. Each 'Phase' is associated with a specific bio-phonon. Therefore a bio-phonon treatment can be utilized to bring a person 'In-Phase' without the use of needles. Scientific studies to examine the effectiveness of listening to a Bio-phonon In-Phase Treatment (BIPT) targeted for the individual to improve or heal medical diseases have not been published in the English language scientific literature. In Western medicine, BIPT is a novel treatment.

This presentation will explore some, but not all, of the theoretical mechanisms underlying frequency healing with bio-phonons on the cellular/genetic level. Mechanisms with which bio-photons work together with bio-phonons will be discussed. Then, the presentation will discuss original research regarding BIPT effectiveness.

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Liquid Crystal Polymer Optics in Astronomy

E. Serabyn[1]

[1] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*

Novel planar optical components made of patterned liquid crystal polymers are enabling new types of astronomical observations Several of these techniques have already been deployed in optical instruments mounted on ground-based telescopes, and further advances will someday allow these approaches to be used on space-based telescopes. Here a brief summary of some of these new instrumental modes is provided.

One of the most rapidly growing fields of astronomy is the search for planets around nearby stars (i.e., "exoplanets"), and observational techniques are being pushed to yet greater sensitivity, so as to be able to detect and measure spectra of terrestrial-analog exoplanets. As observation of such exoplanets is the highest priority of the most recent Astronomy decadal report, astronomers are considering the instrumental approaches needed to see Earth-like exoplanets using a large space telescope, such as the proposed Habitable Worlds Observatory.

In projection on the sky, such exoplanets are located very close to their much brighter host stars, making them very difficult to pick out of the stellar glare. Indeed for terrestrial planets around solar-type stars, the planet to star contrast ratio is roughly a part in ten billion. In order to overcome this huge contrast ratio, it is necessary to suppress the much brighter starlight with a coronagraph, which selectively blocks or redirects the on-axis starlight, while letting the slightly off-axis exoplanet light through. One of the most promising coronagraphs is the optical vortex coronagraph, in which an optical vortex phase plate is centered on a very well-corrected stellar diffraction pattern, but the level of starlight rejection needed to enable terrestrial exoplanet spectroscopy requires phase plates of extremely high accuracy. These can be provided by liquid crystal polymer optics, in which the fast axis orientations closely follow the azimuthal pattern of a geometric-phase-based vortex, and the layer thickness very accurately provides a half wave of retardance. Improvements in device manufacture over the past several years have thus far allowed demonstrations of "starlight" rejection in the lab at roughly the part in a billion level, i.e., within an order of magnitude of the needed performance level..

Other phase-based devices open up other observational modes, such as high-efficency spectropolarimeters based on diffractive waveplates, and both pupil-plane apodizers and wavefront sensors that are based on geometric-phase. In some cases such devices provide a significant improvement over classical optical approaches, while in other cases, completely novel functionalities arise.

Near-Zero-Index Materials for Nonlinear Optics and Beyond

Vladimir M. Shalaev

Purdue University

Very few scientific fields have become as pervasive in basic research and everyday life as nonlinear optics which ushered in tremendous achievements in areas like attosecond physics, ultra-broadband optical communication, and high-resolution sensing. The utility of nonlinear optics has therefore been a compelling motivator to increase generally weak light-matter interactions. In this pursuit, novel materials have been explored including materials where in a particular spectral region the real part of the permittivity *epsilon* is near zero (ENZ) and materials whose losses in that spectral region are also low leading to a near-zero-index (NZI). ENZs and NZIs increase light-matter interactions via the enhanced fields at the interface between the 'normal' and ENZ materials, the "slow-light" effects and relaxed phase matching conditions. One important class of novel ENZ/NZI materials is transparent conducting oxides (TCOs) whose low-losses and high-tunability have made them a leader in NZI-enhanced nonlinear optics like Kerr-nonlinearities [1,2] and frequency generation [3]. More recently, transparent conducting oxides have provided pioneering contributions to ultrafast optically-modulated nonlinear optics, opening the door to exotic time-varying media phenomena, such as negative refraction [4,5], time refraction [6,7], time reflection, and photonic time crystals [8-10].

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Scanning Wave Photopolymerization: Molecular Alignment Technology for Designing Optical Functions

Atsushi Shishido1,2

1Laboratory for Chemistry and Life Science, Institute of Innovative Research, Tokyo Institute of Technology, Yokohama 226-8503, Japan, 2Living Systems Materialogy (LiSM) Research Group, International Research Frontiers Initiative (IRFI), Tokyo Institute of Technology, Yokohama 226-8501, Japan

Hierarchical control of two-dimensional (2D) molecular alignment patterns over large areas is essential for designing high-functional organic materials and devices.1 However, even by the most potent current methods, dye molecules that discolor and destabilize the materials must be doped in, complicating the process. We present a novel molecular alignment technique, termed a scanning wave photopolymerization (SWaP), that achieves a spatial light–triggered mass flow to direct molecular order using scanning light.2 This enables the generation of macroscopic, arbitrary 2D alignment patterns in various optically transparent polymer films from various polymerizable anisotropic molecules with high birefringence by single-step photopolymerization without alignment layers or polarized light sources.2,3 SWaP also produces microscale well and canal structures in the polymer surface.4 This dye-free inscription of microscopic, complex alignment patterns over large areas provides a new pathway for designing higher-performance optical and mechanical devices.

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Discerning the painter's hand: machine learning on 3D topographic images

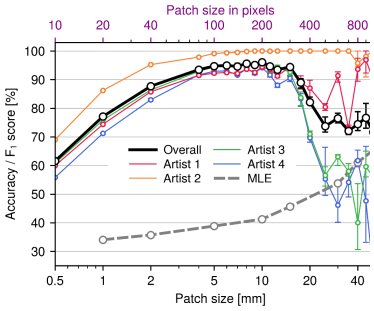
Kenneth Singer[1], Michael Hinczewski[1], Andrew Van Horn[1], Ina Martin[1], Elizabeth Bolman[2], Adam Lowe[3], Carlos Bayod[3], Anthony Ingrisano[4], Dean Yoder[5]

[1]Case Western Reserve University, Department of Physics, [2]Case Western Reserve University, Department of Art History, [3]Factum Foundation, [4]Cleveland Institute of Art, [5]Cleveland Museum of Art

Machine learning (ML) analysis of artwork is receiving increasing attention aimed at advancing connoisseurship, the main method for determining attribution of works of art and other aspects of artistic style. Most of these studies have applied ML to high-resolution photographic images of paintings. Here we will describe our research into the application of ML analysis to surface topographical images of painted works for attribution in a painting workshop milieu. These images were created by high-resolution profilometers. Our studies are focused on whether this surface topography includes information on the "intrinsic style" since we assume the painter is unaware of the surface profile at the cm down to microscopic level.

In our initial study, student painters created a set of paintings with common materials and subjects. Three images from each of four students were divided into square patches of various dimension, randomized, and used as training and verification data in a convolutional neural network (CNN) in order to classify each patch according to artist. Results on attribution accuracy are shown below indicating over 95% accuracy.

In a second study, we report on the analysis of the *Baptism of Christ* (below with hypothetical art historian attribution) by the workshop of the early modern master El Greco. In this study, we developed a statistical method to apply to an unsupervised CNN to test an assortment of areas of this complex work attributing various areas to members of El Greco's workshop. This analysis shows agreement to the number of hands and rough agreement to art connoisseurs' attribution.



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Hyperbolic Metasurfaces in Biophotonics

Giuseppe Strangi

Department of Physics, Case Western Reserve University, 44106 Cleveland (USA)

NLHT - Nanoscience Laboratory for Human Technologies, Department of Physics, University of Calabria, Rende (Italy)

E-mail: giuseppe.strangi@case.edu

Hyperbolic dispersion metamaterials enabled among many other phenomena the diverging photonic density of states and anomalously confined wave propagation, which have demonstrated to have a profound impact at the intersection of classical and quantum optics. This talk will review how we inverse design and engineer metasurfaces that support hyperbolic dispersion and epsilon-near-zero (ENZ) regimes for biophotonic applications. The fundamental focus of this work remains the control of the interaction between light and matter at deeply subwavelength scale by harnessing excitonic physics, strongly correlated phenomena and light-induced forces in optomechanics[1-6].

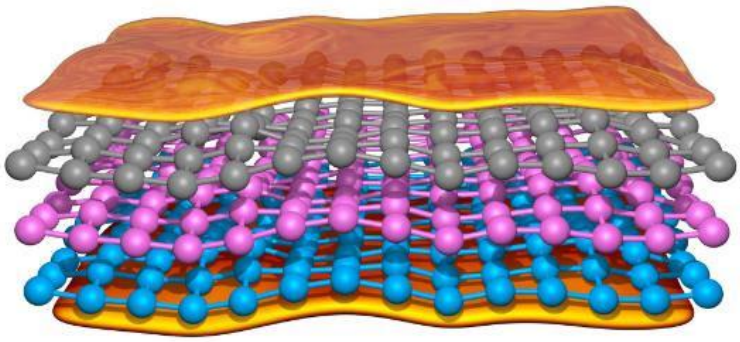

Figure: *2D Metasurface based on Transition Metal Dichalcogenides*

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Coexisting and cooperating light-matter interaction regimes in a polaritonic photovoltaic system

Roberto Termine[1], Vincenzo Caligiuri,[1,2], Svetlana Siprova[2,3], Aniket Patra [2,4], Giuseppe E. Lio[5], Simona Cilurzo[2], Attilio Golemme[1,2] and Antonio De Luca [1,2]

[1]Institute of Nanotechnology CNR-NANOTEC, SS di Rende (CS), Italy
[2]Department of Physics, University of Calabria, Rende (CS), Italy
[3]LPM (Laboratorio Preparazione Materiali), Materia-Star, Polo Tecnologico, Rende (CS), Italy
[4]Istituto Italiano di Tecnologia, via Morego 30, Genova (GE), Italy
[5]CNR-INO and European Laboratory for Non Linear Spectroscopy (LENS), Via Nello Carrara, 1 Sesto Fiorentino (FI), Italy

Usually in the quantum framework formed by light-matter coupling the interaction between an atom and a cavity follows a single feedback channel: the exciton relaxation is observed by the emission of a photon that will be stored in the cavity for several roundtrips. After that, another exciton can be created after the photon re-absorption and so on. Until now the possibility that the excited system could relax through other channels, belonging to different regimes has not been considered.

We prepared a photovoltaic cell specifically engineered to behave as an optical cavity tuned to the excitonic transition of the embedded active material (CH3NH3PbI3 perovskite) in order to study how the cooperation of the strong coupling regime and the photovoltaic effect can lead to the an enhancement of the External Quantum Efficiency (EQE), i.e the wavelength-dependent photocurrent conversion efficiency,

We studied the angular dispersion of such photovoltaic cell and observed that the strong coupling regime is achieved when the cavity mode approaches the energy of the exciton, as demonstrated from the significant enhancement of the EQE respect to a classic configuration serving as a benchmark.

This constitute a proof-of-principle experimental demonstration of how the generation of polaritons can positively influence the properties of a photovoltaic cell. Nonetheless, such a peculiar cooperating dual-light-matter interaction could be exploited in future polaritonic photovoltaic architectures

Inverse Design and Parameter Prediction in Spectrally-Selective Colloidal Quantum Dot Films for Optoelectronics

Hoon Jeong Lee[1], Sreyas Chintapalli[1], Yida Lin[1], Botong Qiu[1], Arlene Chiu[1], Tina Lin[1], Ebuka Arinze[1], Lulin Li[1], Xiaoyun Pan[2], Maria Kamenetska[2,3], Serene Kamal[1], Yijun Zhang[1], Susanna M. Thon[1]

1 Department of Electrical and Computing, Johns Hopkins University, USA
2 Department of Chemistry, Boston University, USA
3 Department of Physics, Boston University, USA

Spectrally selective materials are of great interest for optoelectronic devices in which wavelength-selectivity of the photoactive material is necessary for applications such as multi-junction solar cells, narrow-band photodetectors, transparent photovoltaics, and tailored emission sources. Colloidal quantum dots are a particularly promising material for these applications due to their tunable absorption throughout the near-infrared; their earth-abundant materials basis; and their amenability to a variety of solution-processed, scalable fabrication methods, all of which enable their applications in multi-junction solar cells, color-tuned devices for building-integrated photovoltaics, and flexible electronics [1]. Here, we discuss several avenues for achieving controlled transparency or opacity within multiple wavelength bands in the absorption, reflection, and transmission spectra of colloidal quantum dot films, as well as multi-modal spatially-resolved characterization methods that can be used to train machine learning models for parameter prediction in materials and devices.

Controlled spectral properties are difficult to achieve in traditional semiconductors that typically absorb at all energies above their electronic band gap. We demonstrate an alternate to the use of external bandpass filters for achieving spectral selectivity in optoelectronic thin films: the use of photonic band engineering within the absorbing region of a semiconductor in which resonant photonic bands are strongly coupled to the external reflectivity and transmission spectra [2]. We use optical simulations to systematically study the effect of material absorption on the properties of the photonic bands in a photonic crystal slab structure, finding that the radiating photonic bands induce strong Fano resonance features in the transmission and reflection spectra, even in the presence of material absorption, due to coupling between the bands and external electromagnetic plane waves. These resonances can be tuned by adjusting the photonic crystal structural properties to induce spectral selectivity in the absorbing region of semiconductors. Furthermore, we develop a supervised machine-learning-based inverse design methodology which allows tailoring of the PbS-CQD film optical properties [3]. We demonstrate this tuning method experimentally by fabricating a proof-of-principle photonic structure consisting of a structured PbS CQD film that displays simultaneous near-infrared absorption enhancement and visible transparency enhancement.

In addition to intentional effects due to physical structuring, the morphology, chemical composition, and electronic uniformity of thin-film solution-processed optoelectronics are believed to greatly affect device performance. Although scanning probe microscopies can address variations on the micrometer scale, the field of view is

still limited to well under the typical device area, as well as the size of extrinsic defects introduced during fabrication. We demonstrate a micrometer-resolution 2D characterization method with millimeter-scale field of view which simultaneously collects photoluminescence spectra, photocurrent transients, photovoltage transients, and other optoelectronic measurements of interest [4]. This high-resolution morphology mapping is used to quantify the distribution and strength of the local optoelectronic property variations in colloidal quantum dot solar cells due to film defects, physical damage, and contaminants across nearly the entire test device area, and the extent to which these variations account for overall performance losses. We then employ the massive data sets produced by this multi-modal characterization method to train machine learning models to predict complex materials parameters from simple illuminated current-voltage curves [5]. We trained several neural networks— based on the ResNet architecture—to demonstrate for the first time this type of predictive framework for solar cells based on real, experimentally measured data. We validated the performance of our models by predicting the materials parameters of several different PbS colloidal quantum dot thin film solar cells. This new approach reduces the amount of time needed to fully characterize a solar cell, which usually requires the measurement of complex materials parameters such as current-voltage curves, carrier mobility, photoluminescence, trap state densities, etc., all of which must typically be measured independently by performing several different techniques which can lead to enormous time and cost commitments. Our method requires only simple current-voltage curve measurements to extract all materials parameters of interest and could be applied to any materials system, speeding up development times for solar cells and other complex optoelectronic devices.

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Microfluidic chromonic liquid crystal droplets generation: tunable dimensions and topologies

Tone Caterina, Maria[1,2*]; *Zizzari Alessandra* [3], *Spina Lorenza*[1,2], *Bianco Monica*[3], *De Santo Maria Penelope*[1,2], *Barberi Riccardo*[1,2], *Arima Valentina*[3], *Ciuchi Federica*[2]

1 Physics Department, University of Calabria, Cosenza, Italy

2 CNR Nanotec c/o University of Calabria, Cosenza, Italy

3 CNR Nanotec, Campus Ecotekne, Lecce, Italy

The behavior of lyotropic chromonic liquid crystals (LCLCs) in confined microfluidic environments still awaits exploration, with multiple key variables to be uncovered and understood. As micro-scale networks offer distinct interplays between the surface effects, geometric confinement, and viscosity parameters, one expects rich and unique interactions emerging at the LCLC-microfluidic channel interfaces [1-2]. We report our studies on the behavior of pure and chiral doped nematic Sunset Yellow (SSY) chromonic microdroplets produced through microfluidic flow focusing device. The continuous production of SSY microdroplets with controllable size, from 10 up to hundreds of microns, gives the possibility to study the topological microdroplets textures according to their size. We observed enhanced chirality in our system, and we were able to obtain all the topologies that are typical of common chiral thermotropic LC, even though working with LCLCs. Being able to obtain well defined optical textures in LCLC microdroplets is the first crucial step towards their use for technological applications in biosensing and anticounterfeiting.

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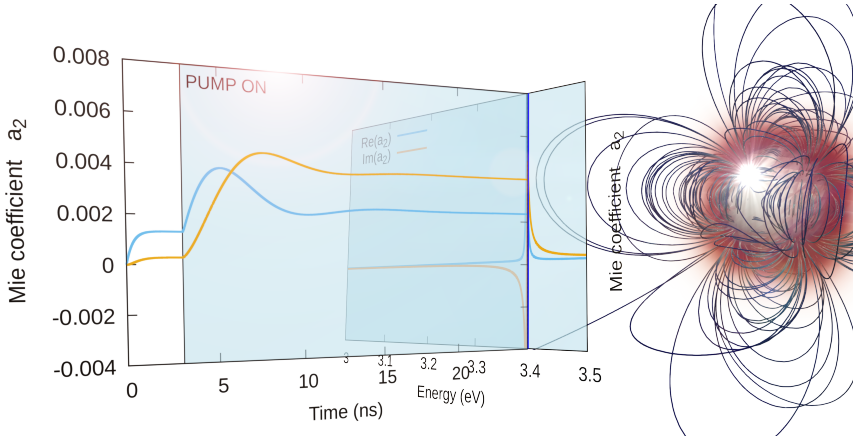
Gain enhanced, spherically symmetric plasmonic nanoparticles: from quasi-static to Mie in the time domain

N. Recalde[1], *D. Bustamante*[2], *M. Mora*[1] , *M. Infusino*[1] *and A. Veltri*[1]

[1] Colegio de Ciencias e Ingenieria, Universidad San Francisco de Quito
[2] Department of Physics, Boston University, Boston (MA), USA



In this work we present a model able to describe the time-evolution of the coupling between spherically symmetric metal nanoparticles and externally pumped gain elements. As in the case of the traditional steady state approach, the size of the particle and the amount of energy provided by the gain elements are key parameters dictating the behavior of these systems.

It is well known, in fact, that while a quasi-static approximation can be used to model nanoparticles when they are much smaller than the exciting wavelength, a more complete scattering theory is necessary to discuss larger nanoparticles. In a previous work, we demonstrated that also when the gain level is enough to drive the system to emission, an emergent mode cascade breaks any attempt to model the system using a quasi-static approach.

In the model we present here both the fields and the polarizations are projected on the Mie vector spherical harmonics. This way, we are able to describe the time evolution of any of the Mie scattering coefficient, effectively transcending the limitation in particle size.

Although the presented approach does not fully describe the emission regime yet, it certainly represents a first step which will eventually allow to give a satisfactory description of the plasmonic emissive regime. Meanwhile it already allows to identify interesting phenomena below the emission threshold.

As an example of the potentialities of this new method, we show how it is in principle possible to enhance a negligible higher mode turning it into the dominant one by wisely choose the emission center-line of the gain material.

A unified theory for loop antennas and its applications across the electromagnetic spectrum

D. H. Werner[1], *P. L. Werner*[2]

1,2 The Pennsylvania State University, Department of Electrical Engineering

Along with dipoles, loops are among one of the simplest and most fundamentally basic of all antennas. Despite this fact, however, the mathematical complexity of the associated radiation integrals has hindered the understanding and modelling of such structures. Recently, a full analytical theory for the radiation properties of loop antennas has been derived for both circular [1-3] and more general elliptical geometries [4], [5] which is able to bridge this gap and provide a basis for better understanding the behavior of these antennas across all frequency ranges of the electromagnetic spectrum. Further, these analytical models have been extended to include the effects of loading [6] and coupling [7]. The loading of antennas greatly expands the design space by making otherwise challenging performance goals more easily realizable. It is demonstrated that by pairing the analytical theory of loop antennas with a powerful global optimizer, previously unidentified designs can be discovered that offer significant radiation pattern shaping in both the radio frequency and optical regimes [6], [8]. Moreover, this analytical formulation has been recently employed to reveal interesting properties such as superdirectivity and high gain (*i.e.*, remarkably high radiation efficiency) over a broad bandwidth at optical wavelengths [9] by enabling rapid parametric studies and optimizations to be carried out. Finally, we suggest how this broadband high gain property of loop antennas could potentially be exploited to enable highly capable optical communication platforms.

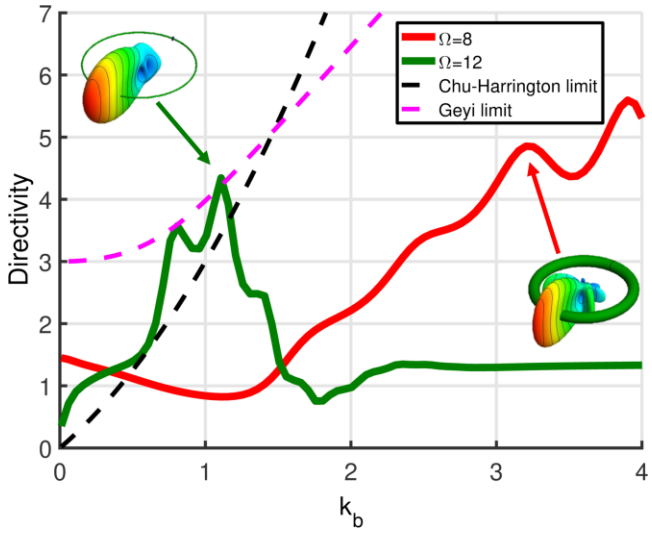


Figure 1: Directivity of a 3000 nm circumference gold nanoloop as a function of its electrical size (k_b). Red shows a thicker $\Omega = 8$ loop exhibiting broadband directivity (inset of radiation pattern at 350 THz). Green shows a thinner $\Omega = 12$ loop with superdirective radiation bypassing the Chu and Geyi limits (inset of radiation pattern is at 118 THz). $\Omega = 2\ln(2\pi b/a)$ where b is the loop radius and a is the wire radius.

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Nanoparticles-doped photonic liquid crystal microstructures for tunable devices applications

Tomasz R. Woliński, Kamil Orzechowski, and Piotr Lesiak

Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland
e-mail address: tomasz.wolinski@pw.edu.pl

Microstructured photonic crystal fibers filled with liquid crystals (LCs) offer a high level of tunability due to significantly improved control of their spectral, polarizing, and guiding properties [1]. Due to high electric field sensitivity as well thermo-optic properties, they are still promising novel optical materials for developing modern photonic sensors and in-fiber telecommunication devices, providing simultaneously interesting tunable properties. Nevertheless, photonic LC-based microstructures possess significant limitations, especially in optical communication, such as not fast enough response times under applying an external electric field and a necessity to use high driving voltage due to a relatively large cladding distance between electrodes. However, metallic nanoparticles-doped nematic liquid crystals may significantly lower threshold voltage and speed up response times of the microstructured photonic liquid crystal fibers to a few milliseconds [2].

Blue Phase Liquid Crystals (BP LCs) are composed of liquid-crystalline molecules with a specific arrangement creating self-assembling 3D cubic structures and exhibit in three structurally distinct types that appear in order of decreasing temperature from the isotropic to cholesteric phase and naturally exist in a relatively narrow temperature range (0.1-5.0 K). BP LCs are characterized by outstanding properties such as 3D Bragg reflections, optical isotropy, no need any alignment layers, ultra-fast switching reaction times (less than 1 ms), and polarization insensitivity in a macroscopic scale for the wavelengths outside their resonance bands [3].

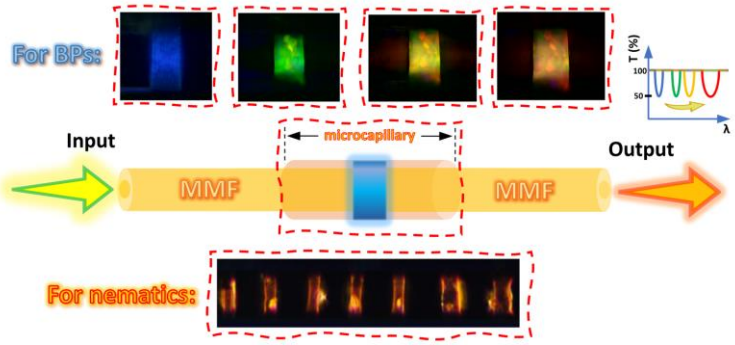

Fig. 1. LC-based photonic microstructure with fiber probes on both sides.

Gold nanoparticles (Au NPs) dispersed in LCs can induce reduction of local order parameter in functional materials, that might be tuned by altering composition of ligand shells surrounding Au NPs enabling modification of thermal stability of the functional

materials. It has been shown that mixtures of colloidal particles and a nematic liquid crystal solvent can influence both phase separation [4,5] as well 3D crystalline structures. Additionally, it has been demonstrated that it is possible to create periodic structures by either stabilizing the periodic phase separation or periodically varying Au NPs concentration induced by the nematic-isotropic phase transition in composites confined in microcapillaries.

In this work, optical properties of the selected photonic microstructures doped with Au NPs based either on nematic or BP liquid crystals (Fig. 1) are discussed. It has been shown that the Au NPs-doped photonic microstructures can provide promising tunable optical properties simultaneously enhancing temperature stability of the LC-system [6]. This is due to the presence of Au NPs with an appropriate organic coating in the LC matrix. Moreover, it has been demonstrated that the selected BP LC-based photonic microstructures seem to be very promising optical materials for realizing electro-optical modulation and switching as well tunable filter applications and sensing capabilities providing better transmission properties.

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Tuning and coupling cavity modes in the surface forces apparatus (SFA)

B. Zappone,[1] *V. Caligiuri,*[1,2] *A. Patra,*[2,3] *R. Krahne,*[3] *A. De Luca*[1,2]

[1] *Consiglio Nazionale delle Ricerche – Istituto di Nanotecnologia (CNR-Nanotec), Rende, Italy*
[2] *Dipartimento di Fisica, Università della Calabria, Rende, Italy*
[3] *Optoelectronics Research Line, Istituto Italiano di Tecnologia, Genova, Italy*

The SFA is designed to measure surface forces between two reflective cylindrical surfaces that create a curve optical cavity with approximate sphere-plane geometry around a single contact point (Fig. 1). Resonant cavity modes are excited using a white light beam under normal incidence. By using nanoscale actuators and analyzing the interference pattern transmitted by the cavity, the SFA routinely achieves sub-nanometer control of the surface distance as well as measurements of the optical properties in the surface gap [1]. We recently introduced the SFA as a convenient and versatile platform to finely tune the resonant modes of a metal-dielectric-metal cavity using rapid and continuous variations of the cavity thickness [2]. The talk will focus on the generation of polaritons due to strong coupling between cavity modes and molecular excitons in a dye-doped SFA cavity [3] (Fig. 1d). We found that the polaritons inherit the epsilon-near-zero (ENZ) character of cavity modes, i.e., the effective permittivity vanishes at a resonance. Moreover, SFA measurements revealed a Rabi splitting proportional to the square root of the number of photons and exceeding 100 meV, highlighting the collective nature of strong coupling.

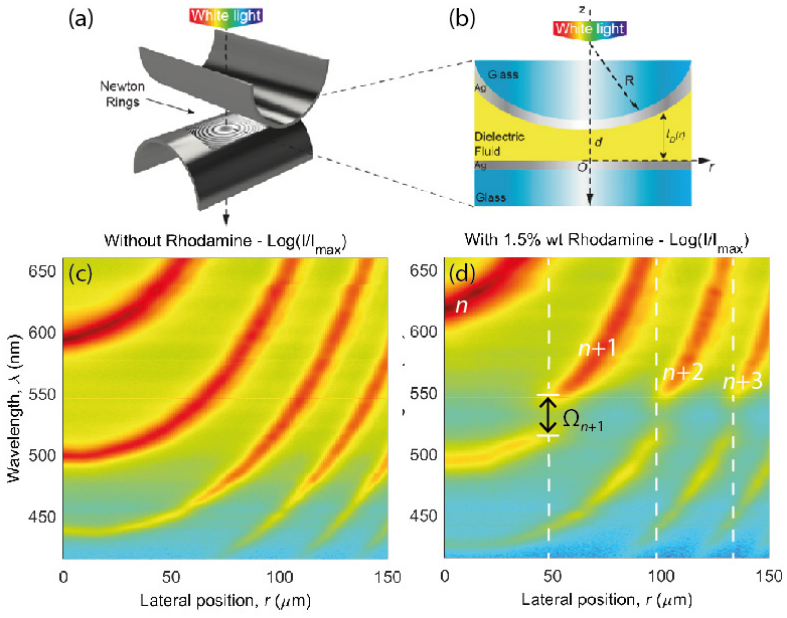

Fig. 1. (a) Single-contact geometry between crossed cylinders. (b) Metal-dielectric-metal cavity with sphere-plane geometry. $R = 2$ is the curvature radius, r is the lateral distance from the contact point O along the bottom cylinder axis, and $t_D(r) \geq d$ is the non-uniform thickness of the dielectric film. (c) Transmitted intensity for a non-adsorbing fluid mixture of ethanol and polyvinyl alcohol. (d) Polariton generation in a mixture doped with fluorescent rhodamine-6 adsorbing around 530 nm. Ω_n is the Rabi splitting for the cavity mode with order n.

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Picophotonics and Continuous Time Crystals

Nikolay I. Zheludev[1, 2]
[1]University of Southampton, UK
[2]Nanyang Technological University, Singapore
E-mail: *zheludev@soton.ac.uk*

Recent advances in picometer scale visualization and localization techniques with electron beams and topologically structured light allow the detection of atomic level displacements in opto-mechanical systems[1] and the study of dynamics and statistics of their picometre scale thermal and driven movements[2]. This opens opportunity to develop pico/nano-opto-mechanical systems, in particular flexible plasmonic metamaterial arrays as a powerful platform to investigate **classical many-body effects in the strongly correlated regime** induced by light. It complements the cold atom and spin platforms where many-body quantum states of bosonic or fermionic matter can be studied.

Among these many-body strongly correlated systems is the **time crystal** that is an eagerly sought phase of matter with **broken time-translation symmetry**. Quantum time crystals with discretely broken time-translation symmetry have been demonstrated in trapped ions, atoms and spins while continuously broken time-translation symmetry has only been observed in an atomic condensate inside an optical cavity.

Recently we demonstrate experimentally that a classical metamaterial nanostructure, a two-dimensional array of plasmonic metamolecules supported on nanowires, exhibit complex picometer scale dynamics in presence of light[3]. It can be driven to a state possessing all the key features of a continuous time crystal: continuous coherent illumination by light resonant with the metamolecules' plasmonic mode triggers a **spontaneous first order phase transition to a superradiant-like state** of transmissivity oscillations, resulting from many-body interactions among the metamolecules, characterized by long-range order in space and time. The continuous time crystal state results from synchronization of picometer scale stochastic thermal movements of the nanowires that is driven by light-induced interactions of plasmonic metamolecules. In interpretation of these experiments, we discuss different routes to synchronization including the **Kuramoto-like mechanism** that rely on nonlinearity of the mechanical sub-system of the array and the mechanism involving **non-reciprocal non-Hamiltonian forces of light pressure**.

We argue that the continuous time crystal state is of interest to applications in all-optical modulation, frequency conversion, timing and all-optical computing.

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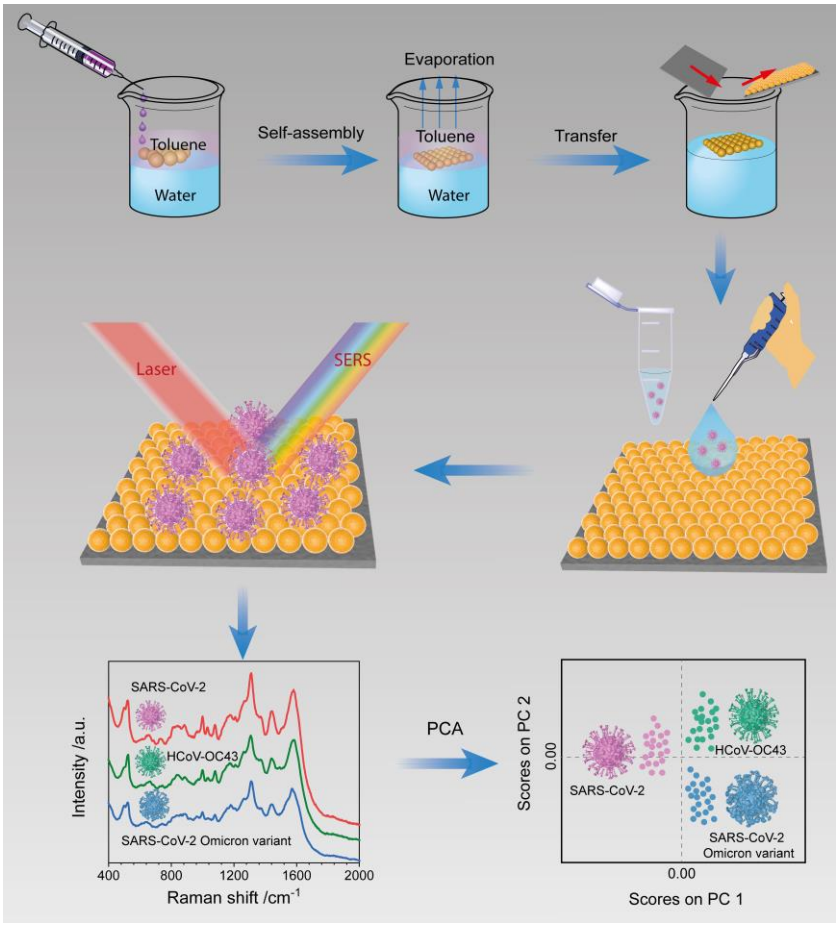
Label-Free Detection and Identification of SARS-CoV-2 Using Surface-enhanced Raman Spectroscopy and Machine Learning

L. Zhou[1], A. Vestri[1], V. Marchesano[1], M. Rippa[1], G. Fusco[2], J. Zhou[3] and L. Petti[1]

[1]Institute of Applied Sciences and Intelligent Systems of CNR, 80072 Pozzuoli, Italy
[2]Istituto Zooprofilattico Sperimentale del Mezzogiorno, Portici 80055, Italy
[3]Institute of Photonics, Faculty of Science, Ningbo University, Ningbo, China

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic and COVID-19 disease have placed an unprecedented burden on worldwide healthcare. The development of rapid detection technique with high sensitivity and high accuracy for SARS-CoV-2 is of great importance to prevent and control of epidemic. At present, a series of detection methods for SARS-CoV-2 virus have been developed. Among them nucleic acid testing for SARS-CoV-2 have become the mainstream technology. However, the assay platform is laboratory-based, and requires expertise in viral RNA extraction and polymerase chain reaction (PCR) which is time-consuming and requires skilled personnel. In this study, we report a label-free testing platform that combines surface-enhanced Raman spectroscopy (SERS) and machine learning for the rapid and accurate detection of SARS-CoV-2. We first prepared the SERS platform by using the liquid/liquid interfacial self-assembly of gold nanoparticles (Au NPs) in toluene/water. And then the SERS spectra of different viruses (SARS-CoV-2, HCoV-OC43 and SARS-CoV-2 Omicron variant) were collected after spreading the viral solutions onto the Au NPs substrates. The virus detection range was determined to be 10^2-10^5 $TCID_{50}$/mL in phosphate buffer solution. Subsequent principal component analysis (PCA) of the SERS spectra provided the key Raman bands to enable effective identification of the SARS-CoV-2. Not only can our technique accurately distinguish between different viruses, but it can also fit for quantitative detection of virus. Our results show that the combination of SERS and PCA could serve as a promising tool for detection of COVID-19.



Acknowledgements

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Bound states in the continuum in near-infrared silicon-slot metasurfaces

D. C. Zografopoulos

Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e Microsistemi (CNR-IMM), Via del fosso del cavaliere 100, 00133, Rome, Italy.

Bound states in the continuum (BIC) are confined, non-radiative states that lie within, but are orthogonal to the radiation continuum in wave propagation systems [1]. Dielectric metasurfaces are being intensely investigated as low-loss components for electromagnetic wave manipulation at the subwavelength level. When combined, these two paradigms provide an unprecedented platform for strong field confinement and high-quality factor resonances in a new generation of flat-optics devices, e.g., for sensing, lasing, and enhanced non-linear phenomena [2]. Here, we provide a brief introduction in the field and highlight some recent developments in the design and experimental demonstration of BIC dielectric metasurfaces resonating in the near-infrared spectrum [3, 4]. The metasurfaces are composed of silicon-slot structures, which allow for strong field enhancement in slotted areas, further enhanced by the physical mechanism of quasi-BIC resonances. Refractometric sensing is investigated, as a promising application that leverages the intense light-matter interaction in the proposed metasurface platform [5].

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Raman spectroscopy-based method for high throughput analysis of whole blood assays

[1,2]Filippo Zorzi, [1]Silvio Bonfadini and [1]Luigino Criante

[1]*Center for Nano Science and Technology@PoliMi, Istituto Italiano di Tecnologia, via Pascoli 70/3, 20133 Milano, Italy*
[2]*Politecnico di Milano, Dipartimento di Fisica, Piazza Leonardo da Vinci 32, 20133, Milano, Italy*

Abstract:

A new method for blood testing is shown, that implements the capability of microfluidics lab-on-chip with optics to perform Raman spectroscopy on flowing samples. In this way the whole volume of blood flowing through the chip can be analyzed, while at the same time performing a fast and complete analysis of the sample.

Summary:

Blood contains a wealth of valuable information that, if accurately detected at an early stage, can prevent even the most serious diseases. Blood testing is now a routine part of a patient's initial health screening and may become mandatory to confirm the presence and efficacy of treatment for many diseases; however, due to the long analysis times needed for complete screenings, hospitals often only perform analysis on an incomplete set of parameters. As a result, there is a risk that diseases that could have been detected with a complete analysis are not prevented. It is therefore necessary to have a technique capable of analyzing more parameters simultaneously, while at the same time reducing the time duration of analysis.

Raman spectroscopy seems to be the ideal candidate to fulfill this purpose [1]. Thanks to its high sensitivity, it has already been tested for recognizing markers of various diseases [2]. Moreover, unlike other techniques, it is a label-free method and therefore does not require any pre-treatment of the sample, including the use of fluorophores that can be toxic. However, together with this high sensitivity there are also some drawbacks, related to the weak signal, the long integration time needed for measurements, and the possibility of laser induced photodegradation of biological samples.

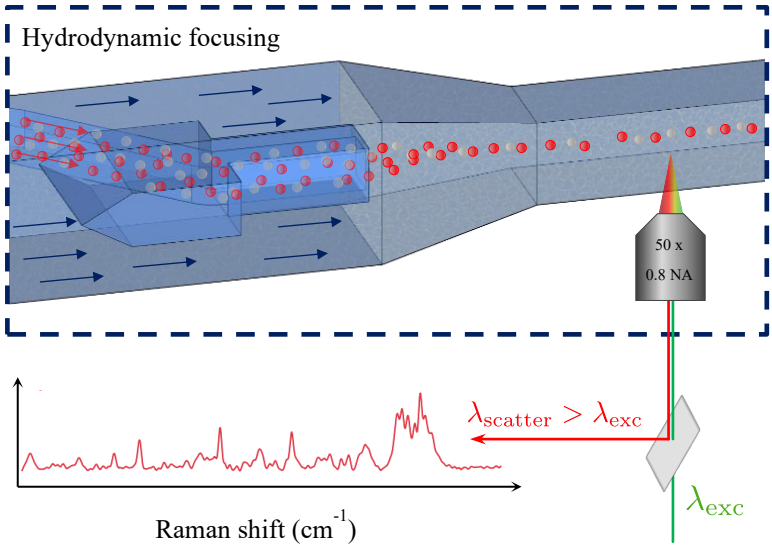

Figure 1 Schematic of the setup. The blood is focused on the center of the outer channel, where is excited by the focalized laser beam. The scattered light is then captured by the objective lens and sent into a spectrometer. From the CCD image, we can retrieve the Raman spectrum of the analyzed sample.

One possible solution may be the analysis of moving samples. Some studies in the literature [3] focus on the use of capillaries for this purpose, although they do not eliminate some drawbacks. In order to avoid clogging, only capillaries with a diameter larger than 100 μm can be used. However, due to the corpuscular nature of blood, the penetration length of light is reduced to

only 10 microns, reducing the volume of analyzed blood to a small percentage of the total volume flowing in the capillary (few percent), dramatically lowering the efficiency of this method.

Here we show a new lab-on-chip based method for fast and more efficient Raman analysis of whole blood assays. Thanks to the FLICE (*Femtosecond Laser Irradiation followed by Chemical Etching*) fabrication technique a 3D hydrodynamic focusing geometry has been realized that is completely buried inside a fused silica substrate (*Figure 1*). The use of fluid focusing for this purpose brings several advantages. Firstly, the shear stress between blood and the buffer is reduced, resulting in a more uniform distribution of cells within the stream. Moreover, the flow rate compared to the capillary is similar, meaning that the sample consumption can be kept relatively low and, since the speed massively increases compared to the capillary, there is the possibility of using higher laser powers (and thus making faster measurements), without the risk of burning the sample.
Finally, this specific geometry allows us to match the focused flow size to the voxel size of the objective lens. In this way it allows us to collect the signal coming from the entire sample volume, massively increasing the collection efficiency, compared to the capillary.

In conclusion, the potential offered by the combination of microfluidics and Raman spectroscopy, can significantly push forward the development of fully integrated devices capable of making high throughput, highly sensitive analysis of whole blood assays, capable of detecting even small variations of blood composition.

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Posters

Flexible Physical Unclonable Functions based on non-deterministic distributed Dye-Doped Fibers and Droplets

Mauro Daniel Luigi Bruno[1,2,*], *Giuseppe Emanuele Lio*[3,4,5], *Antonio Ferraro*[2,1], *Sara Nocentini*[6,4], *Giuseppe Papuzzo*[7], *Agostino Forestiero*[7], *Giovanni Desiderio*[2], *Maria Penelope De Santo*[1,2], *Diederik Sybolt Wiersma*[3,4,6], *Roberto Caputo*[1,2,8], *Giovanni Golemme*[9], *Francesco Riboli*[5,4], *and Riccardo Cristoforo Barberi*[1,2]

[1] *University of Calabria, Physics Department, 87036 Arcavacata di Rende (CS), Italy*
[2] *Consiglio Nazionale delle Ricerche - Istituto di Nanotecnologia CNR-Nanotec, Rende (CS), 87036 Italy*

[3] *Physics Dept., University of Florence, Via Sansone, 1, 50019, Sesto Fiorentino, Florence, Italy*
[4] *European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Via Nello Carrara 1, 50019, Sesto Fiorentino, Florence, Italy*
[5] *Consiglio Nazionale delle Ricerche - National Institute of Optics, CNR-INO, 50019, Sesto Fiorentino (FI), Italy*

[6] *Istituto Nazionale di Ricerca Metrologica (INRiM), Strada delle Cacce 91, Turin, 10135 Italy*
[7] *Institute for High Performance and Networking, CNR-ICAR, via P. Bucci 8-9c, 87036 Rende, Cosenza, Italy*
[8] *Institute of Fundamental and Frontier Sciences, University of Electronic Science and Technology of China, Chengdu 610054, China*
[9] *University of Calabria, Environmental Engineering Department, 87036 Arcavacata di Rende (CS), Italy*

The development of new anti-counterfeiting systems is a constant challenge that involves several research fields. The most secure systems are based on the Physical Unclonable Function (PUF) key paradigm [1,2]. In this work, new strategies based on electrospinning and electrospraying techniques are used for the fabrication of flexible films that embed different PUF keys. Keys are obtained exploiting the characteristics of the fabrication techniques as well as the properties of different materials as polymers and fluorescent dyes.

The proposed labels are based on three encryption levels:

i) a map of the fluorescent polymer droplets produced through electrospraying, with completely random positions, on a dense yarn of polymer nanofibers, fabricated using electrospinning;
ii) a characteristic fluorescence spectrum for each label;
iii) a challenge-response pairs (CRPs) identification protocol based on the intrinsic randomness introduced by the deposition technique.

The labels show characteristics such as non-clonability, ease of reading, low cost and eco-friendly feasible production. Overall, thanks to their multi-level security, these labels can be used for the protection of many daily life products as clothes, luxury goods and personal documents.

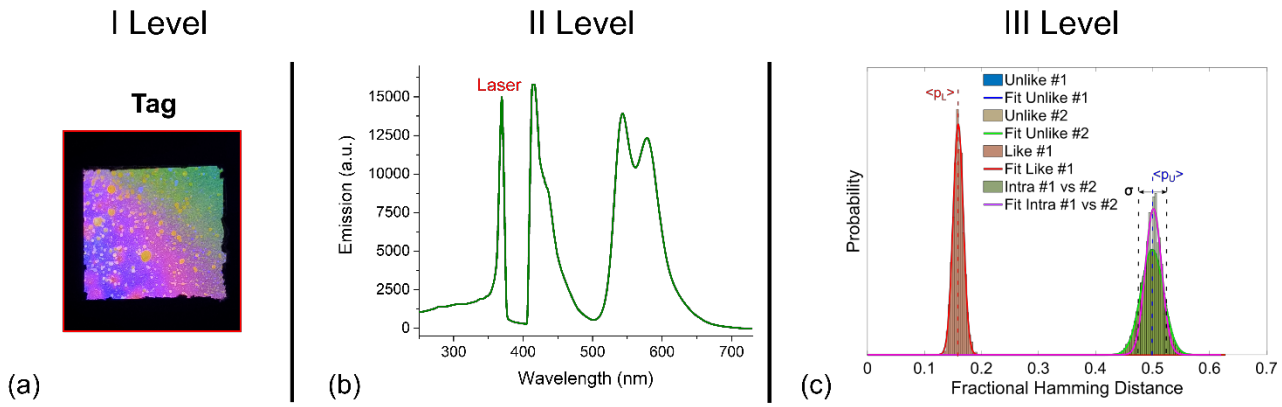

Figure 1: (a) First level, the authentication of the map of points; (c) second level, fluorescence spectrum of the Tag shown in (a); (d) third level, CRPs identification.

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Planar Bio-Photonic Structures based on Micro- and Nano-Structured Bacteria Growth Media

Vincenzo Caligiuri[1,2,3], *Francesca Leone*[1], *Olga Favale*[1], *Maria De Santo*[1], *Mauro Daniel Luigi Bruno*[1,2], *Olga Mileti*[4], *Alfredo Pane*[2], *Aniket Patra*[1,3], *Lucia Petti*[5], *Susana Guzman-Puyol*[6], *Josè Alejandro Heredia-Guerrero*[6], *Roman Krahne*[3], *Noemi Baldino*[4], *Roberto Bartolino,*[2] *Michele Galluccio*[7], *Ferdinanda Annesi*[2] *and Antonio De Luca*[1,2]

1, Dipartimento di Fisica, Università della Calabria, via P. Bucci 33b, 87036 Rende (CS), Italy.

2, Consiglio Nazionale delle Ricerche – Istituto di Nanotecnologia (CNR-Nanotec), via P. Bucci 33c, 87036 Rende, Italy.

3, Optoelectronics Research Line, Istituto Italiano di Tecnologia, via Morego 30, 16163 Genova, Italy.

4, Department of Information, Modeling, Electronics and System Engineering, (D.I.M.E.S.) University of Calabria, Via P. Bucci, Cubo 39C, I-87036 Rende (CS), Italy.

5, Institute of Applied Sciences and Intelligent Systems of CNR, 80072 Pozzuoli, Italy.

6, Instituto de Hortofruticultura Subtropical y Mediterránea "La Mayora", Universidad de Málaga-Consejo Superior de Investigaciones Científicas (IHSM, UMA-CSIC), Bulevar Louis Pasteur, 49, 29010, Málaga, Spain.

7, Dipartimento di Biologia, Ecologia e Scienze della Terra (DiBEST), unità di Biochimica e Biotecnologia Molecolare, Università della Calabria, via P. Bucci 6c, 87036 Rende (CS), Italy

Reducing its environmental footprint represents one of the main challenges for future photonic technologies.[1] The pathway towards such an achievement requires a complete paradigm shift where solid state, bulk cavities are replaced with soft, planar alternatives and inorganic semiconductors based on Pb or Cd are replaced with a biologic counterpart. Luminescent proteins like the famous Green Fluorescent Protein (GFP) offer a valid alternative to inorganic semiconductors and can be expressed by bacteria, whose proliferation can provide exceptionally large amounts of gain materials with no chemical synthesis efforts. However, producing photonic structures with bacteria-viable materials is challenging. In this work, we successfully achieve such a task by replicating

sophisticated photonic structures *via* soft-lithographic processes using either classic LBA growth media or blended with xylan for improved replica fidelity and solubility. We replicate photonic structures from the micro- to the deep sub-micron scale, demonstrating exceptional optical properties, viability for GFP-labeled bacteria, and water solubility. We also engineer surface wettability through micro-structuration and demonstrate that the replicated structures can be easily endowed with plasmonic properties.

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Hybrid anticounterfeiting tag with camouflaged multi security levels

Antonio Ferraro[1,2], Giuseppe Emanuele Li[3,4,5], Mauro Daniel Luigi Bruno[1,2], Sara Nocentini[4,6], Maria Penelope De Santo[1,2], Diederik Sybolt Wiersma[4,5,6], Francesco Riboli[3,4], Roberto Caputo[1,27] and Riccardo Cristoforo Barberi[1,2]

[1]Consiglio Nazionale delle Ricerche, Institute of Nanotechnology, CNR-Nanotec, Rende 87036, Italy
[2]Department of Physics, University of Calabria, Rende 87036, Italy
[3] Consiglio Nazionale delle Ricerche - National Institute of Optics CNR-INO, Sesto Fiorentino (FI), 50019, Italy
[4] European Laboratory for Non-Linear Spectroscopy (LENS) University of Florence, Sesto Fiorentino, 50019, Italy
[5]Physics Department University of Florence, Sesto Fiorentino, 50019, Italy
[6]Istituto Nazionale di Ricerca Metrologica (INRiM), Turin 10135, Italy
[7] Institute of Fundamental and Frontier Sciences, University of Electronic Science and Technology of China, Chengdu 610054, China

The rise of counterfeiting is promoting a thriving research on different materials and technologies to prevent and limit such a phenomenon by developing new anti-counterfeiting identification tags.
Herein we report on the experimental demonstration of multi-level anticounterfeiting Physical Unclonable Function (PUF) tags realized on a flexible and conformable office paper substrate.

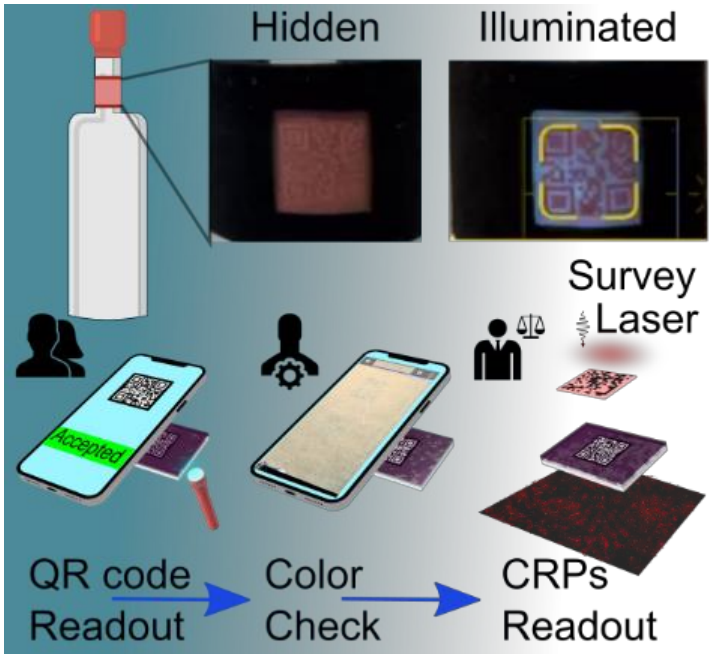

Figure 1: Camouflage anticounterfeiting tag with multi security level.

The first security level is guaranteed by the printing of a QR code which is hidden by a successive deposition of a metal/insulator/metal/insulator (MIMI) metamaterial. The QR code information can be read only by retro-illuminating the tags enabling a variation of the characteristic structural color exhibited by MIMI metamaterials. Then, the proposed tags are attached to a liquor bottle and tested with a smartphone proving its reliability and easy operation.
Furthermore, the QR code has a twofold function. It can be not only a descriptor including a "hyperlink" to the merchandise information but also the first identification level including an alphanumeric hashed code (SHA256).
Thanks to the intrinsic random morphologies of a paper substrate producing characteristic speckle patterns, a third "*forensic"* level is enabled by using a challenge response pair interrogation protocol proving their *strong* nature as physical unclonable function. This level works for the seller like a sample survey where, in case of doubt about the merchandise, he can ask to a forensic laboratory to test if the produced challenge response pairs are enrolled in the central authority.

The proposed camouflage paper-based physical unclonable functions exhibits three different security levels based on QR code and color reading and speckle analysis. These are intended to different possible users: the first and second one are accessible to customers and not specialized persons with a double check on the label genuineness by interrogating a specific repository where all the information, e.g Qr code and color association, are stored.
The third is a forensic level because require sophisticated apparatus and experts in the field and can be adopted for legal actions.
The proposed physical unclonable functions represent an ideal candidate for the protection of goods thanks to their low cost and large-scale production possibilities

Reference

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Fluorescence profile of Opuntia ficus-indica cladodes as promising tool for optical applications

Oriella Gennari[1], *Sephora Kamwe Sighano*[2], *Roberto Caputo*[2], *Lucia Bartella*[3], *Leonardo Di Donna*[3], *Antonio Ferraro*[1]

[1]*Consiglio Nazionale delle Ricerche, Institute of Nanotechnology, CNR-Nanotec, Rende 87036, Italy*
[2]*Department of Physics, University of Calabria, Rende 87036, Italy*
[3]*Department of Chemistry, University of Calabria, Rende 87036, Italy*

The skill of calabrian *Opuntia ficus-indica* bioactive extract to autofluorescence upon UV illumination was explored by fluorescence spectroscopy enabling to investigate the kind and distribution of phenolic compound within green cladodes (Figure 1).
The spectroscopic analysis of the extract dissolved in toluene showed a significative red fluorescence, suggesting an abundance of phenols in the sample [1]; the chemical characterization and quantification by Liquid Chromatography-Mass Spectrometry (LC-MS) confirmed their rich distribution [2, 3].

Fluorescence results proved pronounced features in the visible range (400-800 nm) with a very large Stokes shift, when excited in the UV region. The experiments were performed also in the case of polymers, such as poly(methyl methacrylate) (PMMA), poly(vinylpyrrolidone) (PVP) and polyvinyl alcohol (PVA), mixed with the *OFI* extract. The results showed a signal intensity four times greater than the extract itself (Figure 2).
The rich phenols extract imparted new properties to polymers, making them fluorescent materials, and this could be useful in several applications spanning from nano-optics to anti-counterfeiting and bioimaging [4].

Figure 1: Cladodes of *Opuntia ficus-indica*.

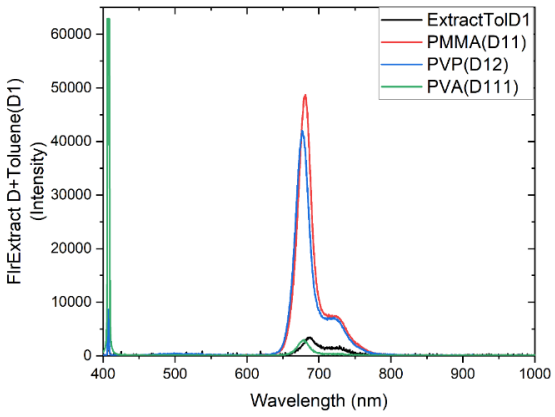

Figure 2: Fluorescent spectrum of *OFI* extract in toluene. The picture reports also the results obtained for PMMA, PVP and PVA.

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The relevance of the protein corona in light-activated antimicrobial applications mediated by plasmonic nanoparticles

A. Guglielmelli [1], *P. D'Aquila* [2], *G. Palermo* [1], *M. Dell'Aglio* [3], *G. Passarino* [2], *G. Strangi* [1,4], *and D. Bellizzi* [2]

[1] *Department of Physics, NLHT-Lab, University of Calabria and CNR-NANOTEC, Institute of Nanotechnology, 87036 Rende, Italy*

[2] *Department of Biology, Ecology and Earth Sciences, University of Calabria, 87036 Rende, Italy*

[3] *CNR-IFN, Institute for photonics and nanotechnologies, c/o Physics Department, Via Amendola 173, 70126 Bari, Italy*

[4] *Department of Physics, Case Western Reserve University, 2076 Adelbert Rd, Cleveland, Ohio 44106, USA*

The emergence of antibiotic-resistant bacteria has become a major public health concern, leading to a growing interest in alternative antimicrobial agents. The antibacterial activity of metal nanoparticles (NPs) has been extensively studied, and it has been shown that can effectively inhibit the growth of various bacteria, including both Gram-positive and Gram-negative strains.

The presence of a protein corona, formed by the adsorption of proteins onto the NPs surface in biological fluids, can significantly affect their toxicity. Understanding the effect of the protein corona on the antimicrobial activity of metal NPs is crucial for their effective use as antimicrobial agents. In this study, the antimicrobial activity of noble metal NPs, such as platinum (Pt), silver (Ag) and gold (Au) with and without human serum albumin (HSA) protein corona against Escherichia coli strains, was investigated.

In addition, the plasmonic photothermal effect related to the AuNPs, which resulted to be the most biocompatible compared to the other considered metals, was evaluated. The obtained results suggest that the HSA protein corona modulated the antimicrobial activity exerted by the metal NPs against *Escherichia coli* bacteria. These findings may pave the way for the investigation and development of innovative nano-approaches to face antibiotic resistance emergence.

Elemental mapping with laser induced breakdown spectroscopy as a tool for quality control.

Miguel Ferreira [1,2], Tomás Lopes[1,2], Pedro Rodrigues[1,2], Rafael Cavaco[1,2], Diana Capela[2], Nuno A. Silva[1,2], Pedro A. S. Jorge,[1,2]

1 Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto, Portugal. 2 INESC TEC, Centre for Applied Photonics, Porto , Rua do Campo Alegre 687, 4169-007, Porto, Portugal.

Laser-induced breakdown spectroscopy (LIBS) is a well-established analytical technique based on the spectroscopic analysis of the radiation emitted by a laser induced plasma. Each emission line can be ascribed to a specific element allowing to obtain the elemental composition of the ablated matter at the laser focal spot. With the adequate laser and optical setup, this technique can produce high resolution surface composition maps as well as in depth composition profiles, with minimum sample destruction, and very little to no preparation [1].

These features make LIBS a very attractive technique and explain its widespread use in many fields of research and industry, going from ore grading in mining applications and real time analysis of molten steel, to the study of delicate cultural items in heritage applications, the profiling of micro and nanocoatings and the detection of nanoparticles.

Presently, some major challenges of LIBS applications include establishing adequate strategies to ensure an accurate identification and quantification of elements when analyzing complex samples. In this context, the use of advanced computational tools contributes for an enhanced performance, providing adequate processing algorithms, visualization tools, and automation strategies that ensure a stable operation and a more efficient extraction of information from the raw data.

In this work, computational tools for LIBS analysis of complex samples will be described. Several examples of improved compositional mapping will be shown, from complex mineral samples of geological interest to the analysis of thin organic coating for quality control in industry.

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New anticounterfeiting tags with the combination of flexible, micro-nano materials for anti-counterfeiting

Sephora Kamwe Sighano[1], Antonio Ferraro[2], Mauro Daniel Luigi Bruno[1,2], Oriella Gennari[2] and Roberto Caputo[1,2,3]

[1]Department of Physics, University of Calabria, Rende 87036, Italy
[2]Consiglio Nazionale delle Ricerche, Institute of Nanotechnology, CNR-Nanotec, Rende 87036, Italy
[3] Institute of Fundamental and Frontier Sciences, University of Electronic Science and Technology of China, Chengdu 610054, China

Anti-counterfeiting methods are developed in response to the counterfeiting activities that continue to cause damage around the world. Several approaches are emerging for the fabrication of new anti-counterfeiting tags, combining the use of new techniques and materials, in order to make it more difficult to reproduce.

We focus on the combination of different materials such as polymers, fluorophores, metals, etc. for the realization of multi-level security tag. We used PVA as a flexible material added with fluorescent dye and dielectric material.

The first step is the manufacture of a flexible thin film using polyvinyl alcohol (PVA) and Titanium dioxide (TiO2) to serve as a label substrate. The flexible nature of the label will facilitate the integration on the product's packaging. The fluorescent dye, previously mixed with Polymethyl methacrylate (PMMA) for easy adhesion to the PVA-TiO2 film, is sprayed on the label, thus creating a random deposit of droplets.

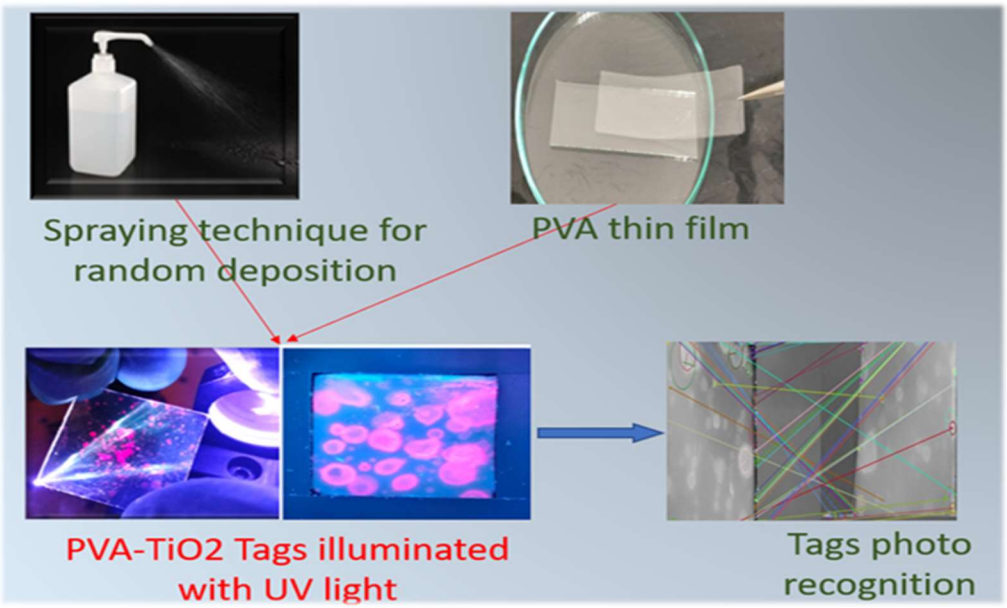

Figure 1: Manufacturing process of anti-counterfeiting tags, from fabrication to reading.

The fabricated tags with fluorescent droplets are illuminated by UV light and photographs are collected for generating a security code. Indeed, the label photos are analyzed using the SIFT algorithm, which will extract character unique features, thus forming a first level of security for the anti-counterfeiting label.
Further levels of security will then be investigated (e.g., morphology, color etc. of the fluorescent dye droplets) to produce an ideal and inexpensive security key for asset protection.

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Nanophotonics for biosensing: development of optical platforms for high sensitivity and specificity

G. Palermo[1]

[1] Department of Physics, NLHT-Lab, University of Calabria and CNR-NANOTEC Istituto di Nanotecnologia, 87036 Rende, Italy

Plasmonics is a branch of optics that deals with the study of surface plasmons. These plasmons can be used to manipulate light at the nanoscale, allowing for the development of novel devices for applications in sensing, imaging, and information processing. One important application of plasmonics is the development of plasmonic biosensors, which can detect and quantify the presence of molecules as biomarkers with high sensitivity and specificity. It is well known that pathological tissues release a whole series of compounds into the vascular system, such as circulating DNA, extracellular vesicles, proteins, metabolites and so on. Going for early detection of these analytes in blood or other body fluids could allow to detect a disease when it is really in an early stage, giving the possibility to intervene promptly. For this reason, it is necessary to develop sensing platforms capable of detecting very small concentrations of analyte, that are of the order of femtomolar or even in the attomolar range. Plasmonic metasurfaces play a key role in the development of the next-generation nanophotonic biosensors, which can detect and quantify the presence of molecules with high sensitivity and specificity. The metal surface is typically patterned with nanoscale features, such as nanoparticles or nanoholes, that can support surface plasmons. These sensors work by measuring the changes in the plasmon resonance of a metal surface caused by the binding of analyte molecules. The shift in plasmon resonance can be measured using various optical techniques, such as reflectance or transmission spectroscopy, and can be used to detect and quantify the presence of analyte molecules. The highest sensitivity for a plasmonic biosensor can be achieved by optimizing the design of the sensor to maximize the interaction between the analyte molecules and the plasmonic field. Our research group addresses this challenge by developing next-generation nanophotonic biosensors based on surface plasmons and metamaterials.

Microfabrication of security devices in reactive mesogens

T. Ritacco[1,2], D.M. Aceti[3], A. Mazzulla[2], G. De Domenico[1], M. Giocondo[2], G. Cipparrone[1,2], and P. Pagliusi[1,2,]*

[1] *Physics Department, University of Calabria, Rende (CS) Italy*

[2] *CNR-Nanotec, Institute of Nanotechnology, SS Cosenza, Rende (CS), Italy*

[3] *Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*

Liquid crystalline photo-curable resins, also known as reactive mesogens (RMs) can be employed to microfabricate polymeric devices presenting both the mechanical properties of polymers and the optical properties of liquid crystals. [1-3]. Among different manufacturing technologies, Two-Photon Lithography (TPL) exhibits several benefits for the precise fabrication of complex 3D structures at the nanoscale level [4] and could be effectively employed for anti-counterfeiting solutions [5-6]

We demonstrate that, when applied to RMs, TPL is an effective technique to locally adjust physico-chemical and optical characteristic of 3D printed microstructures, (i.e. order parameter, alignment, etc.), without the need of other external controls (i.e. temperature, voltage, etc.).

In particular, we show that the birefringence and the optical axis of a nematic RMs film could be deliberately modified, depending on the exposure parameters (i.e., direction, spacing, speed, power of the scanning laser beam). Furthermore, we demonstrate that the photonic band gap of a photo-curable cholesteric RMs mixture [6] can finely tuned across the whole visible range, simply tuning the delivered energy dose in a single-step fabrication session. Eventually, examples of 4D microstructures which can be employed as security devices will be provided.

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* Author for Correspondence: pasquale.pagliusi@fis.unical.it

Intercalation or external binding: How to torque chromonic Sunset Yellow

Spina Lorenza[1,2], De Santo Maria Penelope[1,2], Tone Caterina Maria[1,2], Michela Pisani[3], Francesco Vita[3], Barberi Riccardo[1,2], Ciuchi Federica[1]

1 Phys.Dept. University of Calabria, Arcavacata di Rende (CS), Italy, 2 CNR Nanotec c/o Phys.Dept. University of Calabria, Arcavacata di Rende (CS), Italy, 3 SIMAU Dept. Marche Polytechnic University, 60131 Ancona, Italy.

Being able to obtain well-defined optical textures is the first fundamental step towards using chromonic liquid crystals confined in microspheres for practical applications [1]. It is well known that Frank-Pryce textures, similar to those observed in thermotropic liquid crystal microspheres, can be obtained by doping the chromonic chromolyn with a high-twist amino acid [2].

In this work, we report recent progresses in understanding the supramolecular arrangement and chirality induction in the chromonic liquid crystal Sunset Yellow. In addition to the formation of structures typically found in chiral thermotropic liquid crystals (Layer-like, Toron-like), for the first time, it was observed the Frank Pryce texture in Sunset yellow doped with an L-peptide and confined in spherical geometry by preparing an emulsion using PDMS [3]. Our findings on the ability to control the delicate thermodynamic equilibrium between chromones, chiral dopants and water may open up new perspectives for using these materials in optical and sensing applications.

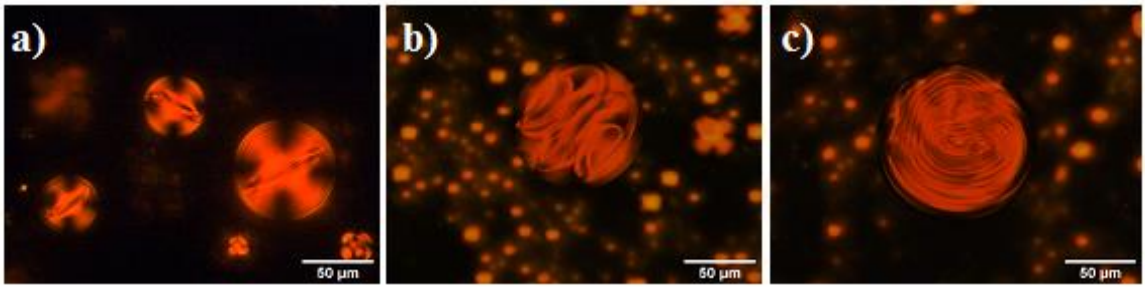

Fig.1 Chiral chromonic microsphere in an emulsion showing: a) Toron-like texture, b) Layer-like texture, c) Frank-Pryce texture.

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Enhancement of Circular Dichroism Response of Biological Chiral Molecules mediated by Plasmonic Nanoparticles

Liliana Valente,[1] Giovanna Palermo[1] and Giuseppe Strangi[1,2]

[1]NLHT-Lab, Department of Physics, University of Calabria, via Ponte P. Bucci, Cubo 33C, 87036 Rende, Cosenza, Italy

[2]Case Western Reserve University, 2076 Adelbert Rd, Cleveland, OH 44106, USA

Circular Dichroism Spectroscopy (CD) contribute to obtaining structural information of a several number of organics and biological molecules. CD define the phenomenon of a different absorption of circularly right-handed and left-handed polarized light given by a chiral molecule [1].
In biomedical context the interaction between light and chiral matter is significant not only for the influence on biological basic functions; using different enantiomeric forms of chiral biomolecules as biological markers permit the identification, the prognosis, and the monitoring of different diseases.
However, the biological molecules size is small compared to the wavelength of the incident light and as consequence the dichroic signals obtained are usually weak and difficult to measure [1].
This aspect is improved by considering the interaction of chiral biological molecule with plasmonic nanoparticles which enhance the dichroic signal (superchirality) and cause a shift of the CD bands in the visible region of the electromagnetic spectrum [2].

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Hydrodynamical simulations of optically controlled microparticle-chain

M. Wiśniewska-Bełej[1], *A. Miniewicz*[1], *P. Karpiński*[1]

[1]*Institute of Advanced Materials, Faculty of Chemistry, Wroclaw University of Science and Technology, Wroclaw, Poland*

In recent years, many new methods of optical manipulation of microparticles have been developed. One among these methods is laser-induced assembly of microparticles (MPs) gathered in a water droplet. [1,2] In our work [3] we have described formation of microparticle chains in droplet of water containing micrometric size polystyrene spheres by illumination reservoir of MPs close to droplet edge by focused laser beam. This microparticles were ejected by light forming a moving chain of MPs. This chain was stabilized by pure optical forces due to formation of an optical waveguide with a core of touching particles. In this work we will present microparticle chain formation and its propagation in water from a hydrodynamic point of view.

To analyze hydrodynamic drag forces acting onto the moving straight microparticle chain toward the droplet center we performed numerical simulations of chain movement by modeling a stationary MPs chain in a tube of water with constant velocity flow. Simulations were performed within COMSOL Multiphysics 5.6 programming platform. Schematic of simulation geometry model is shown in Fig. 1. The velocity of water flow was set being the same as velocity of microparticle movement observed in experiment. We performed calculations for three sizes of MPs, which were used in experiment (with diameters 0.518 μm, 1.05 μm and 2.5 μm) and for different lengths of chains composed of N particles.

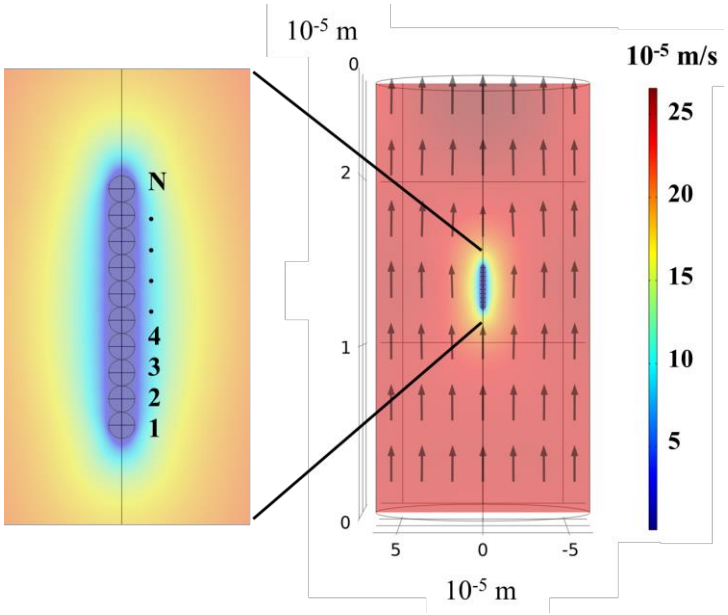

Fig. 1 Schematic of hydrodynamic simulation geometry.

The numerical simulations allowed us to calculate the values of viscous stress tensor acting on each particle. By summing tensor coefficients along the fluid flow

direction we were able to calculate the hydrodynamic drag force and friction coefficient γ acting both onto each microparticle γ_n in a chain and for the whole chain of N microparticles. The friction coefficient distribution in the chain is shown in Fig. 2a. The largest friction value was observed at the first and the last particle in the chain. For the particles situated in the middle of the chain, the friction coefficient γ_n was lower than for γ_1 and γ_N and was weakly dependent on the position of a particle in the chain. Furthermore, the friction coefficient of the whole microparticle chain, obtained for summing up all friction coefficients shows linear increase with increased length of the chain. However, the total friction coefficient γ_N is proportional to the number N of a given particle size in chain, which is shown in Fig. 2b.

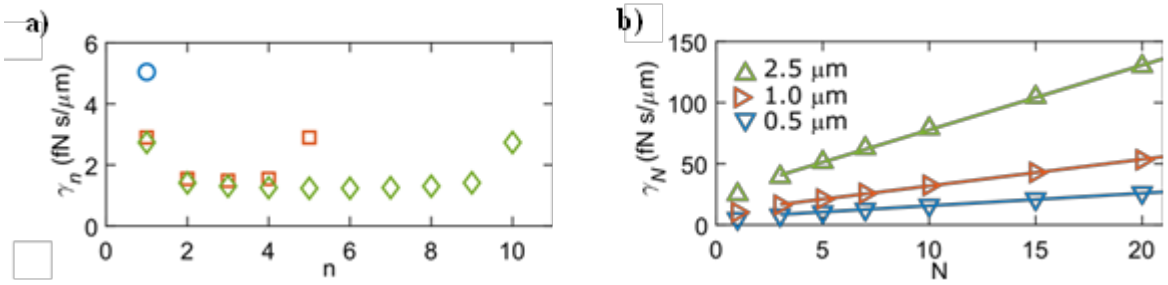

Fig. 2 a) Friction coefficient γ_n of each particle with diameter 0.518 μm. Blue circle – single microparticle, orange square – 5 MPs in a chain, green diamonds – 10 MPs in a chain. b) Friction coefficients of the whole chains of different lengths given by number of MPs for three different MP diameters 0.518 μm (blue), 1.05 μm (orange), 2.56 μm (green).

With the information about the friction coefficient obtained from hydrodynamic simulations and the data collected from optical simulation we could estimate the laser power necessary to obtain the formation of microparticle chains. Moreover, we were able to compare the results of simulations with experimental findings, which lead to better understanding of the whole process. In conclusion, numerical hydrodynamic simulations are helpful tool in analyzing hydrodynamic forces: $F_N = \gamma_N \cdot v$ acting onto MPs chains composed of N spheres moving in liquid with a constant velocity v.

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