Photorefractive Photonics and Beyond 24´

Photorefractive Photonics and Beyond (PR24)

Interaction of Light with Matter

2-5 July, 2024

Book of Abstracts

Palacio de los Infantes | Euroforum

C. del Rey, 38, 28200 San Lorenzo of El Escorial, Madrid

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Photorefractive Photonics and Beyond (PR24)

Interaction of Light with Matter

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Scientific Program

Tuesday, July 2

Time	Schedule
16:00 - 20:00h	**Registration**
20.00	**Welcome party**

Wednesday, July 3

Time	Schedule
8:45 - 9:00 h	**Opening**
9:00 - 11:00 h	**Session 1: Holography, imaging and optical processing and computing** **Session chair: Prof. Marco Bazzan**
9:00 -10:00 h	Plenary - 1 **David D. Nolte** Holographic Optical Coherence Tomography for Personalized Medicine
10:00 - 10:30 h	Invited talk - 1 **Carlos Antón** Emergent materials for quantum photonics
10:30 -10:45 h	Oral presentation - 1 **Dahuai Zheng** Real-time Dynamic Holographic Display Based on LN Crystals
10:45 -11:00 h	Oral presentation - 2 **Germano Montemezzani** PR recording and nonlinear amplification of conical diffraction vector waves
11.00 - 11:30 h	**COFFEE BREAK**
11:30 - 13:00 h	**Session 2: Photorefractive and photovoltaic effects and materials A** **Session chair: Dr. Laura Vitadello**
11:30 - 12.00 h	Invited talk - 2 **Yongfa Kong** The Photorefraction of lithium niobate: from bulk to thin film
12:00 - 12:15 h	Oral presentation - 3 **Marco Bazzan** The thermo-photogalvanic effect in Fe:$LiNbO_3$ and its microscopic interpretation
12:15 - 12:30 h	Oral presentation - 4 **Naoto Tsutsumi** Photorefractivity and Transient Photoconductive Dynamics for Triphenylamine-Based Polymers
12:30 - 12:45 h	Oral presentation - 5 **Al Grabar** Photorefractive parameters of double-doped $Sn_2P_2S_6$ crystals.
12:45 - 13:00 h	Oral presentation - 6 **Gabor Mandula** Photorefractive effect and self-trapped-excitonic photochromism in stoichiometric Bi:Mg:$LiNbO_3$
13:00 - 14:30 h	**LUNCH**

Time	Schedule
14:30 - 16:00 h	**Session 3: Material micro- and nano engineering and integrated optics** **Session chair: Prof. Germano Montemezzani**
14:30 -15.00 h	Invited talk - 3 **Yan Sheng** Nonlinear photonic crystals via all optical poling of ferroelectrics
15:00 -15:15 h	Oral presentation - 7 **Carlos Sebastian** Ferroelectric domain reversal in photovoltaic $LiNbO_3$ crystals driven by visible light
15:15 - 15:30 h	Oral presentation - 8 **Jörg Imbrock** Structured all-optical domain inversion in iron-doped lithium niobate
15:30 -15:45 h	Oral presentation - 9 **Jiaxin Li** Optical Stern-Gerlach effect in two non-parallel slab waveguides
15:45 -16:00 h	Oral presentation - 10 **Sanbing Li** N-type and p-type domain walls fabricated by atomic force microscopy
16:00 - 16:30 h	**COFFEE BREAK**
16:30 - 18:00 h	**Session 4: ...and beyond** **Session chair: Prof. David D. Nolte**
16:30 -17:00 h	Invited talk - 4 **Simonetta Grilli** The pyroelectric effect in ferroelectric materials: new perspectives for biological applications
17:00 -17:15 h	Oral presentation - 11 **Marta Quintanilla** Control of plasmonic heating in biological media following all optical strategies
17:15 -17:30 h	Oral presentation - 12 **Lisa Miccio** Photovoltaic Interplay with living cells at Lithium Niobate interface
17:30 -17:45 h	Oral presentation - 13 **Niklas Dömer** Long-lived, pulse-induced absorption in $LiNb_{(1-x)}Ta_xO_3$ solid solutions
17:45 -18:00 h	Oral presentation – 14 **Sponsor presentation – Izasa scientific**
18:00 - 18:30 h	**COFFEE BREAK**
18:30 - 20:00 h	**POSTER SESSION**
20:00 h	**DINNER**

Thursday, July 4

Time	Schedule
8:45 - 11:00 h	**Session 5: Non-Linear interaction of light with matter** **Prof. Mathieu Chauvet**
8:45 – 9:45 h	Plenary - 1 **Arnan Mitchell** Non-Linear Photonics in $LiNbO_3$ and their applications
9.45 -10:00 h	Oral presentation - 15 **Mariola Ramírez** Ferroelectric Domain Control of Second Harmonic Generation in MoS_2-$LiNbO_3$ heterostructures
10:00 - 13:00 h	**Visit to the Royal Monastery of San Lorenzo de El Escorial**
13.00 - 14:30 h	**LUNCH**
14:30 -15:30 h	**Session 5: Non-Linear interaction of light with matter-CONT** **Prof. Mathieu Chauvet**
14:30 -14:45 h	Oral presentation - 16 **Tsutomu Shimura** Enhancement of the second harmonic generation using Mie and photonic crystal resonance in Silicon surfaces
14.45 - 15:00 h	Oral presentation - 17 **Laura Vittadello** Nonlinear optical properties of low dimensional alkali niobates
15:00 -15:15 h	Oral presentation - 18 **Felix Sauerwein** Gap-free Tuning of Second and Third Harmonic Generation in Mechanochemically Synthesized nanocrystalline $LiNb_{1-x}Ta_xO_3$ Studied with Nonlinear Diffuse Femtosecond-Pulse Reflectometry
15:15 - 15:30 h	
15.30 - 16:00 h	**COFFEE BREAK**

Time	Schedule
16:00 - 17:30 h	**Session 6: Photorefractive and photovoltaic effects and materials B: applications** **Session chair: Prof. Tsutomu Shimura**
16:00 - 16:15 h	Oral presentation - 19 **Juan Wu** Predator-prey behaviors in photorefractive solitons
16:15- 16:30 h	Oral presentation - 20 **Takeo Sasaki** Application of photorefractive liquid crystals to laser ultrasonics
16:30- 16:45 h	Oral presentation - 21 **Adolfo Esteban-Martín** Photorefractive optical transient detection with femtosecond pulses
16:45 - 17:00 h	Oral presentation - 22 **Victor Reshetnyak - CANCELLED** Two-beam energy exchange in a hybrid photorefractive ferroelectric liquid crystal cell
17:00 - 17:15 h	Oral presentation - 23 **Nacera Bouldja** Photorefractive deceleration of light pulses at the visible and infrared wavelengths
17.15 – 17:45 h	**COFFEE BREAK**
18:45 - 19:00 h	**Session 7: Optical and photovoltaic micro-nano manipulation A** **Session chair: Dr. Jörg Imbrock**
17:45 -18:15 h	Invited talk - 5 **Hana Jungová** Applications of light-driven nanomotors and deflecting metagratings in sensing and microscopy
18:15 -18:30 h	Oral presentation - 24 **Manuel I. Marqués** Magnetic control of electrically uncharged magneto-optical particles
18:30 – 18:45 h	Oral presentation - 25 **Sebastian Cremaschini** Optofluidic platform for the manipulation of water droplets on engineered Fe:$LiNbO_3$ surfaces
18:45-19:00 h	Oral presentation - 26 **Riccardo Zamboni** Photovoltaic opto-electrowetting using Fe:$LiNbO_3$ on artificially micropatterned surfaces
19:00 -20:00 h	
20.00 h	**CONFERENCE DINNER**

Friday, July 5

Time	Schedule
8:45 - 11:00 h	**Session 8: Optical and photovoltaic micro-nano manipulation B** **Session chair: Dr. Hana Jungová**
8:45 - 9:45 h	Plenary - 3 **Cinzia Sada** Surfing on the edge of exploring new perspectives: light-driven phenomena as a booster for new applications and scientific progress
9.45 -10:00 h	Oral presentation - 27 **Athira Sadavisan** Droplet manipulation on superhydrophobic surfaces enabled by electrostatic charge printing using Fe:$LiNbO_3$
10:00 - 10:15 h	Oral presentation - 28 **Giovanni Bragato / Cinzia Sada** Integrated optofluidics on lithium niobate: effects of photo-induced electric fields on water droplets with dispersed micro-objects
10:15 - 10:30 h	Oral presentation - 29 **Esther Rincon** Exploring the electric charge of tumour spheroids through their manipulation on photovoltaic ferroelectric platforms
10:30 -10:45 h	Oral presentation - 30 **Sara Coppola** Pyro-electric and photorefractive effect for liquid manipulation and fabrication of 3D polymeric microneedles
10:45 -11:00 h	Oral presentation - 31 **Fengchan Zhang** Brownian motion governs the plasmonic enhancement of colloidal upconverting nanoparticles
11.00 - 11:30 h	**COFFEE BREAK**
11:30 - 13:00 h	**Session 9: Material micro- and nano-engineering and integrated optics** **Session chair: Dr. Lisa Miccio**
11.30 - 12.00 h	Invited talk - 6 **Franzette Paz-Buclatin** Design and fabrication of nanostructured diffractive microlenses inside optical crystals by 3D laser nanolithography
12:00 - 12:15 h	Oral presentation - 32 **Yu Chen Zhang** Photovoltaic effect in monocrystalline lithium niobate films with nanoscale thickness

Time	Schedule
12:15 - 12:30 h	Oral presentation - 33 **Mathieu Chauvet** Poling free high-contrast $LiNbO_3$ waveguides for nonlinear optical frequency conversions
12:30 - 12:45 h	Oral presentation - 34 **Yuqi Zhang** On-chip rare-earth doped lithium niobate waveguide amplifiers
12:45 - 13:00 h	Oral presentation – 35 **Qianqian Kang** Period-halving intensity oscillation in Floquet photonic structures
13:00 -13:15 h	Closing ceremony
13:15 - 14:30 h	**LUNCH**

Poster List

1. Accumulation of micro- and nano-plastics by electrohydrodynamic droplet dispensing for sensitive detection in salt-water**. P. Camarero.**

2. Small electron polarons bound to interstitial tantalum defects in lithium tantalate. **J. Koelmann.**

3. Exciton emissión enhancement in 1L-MoS2 on a ferroelectric substrate undergoing a ferro-to paraelectric phase transition. **D. Hernández-Pinilla**.

4. 2-photon polymerization of patterned polarizers in SU-8 and S1805 photoresist alignment surface **B. Ganazhapa**,.

5. Dynamics of a water droplet suspended in paraffin oil and subjected to a photovoltaic electric field**. A. Mendez**.

6. Lithium Niobate for Light-driven Actuation of Droplets. **A. Zaltron.**

7. Unlocking Single-Particle Multiparametric Sensing: Decoupling Temperature and Viscosity through Upconverting Polarized Spectroscopy. **E. Ortiz.**

8. Brownian motion governs the plasmonic enhancement of colloidal upconverting nanoparticles. **F. Zhang.**

9. Microscale Optical Forces: Exploring Size and Electrostatic Influences **A. Dávila.**

10. Submicro patterning in LiNbO3 by Fe ion implantation for the assessment of novel type of photovoltaic optoelectronic tweezers. **S. K. Padhi.**

11. Harnessing Plasmon Resonances in Ni and Bi2Te3 Nanowire Networks for Enhanced Thermoelectric Performance. **O. Caballero-Calero.**

12. Three-dimensionally nanostructured waveguides inside optical crystals for on-chip instrumentation by fs-laser nanolithography. **P. Molina**.

13. Dimensional analysis of Kukhtarev equations for the photorefractive effect. **A Alcazar**.

14. Imprinting micro-patterns of photovoltaic charge onto non-photovoltaic dielectric substrates. **C. Sebastián-Vicente.**

15. Anomalous small polarons mobility in defective oxides: the case of congruent lithium niobate. **L. Vittadello.**

16. Small polaron trapping kinetics in iron-doped congruent lithium niobate. **M. Bazzan.**

17. Exploring the electric charge of tumour spheroids through their manipulation on photovoltaic ferroelectric platforms. **E. Rincón.**

18. Optical control of ferroelectric liquids on ferroelectric solid substrates. **L. Lucchetti**.

List of contributors

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Bouldja, Nacera	CentraleSupélec, LMOPS	France	**Oral 23**
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Méndez, Angel	Universidad Politécnica de Madrid	Spain	**Poster 5**
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Zhang, Fengchan	Universidad Autónoma de Madrid	Spain	**Poster 8**
Zhang, Yu Chen	Nankai University	China	**Oral 32**
Zhang, Yuqi	Nankai University	China	**Oral 34**
Zheng, Dahuai	Nankai University	China	**Oral 1**

Holographic Optical Coherence Tomography for Personalized Medicine

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The history of holography is dotted with moments of success separated by long stretches of uncertainty as holography struggled to find practical applications. This talk will set the stage for the pursuit of holographic applications by briefly outlining the early history of holography, notably the first practical demonstrations by Emmett Leith at the University of Michigan and photorefractive holography by Alastair Glass and others at Bell Labs [1].

Fast-forward to today and *low-coherence* holography has emerged with advantages for laser ranging applications such as optical coherence tomography (OCT). Holographic OCT was developed by Paul French at Imperial College and by myself at Purdue University in the late 1990's. Initial applications used the ultra-low-intensity character of photorefractive quantum wells (PRQWs) to peer inside living biological tissues in an OCT format called holographic optical coherence *imaging* (HOCI). No *tomographic* reconstruction was required because the photorefractive Fourier-domain speckle holograms were read-out optically to a video camera for direct viewing.

However, the steady march of advances in digital cameras brought the moment, in the early 2000's, when direct recording of holograms on the digital sensor plane provided higher signal-to-noise than photorefractive readout, and in 2007 we converted to digital holography for our OCT applications. The speed of the digital cameras, combined with the full-frame holographic acquisition of images from inside living tissue, allowed us to capture for the first time the dynamic contrast of light scattering from living tissue and to monitor the effects of therapeutic drugs [2]. This launched us down a path of holographic applications in biomedical optics as we developed the technique of ultra-low-frequency (ULF) Doppler spectroscopy of intracellular motions [3] based on holographic phase sensitivity.

Holographic OCT has now completed several pilot clinical trials in human cancer research in which we measured the likelihood that a patient would have a useful response to their prescribed chemotherapy. The trial results in human ovarian, esophageal, breast and blader cancers indicate that holographic OCT can steer cancer patients away from ineffective treatments, improving quality of life and overall survival. Commercial launch of this chemoresistance test is now being pursued.

There are also current and future research directions in microbiology. For instance, we use holographic OCT to monitor the infection of living tissue sentinels by pathogenic bacteria and viruses as microbe invasion and proliferation alter the cellular dynamics of the host sentinel tissue earlier than when they can be detected directly by light scattering. This would provide an "early warning" system that may improve survival of patients from sepsis. Other ongoing applications include drug development as well as applications in in-vitro fertilization (IVF), where holographic OCT is used to help select the most viable embryos.

Acknowledgment: This work was supported by the National Science Foundation grant CBET-2200186.

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[2] K. Jeong, J. J. Turek, and D. D. Nolte, "Volumetric motility-contrast imaging of tissue response to cytoskeletal anti-cancer drugs," *Optics Express,* Article vol. 15, no. 21, pp. 14057-14064, Oct (2007)

[3] D. D. Nolte, "Coherent light scattering from cellular dynamics in living tissues," *Reports on Progress in Physics,* Review vol. 87, no. 3, Mar (2024), Art no. 036601

Emergent materials for quantum photonics

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The control of light-matter interaction at the nanoscale constitutes an avenue for the discovery of new optoelectronic devices and applications. Many emergent materials are gaining prominence, providing novel properties and advantages in quantum information processing applications. Some of these candidates are quantum dots in transition metal dichalcogenides monolayers, defects in hexagonal boron nitride nanocrystals or even perovskite quantum dots. [1]

A fundamental element for the development of the quantum Internet is an efficient source of single photons, capable of emitting photons (1) deterministically or "at the push of a button", (2) one at a time, and (3) with all photons exhibiting identical properties (becoming indistinguishable photons). Obtaining this ideal quantum performance is tremendously challenging and requires a deep understanding of the properties of the quantum material, capable of behaving like an "artificial atom", i.e., confining a single electronic excitation, and delivering a single photon state after spontaneous emission. Controlling this spontaneous emission through light-matter interactions between the quantum emitter and an optical cavity is necessary to approach an optimal performance in single photon emission.

In the first part of the talk, I will discuss recent results to generate single photons based on atomically thin monolayers of WSe_2. The local stress in these monolayers produces a potential capable of trapping single excitons and thus producing single photon emission. These quantum dots can be easily coupled to Fabry-Pérot optical cavities, which improve the emitter performance and makes them state-of-the-art competitive sources of single photons. [2] First quantum communication testbed-applications with these emitters are being implemented, promising a "*bright future*" for these quantum photonic devices. [3]

In the last part of the talk, I will also show our experimental progress on another material platform: single defects in hexagonal boron nitride. This system, operating at ambient conditions, and interfaced with an optical cavity, is a suitable candidate in quantum optical applications, such as free-space quantum key distribution.

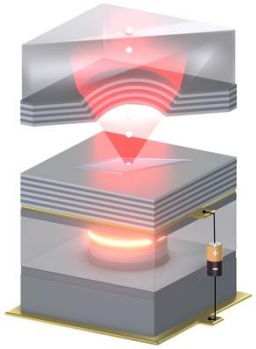

Figure – Schematic of the single photon device, composed by a quantum emitter embedded in an optical cavity.

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[3] T. Gao, M. von Helversen, C. Antón-Solanas, C. Schneider, and T. Heindel, *Atomically-Thin Single-Photon Sources for Quantum Communication*, Npj 2D Mater Appl **7**, 1 (2023).

Real-time Dynamic Holographic Display Based on LN Crystals

Shuolin Wang [a],**Dahuai Zheng** [a,*],Yuqi Zhang [a],Hongde Liu [a], Yongfa Kong [a], Jingjun Xu [a]

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Real immersion experience makes three-dimensional (3D) display a huge market demand. The dreamed 3D display in future should be viewed without auxiliary wearing devices. Holographic 3D display has become an ultimate technique that can display the complete information of objects and bring people an unprecedented sense of presence. At the same time, the realization of holographic 3D display faces many difficulties and challenges, especially the lack of refreshable holographic materials. A real-time refresh of a video requires at least 25 frame per second, that is, the response time of the material should be less than 20 ms. The shorter of the response time, the higher of a refresh rate can be obtained, which is conducive to reducing the flicker of the screen, reducing the visual fatigue of the eyes, making the display more stable and smoother, and obtaining a better viewing experience. Here, a bismuth and magnesium co-doped lithium niobate (LN:Bi,Mg) crystal is reported, with a response time of 7.2 ms. The crystal has been used to demonstrate a real-time holographic display with a refresh rate of 60 Hz, as that of television. In addition, a reasonable calculation indicate that the electron mobility while Bi occupying Nb-site is significantly greater than that in Li-site, which directly induces the fast response of LN:Bi,Mg crystals when the concentration of Mg is above its doping threshold. This work provides an ideal candidate material for holographic 3D display and expands the technique for performance control of LN crystals.

References

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[3] S. Wang, Y. Shan, D. Zheng, S. Liu, F. Bo, H. Liu, Y. Kong, J. Xu, The real-time dynamic holographic display of LN:Bi,Mg crystals and defect-related electron mobility, Opto-Electron. Adv. 5:210135(2022).

Photorefractive recording and nonlinear amplification of conical diffraction vector waves

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Internal conical diffraction (CD) is a well-known linear optical effect observable upon focused-light propagation along an optic axis of an optically biaxial crystal (BC) [1,2]. In the standard configuration involving a unique BC and uniformly polarized input wave, CD creates a double circular ring with spatially varying linear polarization (vector wave), where two diametrically opposite points always possess orthogonal linear polarizations [1,2]. CD beams have recently demonstrated compelling capabilities for various applications in contemporary photonics, such as, optical trapping, free-space optical communication, super-resolution imaging, or polarimetry [2]. In this context novel cascaded configurations where the optical wave traverses several aligned BCs [3] play an important role. They lead to versatile techniques for the tailoring of multiple-ring-shaped vector waves and their optical angular momentum, up to the case where the output pattern loses its intrinsic circular symmetry in so-called conjugate cascades [4].

Here we introduce a combination of the CD effect with the recording and read-out of holograms as well as local two-wave mixing amplification in a photorefractive material, all processes taking place within the same medium [5]. The experiments are performed using nominally undoped photorefractive $Sn_2P_2S_6$ at 633 nm wavelength. They show that the CD photorefractive holograms can successfully be recorded with any combination of the object and reference wave input polarizations, including mutually orthogonal ones. The dependence of the observed effects on the recording and read-out polarizations is discussed, it is shown that the behavior can be qualitatively accounted by a simplified model for the involved complex physical contributions. Our approach opens interesting perspectives for the tailoring of the reconstructed and/or amplified CD vector waves and their static or dynamic manipulation, both in single BC and in cascaded configurations.

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The Photorefraction of lithium niobite: from bulk to thin film

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Lithium niobite ($LiNbO_3$, LN) is a synthetic crystal that has excellent electro-optical, nonlinear optical, acoustic optical and photorefractive performance, and it is thus prominent in various optoelectronic applications. Recent breakthroughs in the fabrication of thin film lithium niobate (TFLN) combine the unique features of the bulk crystal onto an integrated platform with submicron light confinement. Revolutionary performances are expected by moving from bulk to TFLN in the form of lithium-niobate-on-insulator (LNOI) optical communication and wireless communication devices, and this trend may also lead to fundamental breakthroughs in optical computation, microwave photonics, and quantum optics. Here we report several recent progresses in the photorefraction of $LiNbO_3$ from bulk to thin film. It was found the optical damage resistance and photorefraction can be simultaneously enhanced in MgO and Bi_2O_3 co-doped $LiNbO_3$ (LN:Bi,Mg). The experimental results indicate that photorefraction doesn't equal to optical damage. The underground mechanism was analyzed and attributed to that diffusion dominates the transport process of charge carriers, that is to say photorefraction causes only slight optical damage under diffusion mechanism. Furthermore, a photorefractive response time of 7.2 ms was measured at 442 nm laser in a LN:$Bi_{1.25}$,$Mg_{6.0}$ crystal, a binary-electron photorefractive center model was proposed, that is when excited by suitable light, the two lone-pair electrons of Bi^{3+} ions are much easier to lose, which cause the fast response speed. On the other hand, in applications such as second harmonic generation, frequency comb generation, and microwave-to-optics conversion, the device performance is strongly impeded by the photorefractive effect in TFLN.

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The thermo-photogalvanic effect in Fe:$LiNbO_3$ and its microscopic interpretation

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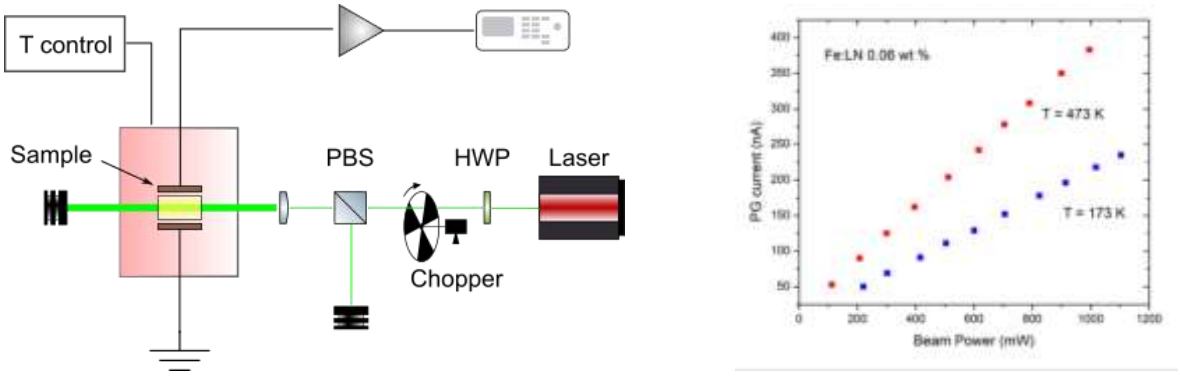
We report, to our knowledge for the first time, on the experimental observation of the thermo-photogalvanic effect (TPGE) relative to the change of the photogalvanic coefficients upon temperature. The effect is observed in Fe-doped lithium niobate (Fe:$LiNbO_3$), a well-known photogalvanic material, by depositing a couple of electrodes on the + and - Z faces of our samples and measuring the closed-circuit photoinduced current as a function of the sample temperature. Our results indicate that the photogalvanic coefficients have a clear temperature dependence increasing of about a factor 2 by passing from 150 K to 500 K.

Our observations are consistent with previous works [1] and are interpreted in the framework of a small-polaron model [2]. At visible wavelengths (532 nm) electrons are photo-emitted from the Fe2+ donor impurities as a Bloch state in the conduction band, lose energy by interaction with the lattice and finally self-localize into a lattice site as a small electron polaron. After this initial stage, polarons can move by thermally activated hopping until they are trapped in an empty Fe3+ acceptor so that the cycle can be repeated. In this process, there is a fraction ϕ of polarons that can be retrapped by the same Fe center they came from and thus do not contribute effectively to the photogalvanic current. By combining the Holstein's formalism [3] for polaron hopping with a simple phenomenological model, we can explain the experimental findings in terms of a temperature-dependent change of the photo-galvanic efficiency $\eta = 1 - \phi(T)$.



(Left) Scheme of the experimental setup. (Right) PG current vs beam power at two different temperatures.

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Photorefractivity and Transient Photoconductive Dynamics for Triphenylamine-Based Polymers

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Photorefractive (PR) polymers, as you know, commonly consisted of photoconductive polymer, sensitizer, optical nonlinear chromophore, and photoconductive plasticizer. PR properties for polymer composites are commonly characterized by the space charge field induced optical diffraction and optical gain. However, the photorefractive dynamics are very complicated and thus have not been cleared yet. We focus on the transient photocurrent of PR polymer composites with different composition ratio to understand their photorefractive dynamics. Recently we measured transient photocurrent with two major peaks, one is in time region between 0.1 and 1 ms and the other is in time region between 0.1 and 1 s. To analyze these transient photocurrents with two major peaks, we propose the two-trap model with two recombination rates which is expanded from the conventional two-trap with one recombination rate [1]. Hole mobility of hole carriers are estimated from the width of density of states (DOS) measured using a photoelectron yield spectroscopy (PYS). Quantum efficiency of photocarrier generation (QE), trapping rate for shallow and deep trap, and recombination rate are evaluated from the analysis of transient photocurrent. PR trap density measured from the photorefractive optical diffraction and optical gain corresponds well to QE for all PR composites.

In PR polymers, in addition to intensity coupling, phase coupling is expected because of the phase shift $\neq 90°$ ($\pi/2$). These unique properties of PR polymers will provide us with interesting phenomena. Furthermore, complex signal generation and detection in PR two wave mixing is unknown field for PR polymers. We think present fundamental aspects are very important to develop new phenomena of PR polymers in future.

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Photorefractive parameters of double-doped $Sn_2P_2S_6$ crystals

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$Sn_2P_2S_6$ crystals are attractive photorefractive materials, sensitive in red and near infrared spectral ranges, with relatively short response times and high sensitivity. These amplitude parameters and dynamics of the photorefractive response can be varied by goaled doping [1].

The report presents data on the variation in photorefractive properties, dielectric and optical spectra achieved as a result of the doping with pairs of the elements such as Te-Cu, Te-Ag, Sb-Cu and Cu-Ag. The doping can be realized during crystal growth by vapor-transport technique in the presence of the doping elements, as well as by post-growth indiffusion of Cu or Ag [2], which create different local defects in the lattice and have different impact on the photorefractive parameters. It was found that among all the studied compounds, the Sb-Cu combination, obtained in the process of growing the $Sn_2P_2S_6$ crystal, forms a complex defect that provides a sufficiently high photorefractive sensitivity. The max two-wave mixing gain in this sample is in order of 15 cm^{-1} (under laser irradiation at 633 nm) and is characterized by high temporal stability of the photorefractive grating and amplified signal beam, which is the main advantage of this crystal compared to the single-doped (Sb or Te) compounds.

The experimental data are compared with first-principle calculations of the electron spectra of these defect states in the $Sn_2P_2S_6$ lattice, and the possible physical origin of this stability is discussed on the basis of the calculated band spectra. The advantages of this dual-doped Sb-Cu compound are illustrated on the examples of the typical photorefractive schemes, namely the dynamic interferometer with phase-modulated signal beam and the efficiency of the multi-beam interactions in the semi-linear and mirrorless photorefractive oscillators.

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Photorefractive effect and self-trapped-excitonic photochromism in stoichiometric Bi:Mg:$LiNbO_3$

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Recently extremely promising research has been published on the realization of real-time dynamic holographic display using bismuth and magnesium co-doped congruent lithium niobate crystals [1, 2]. To understand the microscopic processes of build-up and erasure of light-induced holographic gratings in this material we started systematic investigations by low-intensity near-UV irradiation, absorption spectroscopy and two-wave mixing methods. Bismuth and magnesium co-doped stoichiometric $LiNBO_3$ single crystals were grown with various dopant concentrations. Tracking down the incorporation of dopants and impurities including Fe and H by chemical and IR–UV spectroscopic analyses we assign the various spectroscopic features to specific defect complex types. Absorption bands near 4 eV are ascribed to the generation of self-trapped excitons pinned to dipolar defects consisting of Bi^{3+} ions and their charge-compensators, becoming exceptionally long-lived in the presence of lone pairs. Near-UV illumination in Bi-single-doped crystals induces additional absorption bands at ≈2.7 and ≈3.4 eV annealing near 150°C. Bismuth and magnesium co-doped crystals show similar but slightly blue-shifted photochromic bands with slightly higher thermal stability and an additional stable band at ≈3.2 eV. Two-wave mixing and photochromic measurements have also been carried out as a function of temperature, delay time and intensity to determine activation energies of the charge transfer and the ratio of two- and one-photon processes. The role and the ratio of the amplitude and phase hologram components in real time holographic display applications, as well as undesirable slower charge transfer processes will also be discussed.

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Nonlinear photonic crystals via all optical poling of ferroelectrics

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The concept of nonlinear photonic crystal (NPC) introduced by Berger in 1998 [1], represents a medium with constant refractive index but spatially varying quadratic nonlinearity. NPCs are widely used in studies of nonlinear wave interaction offering potential applications in nonlinear optical control, wave shaping [3], entanglement etc. They have been commonly realized in ferroelectric crystals where electrical poling enables to modulate quadratic nonlinearity in one and two dimensions. However, this technique cannot be employed to create 3-dimensional structures. On the other hand, 3D NPCs would greatly increase their potential applicability.

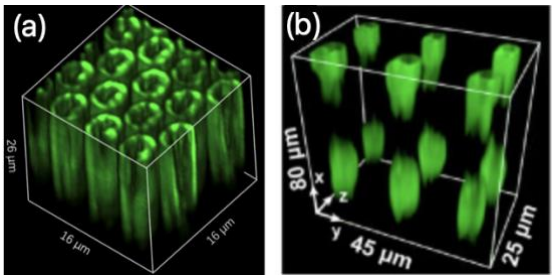

Figure: Optically induced domain patterns. **a)** Hexagonal domain pattern in CBN crystal; (b) 3-dimensional NPC in barium calcium titanate (BCT) crystal

We have shown recently that complex domain patterns can be formed in ferroelectrics using all optical poling [3]. In it, the short pulse infrared beam is focused inside the material leading to its local heating via two photon absorption. Resulting thermoelectric field may invert spontaneous polarization hence creating localized domains and their pattern. Consequently, formation of transparent 3D nonlinear photonic crystals became possible.

In this work we will discuss the all-optical poling technique and its application to form individual ferroelectric domains and their complex pattern in few ferroelectric crystals including, e.g. strontium barium niobate SBN, calcium barium niobate (CBN), and PMN:38PT. We will present our recent experimental results on nonlinear wave shaping using NPC formed via laser poling in ferroelectric crystals. In particular, we will demonstrate formation of second harmonic optical vortices and optical bottle beam [4].

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Ferroelectric domain reversal in photovoltaic $LiNbO_3$ crystals driven by visible light

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Iron-doped $LiNbO_3$ (Fe:$LiNbO_3$) is a promising ferroelectric platform thanks to its prominent bulk photovoltaic effect. Over the past ~15 years, this material has garnered significant attention for a wide range of optoelectronic applications: assembly of micro/nano-objects, optofluidics or manipulation of liquid crystals, among many others. So far, only monodomain Fe:$LiNbO_3$ crystals have been explored in the literature for such applications, overlooking the additional degree of freedom provided by domain-engineered substrates. Nonetheless, the traditional electrical method for domain engineering is complex and costly, involving lithography steps [1]. Herein, we present a novel all-optical approach for local domain inversion, only using continuous-wave visible light (λ = 532 nm) [2]. By enclosing *z*-cut Fe:$LiNbO_3$ crystals in a conductive medium during irradiation (e.g. water), we indisputably demonstrate the local reversal of the spontaneous polarization upon light excitation with low/moderate intensities. Moreover, we study the impact of light intensity, exposure time, laser focusing conditions, incident crystal face and surrounding medium on the size, morphology and depth of the light-inverted domains (see some examples in Figure 1). By tuning these parameters, ensembles of nanodomains, intricate self-assembled nanostructures or quasi-circular micro-domains may be generated. Furthermore, the applicability of our all-optical approach is also successfully showcased in undoped congruent $LiNbO_3$. Finally, we propose a novel qualitative model to explain light-induced domain inversion, which stems from a singular interplay between the bulk photovoltaic effect and external electrostatic screening.

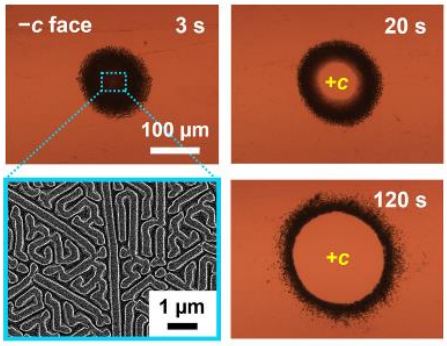

Figure 1 – Inverted spots after selective chemical etching in HF acid. In the experiments, a continuous-wave Gaussian laser beam was employed (diameter d = 150 µm, intensity I = 0.82 kW/cm^2, λ = 532 nm) with different exposure times, indicated at the top-right corner of each image. The grayscale image corresponds to a scanning electron microscope (SEM) inset of the top-left experiment.

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Structured all-optical domain inversion in iron-doped lithium niobate

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Domain-engineered lithium niobate ($LiNbO_3$) finds many applications, such as in quasi-phase matched parametric processes or in the trapping of particles. Ferroelectric domains cannot only be inverted by a high external electric field, but formation can also be induced or assisted by light. For instance, focused infrared laser pulses can directly invert domains [1] or can assist domain formation together with an additional pyroelectric field [2]. Recently, a novel all-optical approach for local domain inversion was presented that uses continuous-wave (cw) laser light [3]. A Gaussian laser beam is focused in z-cut $LiNbO_3$ while the crystal is enclosed in a conductive medium such as water. Domains are inverted in the bulk by the interaction between the photovoltaic effect and external electrostatic screening.

Here, we extend this new concept to form spatially structured ferroelectric domains. An iron-doped $LiNbO_3$ crystal is illuminated by cw laser light. The intensity is modulated in one or two dimensions by two-beam interference or a spatial light modulator, respectively. We use different intensity patterns, such as stripes, squares, triangles, and circles, which can be arranged in different forms of lattices. Domain formation is examined by second-harmonic generation microscopy in 3D and bright-field microscope images of the chemically etched surface (see Fig. 1). We analyze the shape and depth of the domains in dependence on light intensity and illumination time. This approach of simultaneously customizing multiple structured domains offers an efficient method, paving the way for novel applications in optoelectronic research.

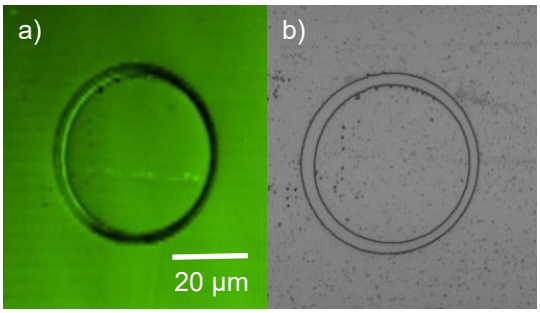

Figure 1 – Ring-shaped inverted ferroelectric domain after illumination of 30 seconds with structured light (λ = 532 nm). a) SHG microscope image of the -c surface. b) Bright-field microscope image after selective chemical etching in HF acid.

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Optical Stern-Gerlach effect in two non-parallel slab waveguides

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Stern-Gerlach (SG) effect, initially found for unveiling the existence of quantized electron spins, is now a general concept describing a state-dependent separation. It has been widely explored in optics to achieve a function of optical splitting, but the current schemes always require a polarization- or wavelength-dependent process [1-3], thus showing limitations for broader applications. In this work, we utilize the spatial modes of light as a new degree of freedom to demonstrate an optical splitting via the SG effect in a two-waveguide system. In two coupled waveguides, the symmetric and anti-symmetric waveguide modes are found to be in analog to a set of orthogonal spin-1/2 states. Deflection and splitting of spatial modes are realized by setting the system to have a spatially inhomogeneous coupling coefficient, which plays the role of a non-uniform magnetic field. By setting coupling coefficient as a linear function, our simulations show that the two modes tend to deflect in opposite directions during propagation. In particular, the excitation of either waveguide in this structure manifests an optical spitting, since the input condition is basically an equal and coherent superposition of the two modes. In experiment, such a splitting is realized in two coupled non-parallel slab waveguides that are light-induced in a photorefractive crystal [4,5]. Limited by the length of the crystal, these phenomena are observed in momentum space. Our approach may find applications in the area of optical sensing and signal processing.

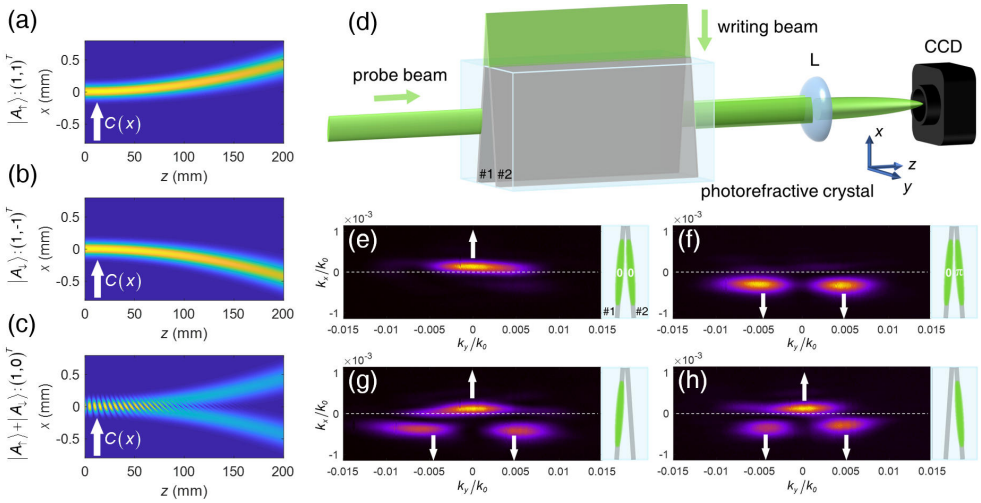

Figure : (a-c) Simulated beam propagations in two non-parallel slab waveguides schematically shown in (d) under different input conditions: (a) symmetric, (b) anti-symmetric modes, and (c) their superposition are injected. (d) Schematic experimental setup showing how to write and probe the non-parallel slab waveguides. (e-h) Output intensity profiles in momentum space under different input conditions (see the insets: gray and green shadings stand for waveguides and input beams, respectively, and 0 and π are phases).

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N-type and p-type domain walls fabricated by atomic force microscopy

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Abstract:

The advent of the lithium niobate on insulator (LNOI) platform has catalyzed significant advancements in optoelectronic integration using lithium niobate, leading to breakthroughs such as efficient second harmonic generation, high-speed electro-optical modulators, and on-chip lasers through rare earth ion doping. Nevertheless, the challenge of low conductivity (approximately 10^{-12} $\Omega^{-1}cm^{-1}$ for 5 mol% MgO-doped LN) and the hurdles in achieving p-type doping have rendered the fabrication of p-n junctions, a critical component for optoelectronics, on LNOI nearly unfeasible. Encouragingly, the possibility of creating n-type and p-type ferroelectric domain walls opens new avenues[1-3].The successful integration of both domain wall types could make the fabrication of p-n junctions based on domain walls possible.

In our study, we have engineered n-type and p-type ferroelectric domain walls on a 600 nm thick x-cut film of 5 mol% MgO-doped LN using atomic force microscopy (AFM). This technique enables the precise fabrication of micro-scale or nano-scale ferroelectric domains with arbitrary shapes. By applying a high voltage through the AFM probe tip, a square domain structure was created, simultaneously generating n-type and p-type domain walls. Our current measurements revealed that the conductivity of n-type and p-type domain walls reached 10^{-5} $\Omega^{-1}cm^{-1}$ and 10^{-8} $\Omega^{-1}cm^{-1}$, respectively, which represent at least four orders of magnitude higher than that of the bulk LN crystal. Although the current conductivity of n-type and p-type domain walls are still low for practical application, further enhancements in conductivity might be achievable through targeted element doping[4,5].

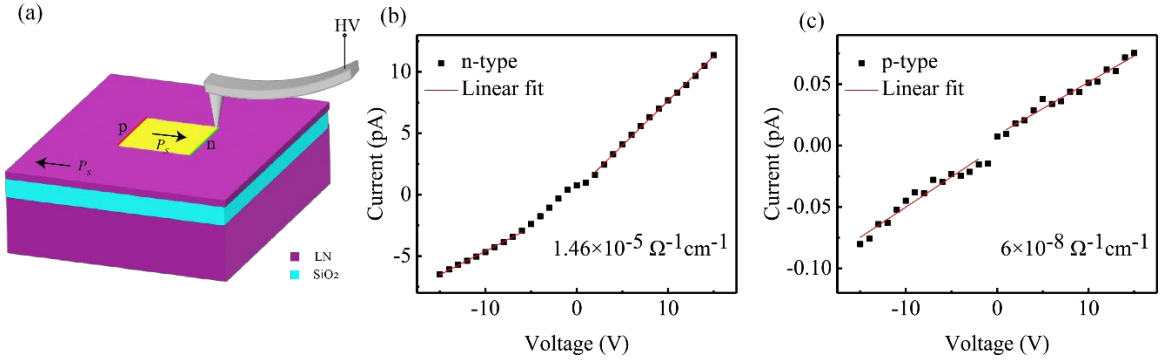

Figure 1 (a) Schematic diagram of domain inversion through a AFM probe tip. (b) Measured I-V curve of a n-type domain wall. (c) Measured I-V curve of a p-type domain wall.

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The pyroelectric effect in ferroelectric materials: new perspectives for biological applications

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Ferroelectrics are functional materials with stable spontaneous polarization that can be reversed by an external electric field. They are the first-choice materials for a wide variety of applications including nonvolatile memories, field-effect transistors, solar cells, sensors, photonics devices, just to cite some. Only in the recent years the interest in potential applications of these materials for biological applications has risen. Here we present the possibility to use a specific property of these materials, i.e. the pyroelectric effect in lithium niobate (LN), for innovative manipulation methods for soft and biological matter. It is well known that in pyroelectric crystals a thermal energy is converted into electricity through the variation of the internal spontaneous polarization. We use periodically poled LN for a dynamic skin-over-liquid platform at microscale or for producing ordered arrays of fiber mats through a pyro-electrospinning process. In all cases the micropatterns have a potential application to address the behaviour of live cells at microscale with the overall advantage to be free from electrodes, nozzles and masks.

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Control of plasmonic heating in biological media following all optical strategies

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Photons reaching plasmonic nanoparticles and tuned to their resonance may be absorbed or scattered. Subsequently, the absorbed energy is typically released to the surroundings in the form of heat.[1] Absorption, thus, induces a local heating that can be used to aid chemical reactions at the nanoscale, in water remediation or, largely, in photothermal therapy against cancer or bacterial infections.[2] All these applications must be performed in aqueous media; though water may absorb part of the excitation wavelength, thus reducing the number of photons reaching the nanoparticles and heating up the optical path. This problem is extreme in the biomedical case, since other components (hemoglobin, melanin, lipids, etc.) contribute not only to absorption, but also to light scattering.[3] To face this lack of control on the illumination, we have tuned the resonance of plasmonic nanoparticles based on gold to the so-called biological windows (regions of the near-infrared range in which light attenuation by tissues is lower). Their heating performance has been characterized. To have access to local thermal information, we have applied luminescent nanothermometry techniques based on the emission of CaF_2:Nd^{3+} nanoparticles. Our experiments illuminating through a model biological tissue or in tumoral spheroids show to what extent the interaction between light and tissue is relevant. In fact, it plays an important role for heating, but also for thermometry, as light emission needs to be recorded after travelling through the tissue. We have solved this second problem through an *in situ* recalibration of the thermometers.

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Photovoltaic Interplay with living cells at Lithium Niobate interface

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Electric fields generated by Photovoltaic (PV) effect in ferroelectric crystals as Lithium Niobate (LN) have been deeply studies and modelled in the last 30 years, also in relation to the type and quantities of doping materials [1]. One of the research field developed in this framework concerns the activation and the exploitation of the evanescent fields on the surface of such crystals for application as parallel trapping of microparticles or liquid/fluid handling [2]. Also polymer structures have been realized by exploiting evanescent field on the surface of LN [3]. Indeed, PV effect is responsible of the activation of virtual electrodes in LN by means of the interaction with light at suitable wavelength and power. The creation of PV electrodes avoids integration of different materials, typically needed for printed electrodes, thus simplifying the fabrication processes. Moreover, virtual electrodes present an intrinsic flexibility in terms of spatial geometry when diffractive optical elements are integrated in the illumination setup. Recently, it has been demonstrated also the possibility to interface biological samples achieving cell patterning and biological fluid manipulation [4]. In this work some examples of interaction of PV field with biological matter will be presents and, also, new perspectives of interaction with neuronal model cell populations will be described. Moreover, some results on Quantitative Phase Imaging of neuronal culture on LN will be showed.

Acknowledgement

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Long-lived, pulse-induced absorption in $LiNb_{(1-x)}Ta_xO_3$ solid solutions

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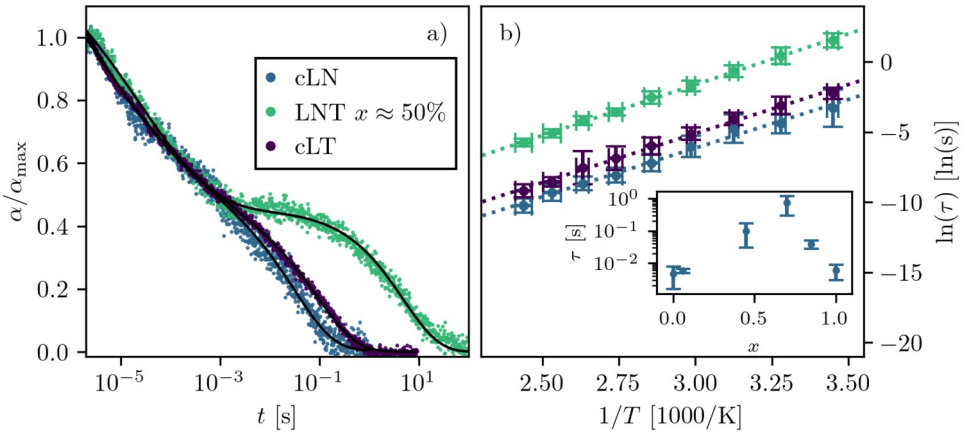
Pulse-induced, red and near-infrared absorption is studied in $LiNb_{1-x}Ta_xO_3$ (LNT) solid solutions with the goal to probe the intrinsic defect structure via the formation, transport and recombination of small bound electron polarons[1]. LNT might provide the possibility to control the optical and especially photorefractive properties of a crystal through its composition between the photorefractive edge compositions $LiNbO_3$ (LN, x=0) and $LiTaO_3$ (LT, x=1).

For this purpose, small polaron densities are generated in LNT on (ultra-)short time scales via two-photon absorption using short, intense pump laser pulses in the blue-green spectral range (photon energy E_p=3.1 eV, pulse duration $\tau_p \approx 50$ fs and E_p=2.33 eV , $\tau_p \approx 6$ ns) while the relaxation kinetics are probed with continuos-wave laser light in the red and near-infrared spectrum (E_{probe} = 1.6 eV/1.96 eV) on time scales from 10^{-8} − 10^{2} s.

As a result, long-lived transients are uncovered with lifetimes of $\tau \approx 350$ ms (LNT), that are by a factor of up to 40 larger in comparison with the widely studied near-infrared transients. The starting amplitudes of LNT are determined in the range of $\alpha^0_{li} \approx 10 - 100$ m^{-1} depending on the composition x and, thus, exceed the ones of congruent LN and congruent LT by a factor of up to ten. The results of LN and LT are interpreted in the model of three-dimensional small polaron hopping transport considering the simultaneous presence of three different type of small bound polarons.

We conclude that the differences between LNT, LN, and LT may be interpreted by changes in the 3D hopping transport mechanisms due to a different number of intrinsic defect centers, i.e. model systems that consist of one (LN), two (LT) and three (LNT) intrinsic defect centers for electron localization [2]. Funded by DFG FOR5044 (Grant No. 426703838, IM37/12-1).



a) Transients of cLN, cLT and LNT at T = 290 K via fs-setup with a probing wavelength of 633 nm. b) τ vs T in an Arrhenius plot for one cLN, cLT and LNT01. The inset shows the 1/e-lifetimes of the transient absorption signal for various samples measued in the ns-setup at 633 nm.

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Lithium Niobate Integrated Circuits for Optical Microcombs: Science, Technology and Applications

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Optical frequency combs were invented more than 20 years ago and have revolutionized precision measurement [1]. Their significance was recognized with the award of the 2005 Nobel Prize in physics, but since then have remained largely within sophisticated laboratories. Recent advances have made it possible to realize optical frequency combs in the form of micro-chips which can be manufactured cheaply, are compact and efficient [2]. The science and technology of microcombs is advancing rapidly but as these platforms become established and begin to standardize, it is the potential of these platforms to transform a diverse array of applications that becomes the new frontier.

Our team has been exploring the applications of optical microcombs for nearly a decade [3]. We have pioneered the use of microcombs for photonic signal processing and have shown record breaking data transmission and pattern recognition capabilities [4].

Silicon nitride has been the platform of choice for microcombs due to its strong waveguide confinement, extraordinarily low optical loss and compatibility with existing silicon electronics manufacturing infrastructure [2]. Thin-film lithium niobate has emerged as a platform that can offer similar confinement, compactness and optical loss but can also offer electro-optic, acousto-optic and nonlinear optical properties [5] which could offset the more specialized manufacturing requirements.

We have recently established a major research center to advance the science and technology of optical microcombs and explore the diverse opportunities for their application. This talk will present an overview of the research of our microcombs centre and will particularly compare silicon nitride and lithium niobate as photonic integration platforms for microcomb systems as well as an outlook for industrialization.

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Ferroelectric Domain Control of Second Harmonic Generation in MoS_2-$LiNbO_3$ heterostructures

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The atomically thin nature of 2D-Transition Metal Dichalcogenide materials (TMDs) offers unprecedented control to adjust their optoelectronic properties by external fields. Among the different approaches, an actively pursued strategy is based on the integration of these low-dimensional materials on ferroelectric substrates. The remnant spontaneous polarization inherent to ferroelectrics offers intriguing interaction mechanisms to locally modulate the physical properties of ultrathin 2D materials and add desired functionalities for the next-generation photonic and opto-electronic functional 2D devices [1,2]. However, despite intensive research on their electrical and linear optical properties, the nonlinear optical performance of 2D/ferroelectric heterostructures remains almost unexplored.

Here, we show the possibility to spatially modulate the quadratic Second Harmonic Generation (SHG) of monolayer MoS_2 through the underneath spontaneous polarization provided by a periodically poled $LiNbO_3$. Different factors affecting the SHG spatial modulation such as the fundamental wavelength, pump power and polarization of the incident light will be discussed with particular emphasis on the role of light induced interfacial charge-transfer processes in TMDs based ferroelectric heterostructures.

The results contribute to the fundamental understanding of the nonlinear properties of TMDs under external stimuli and offer additional insights for the electrical control of harmonic generation in ultrathin integrated devices.

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Enhancement of the second harmonic generation using Mie and photonic crystal resonance in Silicon surfaces

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In silicon photonics, it is difficult to realize wavelength conversion devices due to the spatial inversion symmetry of silicon. We have attempted to enhance the surface second harmonic generation[1] in silicon using surface nanostructures. Using nanostructures similar to metasurfaces, we have numerically demonstrated that the efficiency of second harmonic generation can be significantly increased by simultaneously inducing Mie resonances at each meta-atom and photonic crystal resonances due to the two-dimensional arrangement of meta-atoms. The structure consists of a two-dimensional array of submicron-order amorphous silicon equilateral triangular prisms on a silicon dioxide substrate. Finite-element methods and FDTD were used for the simulations. First, we determined the conditions under which the total scattering cross section is maximized when a plane wave of wavelength 1500 nm is incident from directly above, and found the height and bottom size conditions of the equilateral triangular columns. It is assumed that the wavelength that gives the peak scattering cross section coincides with that of the Mie resonance peak. Next, the equilateral triangular prisms obtained here were arranged in a two-dimensional rectangular lattice, and the lattice spacing in the x- and y-directions was varied to search for the condition that maximizes the second harmonic generation efficiency. As a result, it was found that an increase in the second harmonic generation efficiency of about five orders of magnitude at the maximum was realized. It was found that the two-dimensional array of meta-atoms functions as a photonic crystal and resonance occurs at the Γ point.

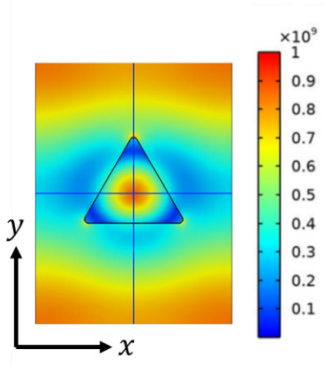

Figure Enhanced optical field of fundamental frequency by Mie and photonic crystal resonances. Incident light has y polarization.

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Nonlinear optical properties of low dimensional alkali niobates

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The recent progress in the synthesis methods made available in nano form the alkali niobate class, to which belong the well-established photorefractive materials like $LiNbO_3$, $KNbO_3$ or $LiTaO_3$. These new methodologies allow the synthesis of nanosized structure with different dimensionalities at a high degree of crystallographic quality. These include nanocrystallites with sizes down to 10 nm as well as more complex periodic arrangements in the form of two-dimensional photonic crystals [1]. The growing interest for these materials is rooted in their multi-faceted, pronounced physical characteristics, such as ferroelectric, photovoltaic, piezoelectric, photovoltaic and nonlinear optical properties. For instance, the latter one allows for a particular type of multiphoton imaging (non-bleaching, non-blinking, high-contrast, etc.) where the established fluorescent nanomarkers fails. In addition, the further cited effects, like the photovoltaic effect, are promising in the context of optogenetics, e.g. in the framework of the cellular environment manipulation via photo induce electrostatic field.
In this presentation, a review on my group activity based on the nonlinear optical characterization (in particular on second and third harmonic generation) is presented for nanoparticles as well as two-dimensional photonic crystals. For example, the analysis reveals that the harmonic emission can be generated not only in the visible but also in the near infrared (NIR) region. These results foster novel materials applications in the context of in-vivo imaging [2,3]. Indeed, in the NIR the skin tissue shows reduced light scattering and absorption potentially permitting to perform deep-tissue imaging with the lowest light induced damage.

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Gap-free Tuning of Second and Third Harmonic Generation in Mechanochemically Synthesized nanocrystalline $LiNb_{1-x}Ta_xO_3$ Studied with Nonlinear Diffuse Femtosecond-Pulse Reflectometry

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The gap-free tuning of second (SHG) and third (THG) harmonic emission is studied in the model system $LiNb_{1-x}Ta_xO_3$ between the established photorefractive edge compositions lithium niobate ($LiNbO_3$, x=0, LN) and lithium tantalate ($LiTaO_3$, x=1, LT) [1]. The purpose of our study is to demonstrate the existence of optical nonlinearities of the second and third order in the ferroelectric solid solution system, but also to address the question about the suitability of LNT in the field of nonlinear and quantum optics, in particular as a promising nonlinear optical material for frequency conversion with tunable composition.
For this purpose, harmonic generation is studied in nanosized crystallites of mechanochemically synthesized LNT using nonlinear diffuse reflectometry with wavelength-tunable fundamental femtosecond laser pulses from 1200 nm to 2000 nm. As a result, a gap-free harmonic emission is validated (cf. Fig. 1 for $LiNb_{0.5}Ta_{0.5}O_3$,) that accords with the theoretically expected energy relations, dependencies on intensity and wavelength, as well as spectral bandwidths for harmonic generation. The SHG/THG harmonic ratio >> 1 is characteristic of the ferroelectric bulk nature of the LNT nanocrystallites [2]. We can conclude that LNT is particularly attractive for applications in nonlinear optics that benefit from the possibility of the composition-dependent control of mechanical, electrical, and/or optical properties.

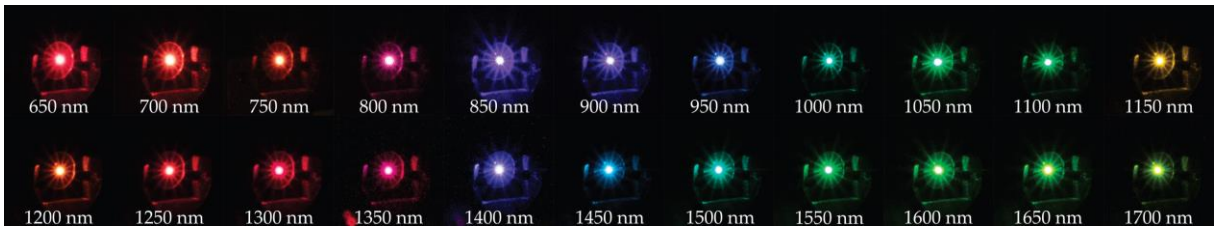

Figure 1: Digital images of diffuse remission of $LiNb_{0.5}Ta_{0.5}O_3$ nanoparticles under exposure to a train of fs-pulses tuned from 650 to 1700 nm in steps of 50 nm. The respective fundamental wavelengths are given below each image.

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Predator-prey behaviors in photorefractive solitons

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Chase-and-escape motion, typical behavior between a predator and a prey, is an important dynamic in animate systems. It has been concerned recently in optics aiming for achieving novel light steering and switching functions. But thus far, this optical counterpart was realized only in one dimension [1-3], as maintaining chase-and-escape interactions is still a challenge. Here we report optical predator-prey dynamics in two dimensions for the first time, based on photorefractive solitons. The solitons are generated through a mutual confinement of two optical beams, where the beam expansion subject to a self-defocusing nonlinearity in one beam is counteracted by the self-focusing nonlinearity experienced by the other beam, thereby providing a sufficient strength of nonlinear interaction for a long distance of evolution. The two beams, basically subject to a nonreciprocal interaction, are able to form a localized or an oblique spiral chase-and-escape motion. Unusual optical phenomena are found in these dynamics: 1. the resulting transverse beam shift can be enhanced by merely strengthening the internal interactions of the two beams, and such transverse travelling shifts are unexpectedly opposite to the applied initial momentum in certain input conditions; 2. in contrast to conventional optical spiral dynamics [4,5], the light interactions presented here show a non-conservation of angular momentum. These phenomena evidently support that the internal interactions contribute to the whole motion of the two beams. Our results may inspire more fundamental studies by exploring analogous animate phenomena in optics, and furthermore, pave a way to build a link between light and active matters.

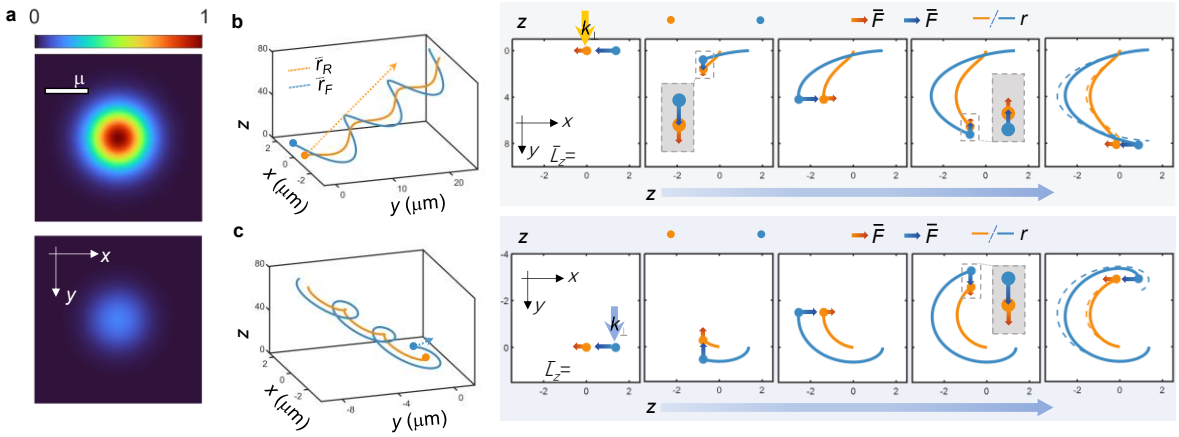

Figure: **a** A typical soliton solution where R- and F- beams are mutually confined. **b-c** Trajectories (solid, center-of-mass) of the beams during propagation with an initial separation and that **b** only R-beam or **c** only F-beam has initial tilts (i.e., $k_\perp$). $\bar{L}_z$ is total angular momentum of the two beams.

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Application of photorefractive liquid crystals to laser ultrasonics

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The photorefractive effect of flexoelectric smectic liquid crystal mixtures was investigated and applied to a laser ultrasonic measurement. Smectic liquid crystal mixtures, composed of smectic-C liquid crystals, photoconductive chiral compounds, and a sensitizer, exhibit a fast photorefractive effect. The photorefractive liquid crystal prepared in this study enabled a noise-free laser ultrasonic measurement. The principle of ultrasonic measurement is that a nanosecond laser pulse is shot on an object to generate an ultrasonic vibration, a continuous laser beam is shined on the object, and the ultrasonic variation is detected using photorefractive asymmetric energy exchange. This method can be used to investigate an object's thickness and internal structure without contact. Compared to traditional laser ultrasonic methods, this system offers a simpler optical setup and allows for more precise measurements that are unaffected by environmental vibrations.

Photorefractive optical transient detection with femtosecond pulses

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An optical transient detection (OTD) system is an adaptive interferometer that detects temporal changes while suppressing static background, improving contrast when measuring intensity and phase. Several systems have been implemented for many applications, including transient detection microscopy [1] as well as quantitative measurement of phase changes [2-4]. However, most OTD systems are based on photorefractive two-wave mixing in the visible range and using continuous-wave lasers.

We report on experimental demonstration of OTD with femtosecond pulses. Coherent ultrafast laser sources providing high-repetition-rate femtosecond pulses are of interest for many applications and the high peak power of the ultrashort pulses further make possible up-conversion from infrared into the visible range, enabling measurements with standard GaP- or Si-based detectors.

The experimental setup [5] is based on a 805 nm KLM Ti:sapphire laser, providing 1.5W of average power in ~130 fs pulses at 76MHz repetition rate, and BaTiO3 and SBN crystals. Frequency doubling of the laser is achieved in a single-pass through a BiB3O6 nonlinear crystal.

Experimental results reveal the relation between input-phase changes (from 0 to π) in the infrared and output intensities detected in the visible range, and thus demonstrates its potential as a sensor. Moreover, we will present preliminary experimental results of OTD in photorefractive materials directly pumped in the visible by femtosecond pulses, providing more background suppression and less input signal average power.

We believe that this work opens up new possibilities by exploiting unsurpassed wavelength flexibility for both sampling and detection in single-spot detection as well as imaging.

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Two-beam energy exchange in a hybrid photorefractive-ferroelectric liquid crystal cell

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In recent years, significant progress has been made in studying energy transfer between light beams in hybrid systems consisting of a liquid crystal (LC) layer placed between two photorefractive windows. Incident intersecting light beams interfere and induce a spatially periodic space charge field in photorefractive windows. The photorefractive field penetrates the LC layer and modulates the LC director, creating the director grating. The light beams are diffracted by the director grating, leading to an exchange of intensity between beams and the amplification of one of them. In conventional LCs, the main mechanism responsible for the LC director modulation is the interaction of the photorefractive field with the LC flexoelectric polarization. In this case, the exponential gain coefficient can reach values significantly exceeding those in solid inorganic photorefractive crystals [1]. In this report, we theoretically study energy transfer between light beams in hybrid systems when a ferroelectric nematic liquid crystal (FLC) is placed between two photorefractive windows. FLCs are new photonic materials that can create real innovations in LC-based technologies [2-4]. Since one of the most striking characteristics of FLC is the presence of high values of electric polarization, much higher than the values of flexoelectric polarization, it can be assumed that the main mechanism of director grating formation in FLC based hybrid systems is the interaction of the photorefractive field with the FLC polarization. The dependence of the beam gain on the parameters of a hybrid system has been studied and a comparison has been made with the case when the hybrid system contains a non-ferroelectric LC. In particular, it is shown that the gain in a FLC based hybrid system can be more than two orders of magnitude greater compared to the gain in a system with a conventional LC.

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Photorefractive deceleration of light pulses at the visible and infrared wavelengths

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Photorefractive (PR) crystals are considered among the most promising materials for studying the deceleration of the group velocity of light pulses at room temperature [1]. Their specific optical properties enable the exploitation of various nonlinear phenomena, such as beam fanning and two-wave mixing to manipulate the speed of long and short light pulses [2]. Due to these advantages, PR crystals can become indispensable materials in the study and development of innovative future optical devices.

In this work, we theoretically and experimentally demonstrate that the PR crystal can decelerate the group velocity of light pulses over a broad spectrum of wavelengths. We show that the beam fanning and the two-wave mixing (TWM) effects can achieve slowdown light pulses at different wavelengths, including 638 nm, 1064 nm, and 1310 nm. Additionally, we demonstrate that a 100 ns pulse can slow down by 25 ns at 1064 nm and by 10 ns at 1310 nm, respectively. Additionally, these pulses do not suffer from the same broadening observed in the visible regime with longer pulses. Finally, we illustrate that both the time delay and the distortion of the pulse propagating along the crystal can be controlled by changing the input parameters, such as its intensity, duration, and gain (depletion factor) of the TWM (of the beam fanning).

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Applications of light-driven nanomotors and deflecting metagratings in sensing and microscopy

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The last decade has seen remarkable advancements in the development of nanomotion detectors as noninvasive monitoring devices of cellular life and health. However, hundreds or thousands of cells are often needed for the analysis and it is not possible to distinguish various nanomotion patterns due to insufficient spatial resolution of the current techniques. In our research we use a gold nanorod (rotary nanomotor) spinning at kHz frequencies [1] that is trapped in optical tweezers to detect nanomotions of single cells. We show that the light-powered nanomotors can be detections of nanomotions of single mammalian cells with an unprecedented spatial resolution [2]. This new technique can provide insights into fundamental cellular processes, potentially leading to the development of new diagnostic tools.

In the second part of my talk, I will discuss our recent research on flat metaoptics, components aimed at replacing classical optical elements, potentially leading to highly compact biophotonics devices. We demonstrate curved GaAs metagratings integrated on vertical-cavity surface-emitting lasers (VCSELs) that enable on-chip illumination for total internal reflection and dark field microscopy, with rapid switching between the two illumination modes [3]. Our approach provides a versatile illumination solution for high-contrast imaging, compatible with conventional microscopy setups and integrable with biophotonics devices such as portable microscopy and lab-on-a-chip devices.

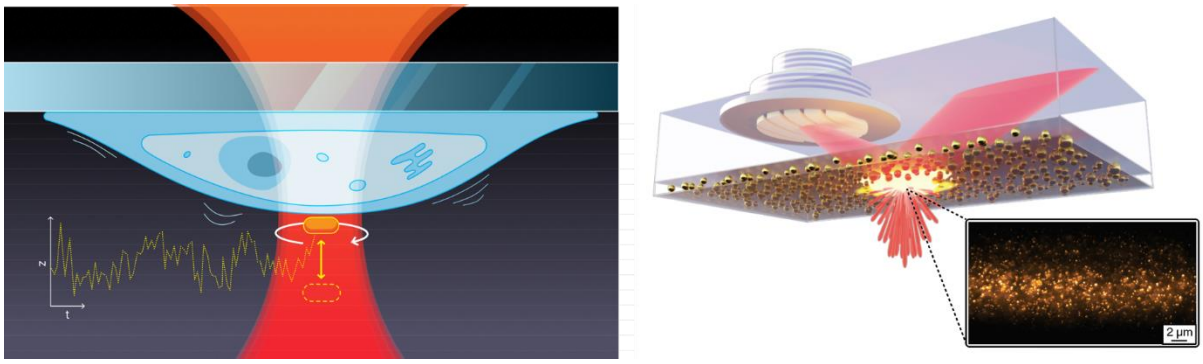

Figure: Detection of cellular nanomotion with a gold-rotary nanomotor (left). Miniaturized illumination module for high-contrast microscopy (right).

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Magnetic control of electrically uncharged magneto-optical particles

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Constant magnetic fields are known to interact with electrically charged particles inducing Lorentz forces that point in a direction perpendicular to the field. However, if the particle is electrically discharged, it is impossible to induce a force using a constant magnetic field. An exotic option is to mimic a magnetic charge on a neutral particle. This false magnetic monopole will interact with the magnetic field just as an electric charge would do with an electric field through the Coulomb interaction. Attempts to generate this magnetic charge have mainly relied on quasiparticles generated using condensed matter spin ice networks [1-3]. In this work we present another option based on neutral magneto-optical particles illuminated by a spinning monochromatic light field [4]. We will analyze the behavior of these particles under different fluctuating isotropic optical configurations [5,6], and we will calculate the value of the induced magnetic charge. We will prove that this is a purely non-reciprocal effect as the reciprocal equivalent (a chiral dipole) despite presenting a dichroic response, does not experience any force when illuminated by the spinning field. The magnetic charge induced by impinging radiation on the magneto-optical dipole is found to depend linearly on the helicity of the field. In addition, this artificial monopole experiences a dichroic permanent optical torque and does not interact with an external electric field.

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Rare-earth doped YVO_4 crystals beyond lasing: applications in thermometry and optofluidics

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Yttrium vanadate (YVO_4) is one of the most popular materials used in optics, often used as a host material for lasers based on emission from rare earth (RE) ions, like Neodymium (Nd) or Ytterbium (Yb).[1] It is observed in a zircon-type structure and shows significant birefringence of around Δn=0.2.[1] In this work we explore un-doped and RE-doped YVO_4 microcrystals as a candidates for optical cooling, optical tweezers, and Raman and luminescence thermometry. We synthesize microcrystals using a novel micro-wave-assisted mineralization route, obtaining few micrometer-sized polyhedral crystals. Due to high refractive index of YVO_4 microcrystals they can be easily optically trapped. Additionally, high birefringence allows to induce strong angular momentum on them by circularly polarized light. The angular momentum acting on them cause their spinning with average frequencies of ~100 Hz (at ~100 mW), which are comparable to spinning frequencies observed for nano-waterite.[2] In Figure 1, we show the Raman spectrum for un-doped crystals at 373 K. We can use frequency shift of the Raman modes as a temperature indicator. In the inset we show linear softening of marked A_{1g} mode with increasing temperature (T) of the sample in the range from 275 to 375 K.

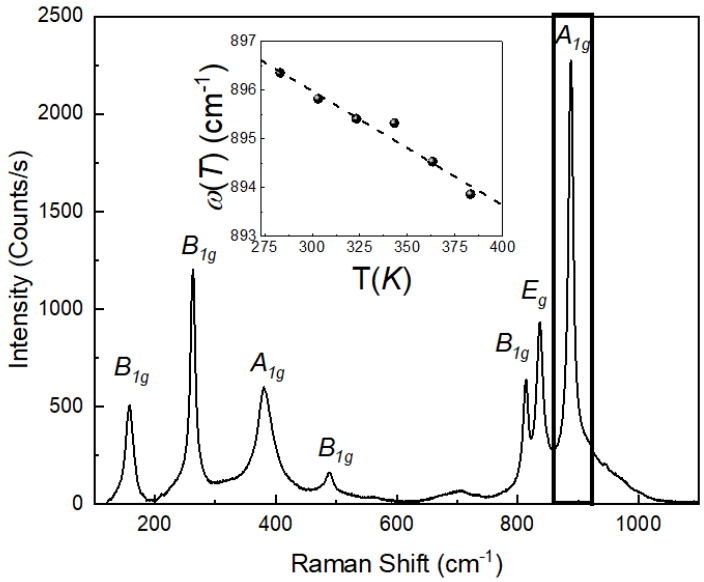

Figure 1: The Raman spectra of YVO_4 microcrystals taken at 373 K, with the mode symmetries marked. Inset: Frequency of the highlighted A_{1g} mode versus Temperature, T.

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(Preferred oral or poster contribution)

Optofluidic platform for the manipulation of water droplets on engineered Fe:$LiNbO_3$ surfaces

(Oral contribution)

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The actuation of liquid droplets on a surface has relevance in many industrial fields and in microfluidics. In recent years, various strategies have been exploited to accomplish the task: in this work we present an optofluidic platform, which allows reproducing the basic droplet handling operations obtained in a common closed microfluidic device [1]. This platform is based on a z-cut iron-doped lithium niobate crystal (Fe:$LiNbO_3$): when illuminated with light, surface charges of opposite signs are generated at the two faces of the substrate due to the photovoltaic effect [2]. The crystal face in contact with the droplets is coated with a lubricant-infused layer (LIS), which produces a very slippery and robust surface for prolonged use [3]. In this way, microliter water droplets having a size of some millimeters, can be easily actuated, guided, merged and even split by simply illuminating the crystal with suitable static or dynamic light patterns (see Figure (A)). The actuated droplets can cover distances of some centimeters in a few seconds. This optofluidic platform is highly flexible and reconfigurable and does not require moving parts.
In particular, the splitting phenomenon has been studied in detail: when the droplet splits, one fragment remains trapped in the illuminated region, while the other one follows three well-defined trajectories separated by 120°, reflecting the crystallographic anisotropy typical of Fe:$LiNbO_3$ [4]. Numerical simulations explain this phenomenon as the interplay of pyroelectric, piezoelectric and photovoltaic effects, originated when Fe:$LiNbO_3$ is illuminated (see Figure (B)).

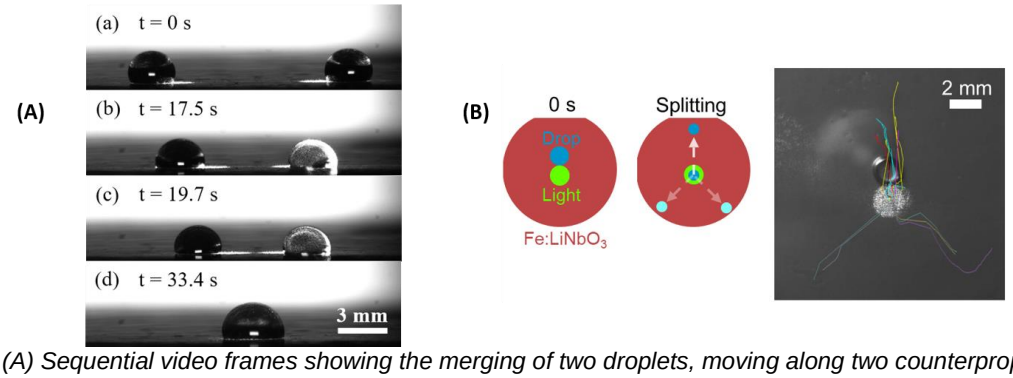

Figure – (A) Sequential video frames showing the merging of two droplets, moving along two counterpropagating directions; (B) Scheme of droplet splitting on Fe:$LiNbO_3$; the three directions of motion of split fragment separated by 120° each are highlighted.

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Photovoltaic opto-electrowetting using Fe:$LiNbO_3$ on artificially micropatterned surfaces

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The electrowetting technique has become one of the most reliable and widely used methods to locally control the wettability of the substrate [1]. Therefore, it is gaining great success as the main method for controlling droplets in digital microfluidics [1]. A large improvement in the customization of the digital microfluidic platform has been achieved with the introduction of opto-electrowetting, which allows the generation of electric fields with light [2]. Among the techniques and substrates used to transduce light stimulus into electric fields, the bulk photovoltaic effect exhibited by ferroelectric crystals has shown remarkable performance due to moderate light intensities ($<10^4$ W m^{-2}) to achieve strong electric fields (~kV mm^{-1}) [3]. However, despite the success of this technique, crystalline materials can hardly be sculpted and customization of the wetting properties requires coatings and treatments, which are not always easy to achieve in the crystal [4].

In this contribution, we present a method for controlling wetting on artificially micropatterned surfaces using the photovoltaic electric field on Fe:$LiNbO_3$. The long-range interaction between the photovoltaic field and the water droplets suspended on an artificial microstructured substrate induces a wetting transition. Droplets in initial Cassie-Baxter states undergo a transition to Wenzel states. This transition is caused by the Maxwell stress induced by the evanescent photovoltaic field acting against the capillary pressure that maintains the droplets suspended on the microstructures. In the presence of the Maxwell stress, the liquid is drawn into the microstructures, emptying the air pocket characterizing the Cassie-Baxter state.

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Surfing on the edge of exploring new perspectives: light-driven phenomena as a booster for new applications and scientific progress

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From the very beginning, fundamental research on light-driven phenomena in materials has triggered interdisciplinary applications. Optical sensing and storage, as well as optical nonlinear effects, have dominated scientific research for a long time, showing relative advantages and disadvantages. It was not expected that what was then seen as a possible limitation would turn out to be such a great potential. In fact, the effect of generating electric fields through light-matter interactions, including their modulation and shaping, has allowed the field to be broadened to include, for example, the manipulation of optical particles, both inorganic and organic, even living ones. Advanced photonics applications have just been proposed for green sustainability, supported by research into new materials, both in hybrid configurations and in integrated platforms. Surfing on the edge of exploring new perspectives, this talk will present some ideas recently proposed by the scientific community to think out of the box and use light-driven phenomena as a booster for new applications and scientific progress.

Droplet manipulation on superhydrophobic surfaces enabled by electrostatic charge printing using Fe:$LiNbO_3$

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The study of droplet wetting and trapping on superhydrophobic surfaces with the help of an electric field has many applications in microfluidic devices, medical diagnosis, etc [1]. This requires the introduction of active materials able to generate electric fields in response to an external stimulus in a controlled way. Among other materials, Fe:$LiNbO_3$ has been proven to be an optimal substrate for inducing strong and localized electric fields via its photovoltaic effect using light stimulus [2]. The advantage of this technique is the ability to of shape virtual electrodes on the Fe:$LiNbO_3$ crystal, induced by structured light for droplet manipulation [3]. However, this method is hindered by the crystalline nature of this material, which is hard to sculpt and bend due to its lack of flexibility.

Hence, we take advantage of this method to transfer the virtual electrodes on Fe:$LiNbO_3$ to passive dielectric substrates. The method enables the charging of the dielectric passive substrate in simple contact with the illuminated region of Fe:$LiNbO_3$. In a such a way, a mirror replica of the charge pattern on Fe:$LiNbO_3$ is formed on the dielectric substrate. After removal of the Fe:$LiNbO_3$, the passive substrates are used for droplet manipulation taking advantage of the printed charges. Without the crystal during droplet manipulation, a passive substrate with unique features can be employed, such as a flexible superhydrophobic thin film. To study the performance of printed virtual electrodes, we studied the trajectories of water droplets sliding on these films at different inclinations. We have achieved different manipulation phenomena and will report on: dielectrophoretic trapping, electrowetting, and droplet pinning.

Acknowledgments: This work has been funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - 5126330344.

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Integrated optofluidics on lithium niobate: effects of photo-induced electric fields on water droplets with dispersed micro-objects

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Recently, the development of new opto-microfluidic sensing devices in $LiNbO_3$ has gained increasing interest due to the promising features allowed by the combination of microfluidic and optical stages on the same platform, that addresses the need for integrating in the same portable device several tools which carry out different tasks, e.g. manipulation of droplets, optical sensing, targets identification and sorting [1]. In particular, the possibility of exploiting external electric fields to move droplets, sort and merge them as well as modify their shape has been explored in the last years [3]. The actuation and control of liquid droplets represent in fact a major challenge not only for many industrial processes but also for chemical, biological and medical applications. Active control of droplets by means of electric fields is typically achieved by metallic electrodes that cannot be reconfigured. An interesting alternative to bypass this constraint is provided by the so-called virtual electrodes, i.e. electrodes generated by light-induced phenomena able to locally modify the conductivity of the substrate. In this work a new concept of droplet-based opto-microfluidic platform integrated in lithium niobate is presented that combines microfluidics with integrated optics and virtual electrodes made by photovoltaic phenomena to enable either the modification or the actuation of dispersed objects within water droplets. Since the droplets lengths was proven to be sensitive to the photo-induced electric field with a dependence on the droplets' velocity [1] and on the dissolved electrolytes concentration, interesting novel perspectives will be discussed in the field of optical sensing.

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Exploring the electric charge of tumour spheroids through their manipulation on photovoltaic ferroelectric platforms

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Optoelectronic ferroelectric platforms have been widely used for the manipulation of micro/nano-objects thanks to the bulk photovoltaic effect (PVE) [1]. These kind of optic manipulation takes advantage of the light-induced electric fields generated in some ferroelectric crystals, being particularly strong in $LiNbO_3$:Fe. Recently, a method to manipulate aqueous solution micro-droplets using these optoelectronic platforms have been developed [2]. It allows the manipulation of bio-materials such as DNA and sperm, homogeneously dispersed inside the droplet [3]. In this work we report the application of this technique to the manipulation and characterization of non-homogeneous droplets containing one multicellular spheroid, i.e. a 3D cell model whose metabolism is close to the one of tissues [4]. Two cell lines of human cancer have been used: U-87 MG and MCF-7.
Hybrid droplets (1-mm-diameter), consisting of cell culture medium with one distinguishable spheroid (diameter between 350 and 500 μm) are suspended in the air-paraffin interphase (see figure 1). When light illuminates the ferroelectric substrate, the migration of the hybrid droplet is achieved under the influence of the light-induced electric field.
The results show a change in the migration behavior of hybrid droplets compared with that of only cell culture medium (even as strong as a complete reversal of the movement) that depends on the face of the ferroelectric substrate being illuminated. Careful experiments with water, cell culture medium, and hybrid droplets have been conducted. Their analysis, to the light of a developed model, demonstrates a negative charge for the spheroids and allows estimating its charge density.

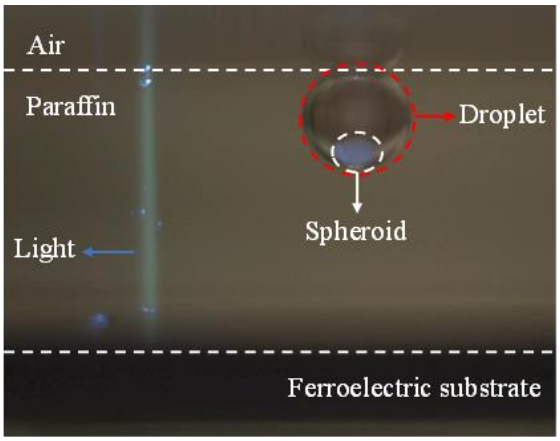

Figure 1: *Schematics of the PV ferroelectric platform showing the hanging droplet containing the spheroid. The ferroelectric substrate is illuminated with a laser beam that generates a PV electric that manipulates the droplet.*

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Pyro-electric and photorefractive effect for liquid manipulation and fabrication of 3D polymeric microneedles

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Manipulating polymers, dispensing and jetting liquid from a larger mother droplet or a liquid film using conventional methods require strong electric fields and very expensive equipment. In alternative, some years ago an innovative and efficient method was proposed for reaching high electric fields completely avoiding the use of external electrodes and very expensive nozzles [1,2]. The method prosed exploits the pyroelectric-EHD effect presented by lithium niobate (LN) when it undergoes to a temperature gradient. Different approaches have been experimented based on the pyro-EHD manipulation of liquids and polymers [3]. Recently, the use of iron doped lithium it has also been proposed for manipulating liquid in a contact-free modality through an external light source [4]. In fact, the iron doped LN presents photovoltaic in combination with slight pyroelectric effects. Here we report on the innovative methods proposed for liquid dispensing and for manipulating polymeric solutions. We demonstrate that efficient drop blasting and liquid jetting can be easily achieved through visible laser light and by temperature gradient in different optical configurations. We also describe different microstructures that could be fabricated using the proposed technology and that could find application in micro-fluidic, optics and biomedicine. In particular, we will focus on the fabrication and functionalization of chip and portable devices where polymeric microneedles will represent the smart components that could be used both for transdermal drug delivery and as biosensing components. We will also focus on the optical properties of the 3D microstructures proposed. We believe that functionalized microneedles with advanced light focusing properties will open to new minimally invasive treatments for nonmelanoma skin cancer.

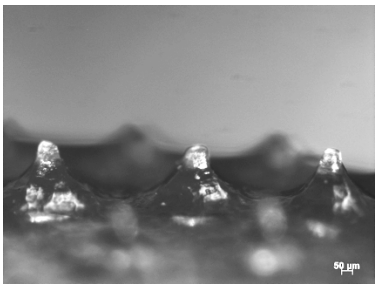

Figure – Polymeric microneedles.

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Deciphering the role of Brownian motion in plasmonic enhancement in single colloidal upconverting nanoparticle

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Upconverting nanoparticles (UCNP) are essential in modern photonics due to their ability to convert infrared to visible light. Their main drawback is the low brightness, owing to the relatively low absorption coefficient of the lanthanide ions and their reduced quantum yield. This drawback can be solved by combining UCNPs with plasmonic nanostructures (PNSs). Plasmon-enhanced upconversion has been widely demonstrated in dry environments, where upconverting nanoparticles are immobilized so that the UCNP−PNS distance is controlled and fixed. Nevertheless, the situation becomes more complex if UCNPs are suspended in an aqueous medium. Brownian motion can introduce continuous fluctuations in the UCNP−PNS distance, competing with plasmon-enhanced luminescence.

In this study, we employ optical tweezers (OTs) for 3D manipulation of an individual UCNP in the proximity of Au plasmonic nanoparticles (PNPs), enabling the exploration of plasmon-enhanced upconversion luminescence in water. A continuous-wave 980 nm laser beam is focused within a microchamber containing the colloidal dispersion of UCNPs to create the optical trap and excite the upconverting luminescence. The base of the microchamber is a glass substrate deposited with Au PNPs. The magnitude of plasmon-enhanced luminescence in a single UCNP as a function of OT−PNS distance was studied. There are two differences between our results and those reported for static UCNP-PNPs systems. First, the plasmon-induced enhancement is moderate (20%). Second, our results arise from a long-range effect, extending up to UCNP-PNP separations as large as 1 μm. Comparison between experimental and numerical simulations evidence the key role of Brownian motion in limiting the plasmon-enhanced luminescence. The three-dimensional Brownian fluctuations of the upconverting nanoparticle leads to an “average effect” that explains the magnitude and spatial extension of luminescence. The findings contribute to the understanding of the complex interplay among plasmonic effects, optical trapping, and Brownian motion in colloidal systems.

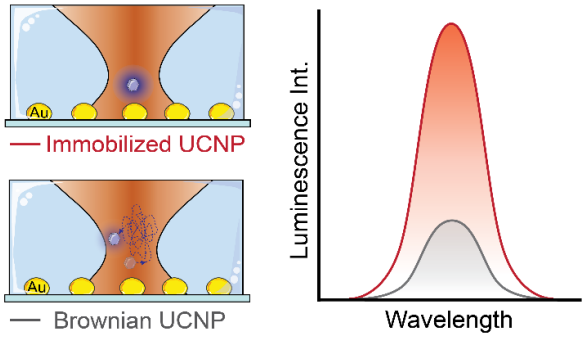

Figure – Different plasmon-enhanced luminescence between immobilized UCNP (simulation) and colloidal UCNP subjected to Brownian motion.

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Acknowledgments

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(Preferred poster contribution)

Design and fabrication of nanostructured diffractive microlenses inside optical crystals by 3D laser nanolithography

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Efficient light focusing is fundamental in various scientific and industrial processes such as in lasers, microscopy, spectroscopy and optical manipulation among others. Conventionally, this is achieved through refractive lenses. However, the size of these lenses hinders its integration in compact optical systems. Recently, there has been a growing interest in wavelength-thickness diffractive microlenses which exploit the fundamental phenomenon of diffraction to manipulate light and rely on an air-dielectric high-contrast sub-wavelength architecture to do so with minimal footprint.

In this work, we present a nanostructured diffractive microlens hollow design inside a crystal, providing both physical protection to the lens and a maximal degree of compactness. This design is fabricated by means of 3D femtosecond laser nanolithography [1,2]. The focusing capabilities of the designed structures were numerically simulated using both the Finite-Difference Time-Domain (FDTD) and the Beam Propagation Methods (BPM). Once the design of diverse microlenses for focusing on outer air or water was successfully achieved, key experimental constraints related to achieving a good fidelity between design and real fabricated structures were analyzed and new fabrication parameters were developed. Medium to high 1.3NA lens designs were obtained. The first fabrication tests of a 20 μm diameter microlens with 0.49 NA and a free-space design wavelength of 0.8 μm showing a near diffraction-limited focal spot will be presented.

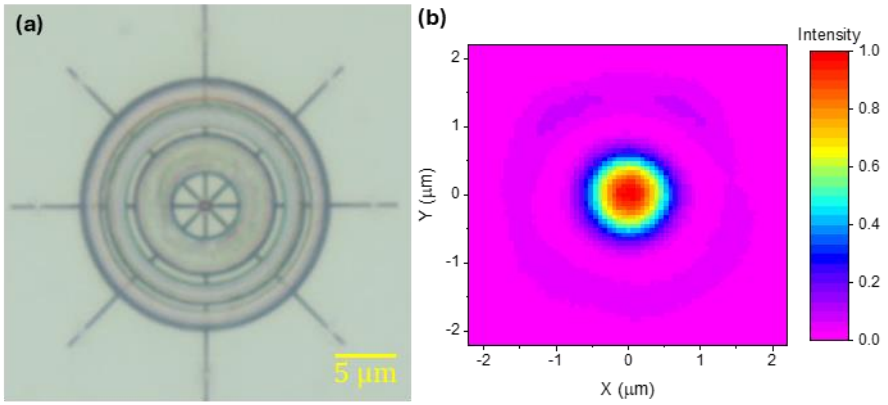

Figure (a) Optical microscope image of the fabricated nanostructured diffractive hollow lens embedded 10 μm from the surface. *(b)* Intensity distribution of the experimentally obtained focal spot with $FWHM_x$ of 0.89 μm

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Photovoltaic effect in monocrystalline lithium niobate films with nanoscale thickness

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Abstract:

The photovoltaic (PV) effect in lithium niobate (LN) was first observed in 1960s[1], and was found to be enhanced greatly in iron-doped LN crystals[2]. Nevertheless, the energy conversion efficiency η is extremely low, usually in the range of 10^{-6}~10^{-4}. Recently, the successful preparation of monocrystalline thin film LN on insulator (LNOI) by crystal-ion-slicing technology opens up the exploration of LN at nanoscale thickness and forges ahead for the development of opto-electronics, yielding memristor[3], domain-wall p-n junction[4], and vibrational energy harvester[5].

Here, the PV effect of LN with a nanoscale thickness was studied under the illumination of 325-nm irradiation, and it was found that the PV effect is originated from the Schottky barrier (1.15 eV) formed at the electrode/LN interface, different from the bulk PV effect reported previously in the bulk crystals. The structure of the PV device was shown schematically in Fig.1(a). With a light power density of 135 mW/cm^2, the dependence of short-circuit density ($|J_{sc}|$) and open-circuit voltage (V_{oc}) on LN film thickness d is illustrated in Fig.1(b). The values of $|J_{sc}|$ and V_{oc} were found to be 0.377 mA/cm^2 and 0.8 V, respectively, at a LN film thickness of 16 nm. Moreover, the J-V characteristics are film-thickness dependent, as shown in Fig.1(c), mainly due to the increasing contribution of the polarization-induced asymmetric conduction from the bulk layer with the increase of film thickness. Interestingly, direct tunneling of electron was found to be the dominant conduction mechanism in ultra-thin LN films. The energy conversion efficiency η was determined to be 0.1% at 16 nm. These results could be useful for developing integrated opto-electronic devices such as PV devices and photo-detectors based on LNOI.

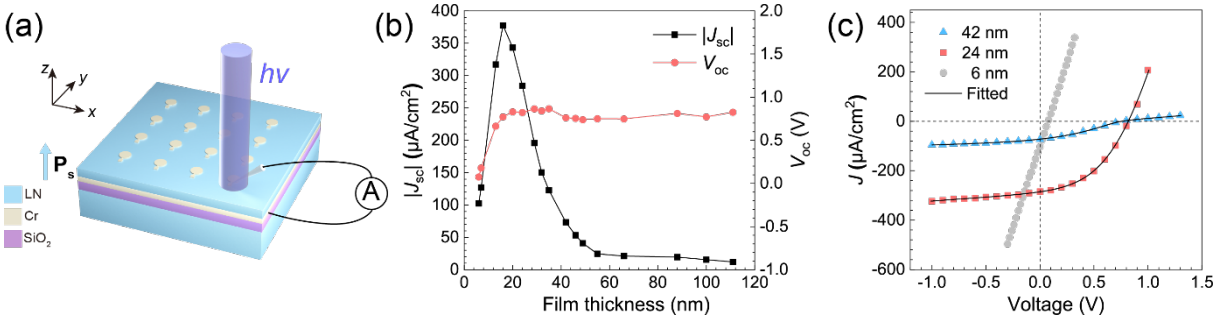

Figure 1- (a) Schematic structure of the PV device. (b) The dependence of $|J_{sc}|$ and V_{oc} on the film thickness d. (c) The J-V characteristics of the devices with different film thickness d.

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Poling free high-contrast $LiNbO_3$ waveguides for nonlinear optical frequency conversions

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The emergence of $LiNbO_3$ films enables the design of optical waveguides with highly confined modes. This tight confinement along with the strong $\chi^{(2)}$coefficients of $LiNbO_3$ offer a great potential for the development of frequency conversion components. High conversion efficiencies have already been demonstrated in such arrangements for which the phase matching condition is fulfilled by a periodic poling of the crystal (PPLN). In the present work, we uncover configurations for which tailored high-contrast $LiNbO_3$ waveguides can provide nonlinear conversion characteristics that supplement PPLN structures.
First, poling free waveguides can not only be easier to fabricate but also facilitates the separation of the output wavelengths thanks to their different polarizations. Above all, for some specific designs, they exhibit distinctive performances. As an emblematic example, the outstanding characteristics of an integrated component conceived for efficient second harmonic generation over the full telecom bandwidth will be presented.

On-chip rare-earth doped lithium niobate waveguide amplifiers

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The ability to amplify optical signals is of pivotal importance in photonic integrated circuits (PICs). Recently, lithium niobate on insulator (LNOI) has attracted increasing interest as an emerging PIC platform. However, the shortage of efficient active devices on the LNOI platform limits the development of optical amplification. Here, we report the high gain and efficient waveguide amplifiers based on ytterbium doped and erbium-ytterbium co-doped LNOI, using electron beam lithography and inductively coupled plasma reactive ion etching processes. As shown in Fig. 1, a net internal gain of ~18 dB/cm in the 1064 nm band was achieved under a pump power of 10 mW at 974 nm through the fabrication of ytterbium doped LNOI waveguide amplifiers. In addition, signal amplification emerges at a low pump power of 0.1 mW, and the net internal gain in the communication band is 16.52 dB/cm under pumping of a 974 nm continuous laser by erbium-ytterbium co-doped LNOI waveguide amplifier. Benefiting from the efficient pumping facilitated by energy transfer between ytterbium and erbium ions, an internal conversion efficiency of 10% has been achieved, which is currently the most efficient waveguide amplifier under unidirectional pumping reported on the LNOI platform. This work proposes new active devices for LNOI integrated optical systems that may become an important fundamental component of future lithium niobate photonic integration platforms.

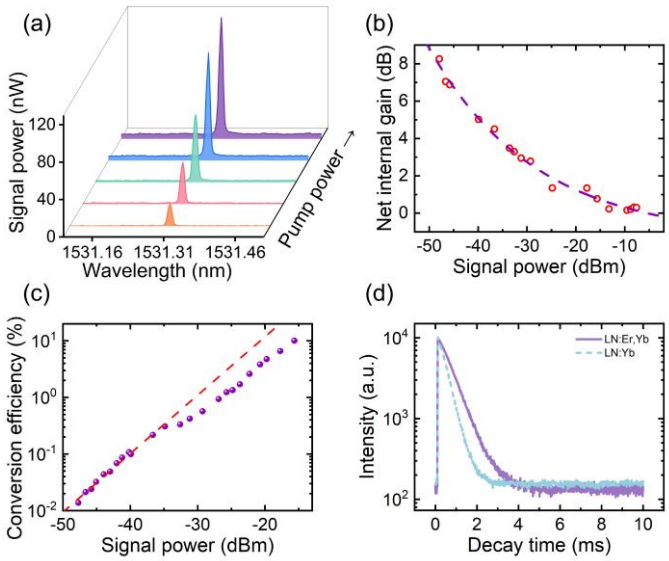

Figure 1. Gain characteristics of LNOI waveguide amplifier. (a) Measured signal spectra with increasing pump powers. (b) Net internal gain as a function of increasing signal power at a fixed pump power. (c) The measured internal conversion efficiency is used as a function of signal power. (d). Decay curves of the Yb^{3+} emission at 1062 nm in Er^{3+} / Yb^{3+} co-doped and Yb^{3+} doped LN, excited under 980 nm.

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Period-halving intensity oscillation in Floquet photonic structures

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Floquet drive is a way to vary parameters of a system periodically [1]. It was recently employed for realizing time crystals in a discrete form, where spontaneous time-translation symmetry breaking takes place [2], typically manifesting as period-doubling effect (i.e., an observable oscillates twice as slow as the applied drive). Can an observable oscillate faster than the drive? This question has not been concerned, since people usually think the minimum of the oscillation period is equal to the Floquet period. Here, we report an effect of period-halving oscillation in a photonic structure. By allowing any two instantaneous Hamiltonians separated in a distance of a half period to meet a chiral symmetry, the zero-energy mode in this system can repeat its intensity profiles every half period along the propagation, thereby leading to a period-halving effect. Such dynamics are unique for zero-energy modes, while non-zero-energy modes in the same system still oscillate with the period of the Floquet drive. To illustrate such a period-halving effect, we use a photonic structure including three waveguides [Fig. 1(a)] as a typical example. Three eigenstates exist in this structure, having either zero or non-zero eigenvalues. They all exhibit a periodic intensity oscillation during propagation, but the period is halving only for the zero-energy mode [Figs. 1(b-d)]. In experiment, this structure is fabricated in a photorefractive crystal [4]. We observe a period-halving intensity oscillation for the zero-energy mode [Figs. 1(e-g)], while in contrast, a non-zero mode still has an intensity oscillation of the drive period.

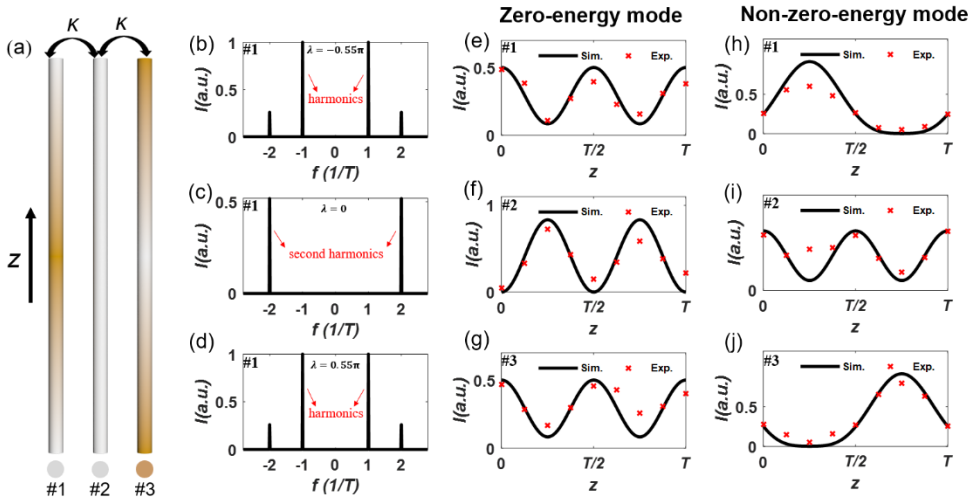

Fig. 1. (a) Sketch of three coupled waveguides upon Floquet drives (deeper color stands for a larger modulation of refractive index and κ is coupling coefficient). (b-d) Fourier transform of the intensity distribution of three eigenstates in (a) along the 1st waveguide. (e-j) Measured and simulated intensity distributions of the zero-energy and non-zero-energy modes during propagation along each waveguide in a Floquet period.

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Poster List

1. Accumulation of micro- and nano-plastics by electrohydrodynamic droplet dispensing for sensitive detection in salt-water**. P Camarero.**

2. Small electron polarons bound to interstitial tantalum defects in lithium tantalate. **Julian Koelmann.**

3. Exciton emissión enhancement in 1L-MoS2 on a ferroelectric substrate undergoing a ferro-to paraelectric phase transition. **D. Hernández-Pinilla**.

4. 2-photon polymerization of patterned polarizers in SU-8 and S1805 photoresist alignment surface **B. Ganazhapa**,.

5. Dynamics of a water droplet suspended in paraffin oil and subjected to a photovoltaic electric field**. A. Mendez**.

6. Lithium Niobate for Light-driven Actuation of Droplets. **Ana María Zaltron.**

7. Unlocking Single-Particle Multiparametric Sensing: Decoupling Temperature and Viscosity through Upconverting Polarized Spectroscopy. **Elisa Ortiz.**

8. Brownian motion governs the plasmonic enhancement of colloidal upconverting nanoparticles. **Fengchan Zhang.**

9. Microscale Optical Forces: Exploring Size and Electrostatic Influences **A. Dávila.**

10. Submicro patterning in LiNbO3 by Fe ion implantation for the assessment of novel type of photovoltaic optoelectronic tweezers.**S. K. Padhi.**

11. Harnessing Plasmon Resonances in Ni and Bi2Te3 Nanowire Networks for Enhanced Thermoelectric Performance. **O Caballero-Calero.**

12. Three-dimensionally nanostructured waveguides inside optical crystals for on-chip instrumentation by fs-laser nanolithography. **P. Molina**.

13. Dimensional analysis of Kukhtarev equations for the photorefractive effect. **A Alcazar**.

14. Imprinting micro-patterns of photovoltaic charge onto non-photovoltaic dielectric substrates. **C. Sebastián-Vicente.**

15. Anomalous small polarons mobility in defective oxides: the case of congruent lithium niobate. **L. Vittadello.**

16. Small polaron trapping kinetics in iron-doped congruent lithium niobate. **M. Bazzan.**

17. Exploring the electric charge of tumour spheroids through their manipulation on photovoltaic ferroelectric platforms. **E. Rincón.**

18. Optical control of ferroelectric liquids on ferroelectric solid substrates. **L. Lucchetti**.

Accumulation of micro- and nano-plastics by electrohydrodynamic droplet dispensing for sensitive detection in salt-water

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Numerous benefits of plastics (affordability, light weight and biodurability) [1] lead to undue and excessive daily usage, resulting in environmental pollution from their degradation into micro- and nano-plastics. These pollutants pose risks to both the environment and human health. [1, 2] However, detecting low-concentration samples of micro- and nano-plastics is challenging due to their weak signals.

In light of this, we propose a technique aimed at accumulating micro- and nano-plastics to enable Raman detection. This procedure is based on an optoelectronic platform, where high light-induced electric fields can be generated by the bulk photovoltaic effect. $LiNbO_3$:Fe, a reference ferroelectric material, is used as active material for the platform.[3] When a micro-drop–reservoir approaches the illuminated $LiNbO_3$:Fe crystal, the light-induced electric field is strong enough to generate an attractive force between them causing a high number of droplets to be ejected towards the crystal (see Fig. 1 (a)). These droplets reach the bottom part of the crystal and, upon evaporation, they deposit their contents onto the crystal surface. Fig. 1(b-c) reveals successful accumulation of micro- and nano-plastic, both with a gaussian-like distribution (see Fig. 1(d)).

In this study, we investigate the influence of initial micro- and nano-plastics concentrations in the reservoir drop on their deposition and accumulation. Additionally, we evaluate the role of salinity in salt-water (containing NaCl) of micro- and nano-plastic accumulation to simulate seawater conditions. Further results demonstrate technique's viability when it is applied in biological saline solutions (Phosphate Buffer Solution) and marine water.

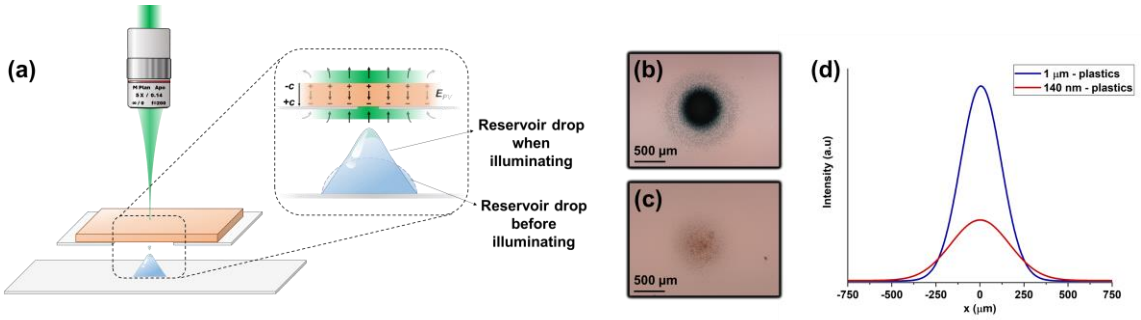

Figure 1. (a) Experimental set up: the 532 nm laser beam is focused in the $LiNbO_3$:Fe. Under the mobile platform, the reservoir drop is located. On the right, a frontal view of the crystal shows the electric field distribution generated by the photovoltaic effect. (b) and (c) Micro-photographs of the distributions of the accumulated micro- and nano-plastics, respectively. Scale bar: 200µm. (d) Gaussian profile of the micro- (blue) and nano-(red) plastics.

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Small electron polarons bound to interstitial tantalum defects in lithium tantalate

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The absorption features of optically generated, short-lived small bound electron polarons are inspected in congruent lithium tantalate, $LiTaO_3$ (LT), in order to address the question whether it is possible to localize electrons at interstitial Ta_V:V_{Li} defect pairs by strong, short-range electron-phonon coupling. Solid-state photoabsorption spectroscopy under light exposure and density functional theory are used for an experimental and theoretical access to the spectral features of small bound polaron states and to calculate the binding energies of the small bound Ta_{Li}^{4+} (antisite) and Ta_V^{4+}:$V_{Li}$$ (interstitial site) electron polarons. As a result, two energetically well separated $\delta E \approx 0.5$ eV absorption features with a distinct dependence on the probe light polarization and peaking at 1.6 eV and 2.1 eV are discovered.
We contrast our results to the interpretation of a single small bound Ta_{Li}^{4+} electron state with strong anisotropy of the lattice distortion and discuss the optical generation of interstitial Ta_V^{4+}:V_{Li} small polarons in the framework of optical gating of Ta_V^{4+}:Ta_{Ta}^{4+} bipolarons.
We can conclude that the appearance of carrier localization at Ta_V:V_{Li} must be considered as additional intermediate state for the 3D hopping transport mechanisms at room temperature in addition to Ta_{Li}, as well, and, thus, impacts a variety of optical, photoelectrical and electrical applications of LT in nonlinear photonics. Furthermore, it is envisaged that LT represents a promising model system for the further examination of the small-polaron based photogalvanic effect in polar oxides with the unique feature of two, energetically well separated small polaron states.

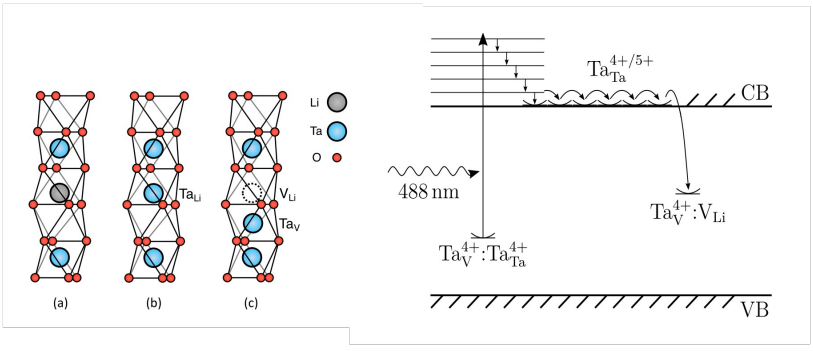

Figure- **Left:** Initial Defect structure in LT, Structural models of (a) defect free LiTaO3, (b) Ta_{Li}^{5+} antisite, and (c) Ta_V^{5+}:V_{Li} interstitial defect pair. **Right:** Sketch of the formation process of interstitial polarons assuming the initial presence of bipolarons

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Exciton emission enhancement in 1L-MoS_2 on a ferroelectric substrate undergoing a ferro-to paraelectric phase transition

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MoS_2 monolayer (1L-MoS_2) is a 2D semiconducting material with excellent optoelectronic properties, which holds potential for a variety of applications in spintronics, optoelectronics and integrated circuitry [1]. Due to its atomic thickness nature, this material provides the possibility of engineering its properties by means of its surrounding environment. In this regard, ferroelectric substrates have the potential to modify the carrier concentration of 2D materials enabling the manipulation of their electronic and photonic properties [2].

In this study, the relaxor-ferroelectric Strontium Barium Niobate (SBN) crystal, $Sr_{0.6}Ba_{0.4}(NbO_3)_2$, featuring a low Curie temperature (Tc ~ 70ºC), is used as a substrate for a 1L-MoS_2. The goal is to investigate how the transition from ferro-to-paraelectric state affects the optical properties of 1L-MoS_2. To this aim, the evolution of the 1L-MoS_2 photoluminescence (PL) is followed in the 30-90ºC temperature range. The results reveal a notable modification of the 1L-MoS_2 PL during the phase transition of SBN.

Contrary to what might be expected, the increase in temperature does not cause an emission quenching but rather a significant enhancement of the 1L-MoS_2 PL. This enhancement is correlated with a boost of the exciton population produced by the varying balance between polarization and screening charges along the phase transition of the SBN substrate.

The work highlights the importance of the association of 2D materials and ferroelectrics to boost the concentration of excitons and paves the way for cutting-edge switchable devices in the fields of photonics and optoelectronics.

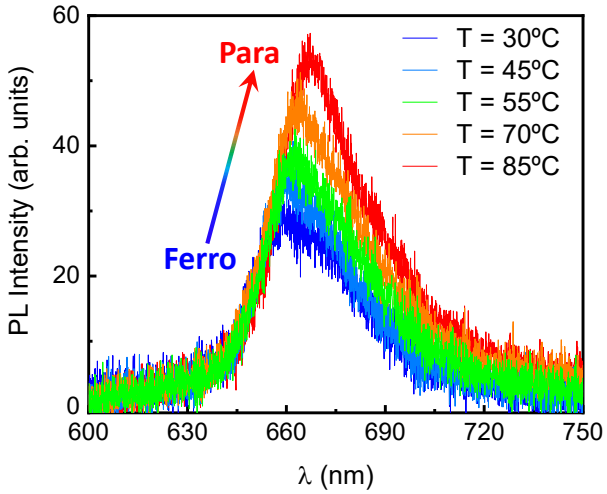

Figure 1 – Evolution of 1L-MoS_2 PL with temperature on an SBN substrate undergoing a ferroelectric to paraelectric phase transition.

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2-photon polymerization of patterned polarizers in SU-8 and S1805 photoresist alignment surface

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Patterned polarizers are prepared using liquid crystals (LC) doped with dichroic dye and photopolymerization to create patterns for surface alignment in photoresists. Alignment techniques are commonly employed to generate complex aligned films [1] – *e.g.,* photoalignment with uniform UV exposure is used to create uniformly aligned films with multiple exposures, or direct laser writing (DLW) with a UV beam laser – but they allow for limited resolution in surface alignment. If high-resolution alignments on the same surface are required, new fast and efficient techniques are explored for creating nano-grooves in conventional photoresist [2].

In this work, surface alignment using 2-photon polymerization direct laser writing (2PP-DLW) technique is employed to create high-resolution groove patterns at arbitrary angles in both negative-tone and positive photoresists. These angles determine the orientation of the LC molecules at any point on the substrate surface, thereby determining the brightness intensity within the patterns in combination with a linear polarizer. Two complementary photoresists are utilized (see Figure - a): the conventional negative-tone SU-8 photoresist and, in this context novel, positive-tone S1805 photoresist. Customized equipment (depicted in Figure - b) has been designed and constructed for this purpose. The equipment is equipped with a 780 nm and 250 mW femtosecond fiber laser to induce 2PP. It also has a number of CNC stages, including xyz nano-positioners based on galvanometers (x,y) and a piezoelectric unit (z-axis), as well as coarse 200x200 mm^2 x,y micro-positioners to deal with large samples. Preliminary tests have successfully produced repetitive submicron complex patterns in LC without dichroic dye, which are compared with patterns obtained using dye-doped LCs.

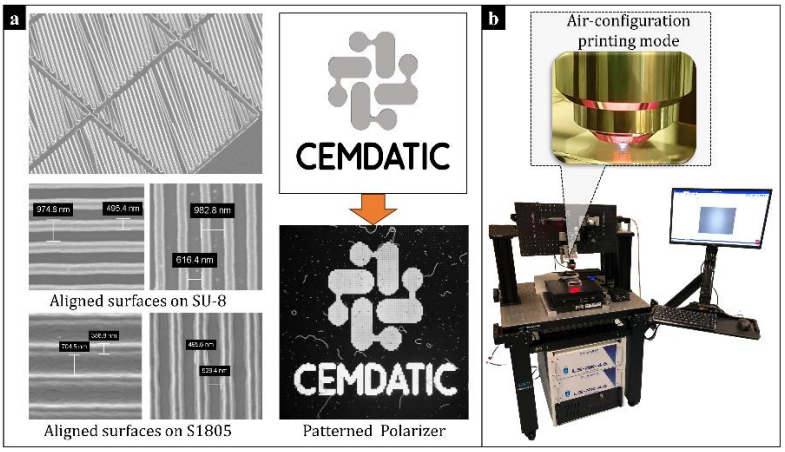

Figure - a) SEM images of aligned surfaces of patterned grooves on SU-8 and S1805 photoresist. b) Custom-built 2PP equipment.

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Dynamics of a water droplet suspended in paraffin oil and subjected to a photovoltaic electric field

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The electric field generated by illuminating ferroelectric substrates with a strong bulk photovoltaic effect has been widely used to manipulate micro- and nano-objects. [1] through electrophoretic and dielectrophoretic forces. To accurately predict and control the electrically-induced dynamics of these objects, a deep understanding of the generated electric field and its interaction with the surrounding substrate is necessary [2]. This understanding becomes even more important when electrophoretic or dielectrophoretic forces are not the only forces acting on the object.

This work studies the dynamics of a small water droplet initially deposited at the interface between the paraffin layer and the air. In the absence of an electric field, the position of this droplet depends on the interaction between two weak forces: gravity and surface tension [3]. Thus, a sufficiently small droplet can be suspended at the interface. When the dielectrophoretic forces, generated by an electric field are also acting on the water droplet [3], with the objective of using this field to manipulate and redirect the droplet.

We use the finite elements software COMSOL© to simulate the evanescent electric field produced by the photovoltaic surface charge that appears in the surface of a Z-cut lithium niobate substrate when it is illuminated.

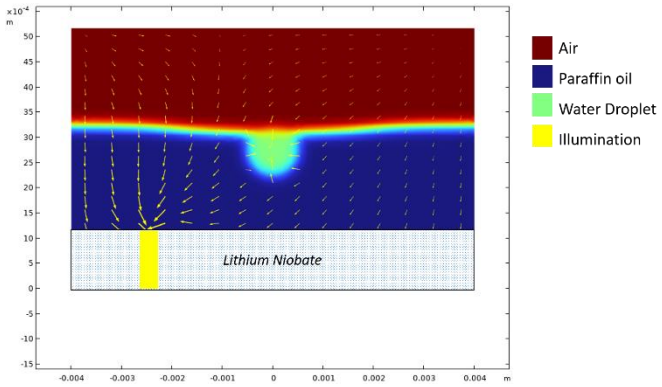

Figure 1: Schematic representation of a water droplet suspended at a paraffin-air interface. The arrows represent the dielectrophoretic force induced by an photovoltaic field generated through the illumination of a z-cut iron doped lithium niobate crystal.

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Lithium Niobate for Light-driven Actuation of Droplets

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The actuation and control of liquid droplets is a key function in many microfluidic applications, both in scientific research and industry. Over the years, several strategies have been employed to accomplish this task and optical approaches have recently emerged, thanks to the high versatility and reconfigurability of the optofluidic devices. In this work, we present an optofluidic platform based on a iron-doped z-cut lithium niobate crystal (Fe:LiNbO3): the remarkable photovoltaic, piezoelectric and pyroelectric properties of this material have been synergically employed to actuate, merge and split water droplets, solely by using laser beams [1]. The engineering of the Fe:LiNbO3 surface with a lubrificated-infused layer (LIS) guarantees a very slippery and robust device, suitable for prolonged use and the manipulation of water droplets with volumes up to some microliters [2]. Furthermore, the remarkable light-induced properties of LiNbO3 can be used to actuate also other liquids, as the case of nematic liquid crystals (LCs), thus representing an innovative approach for achieve a full light-driven actuation also in LCs-based technology [3,4].

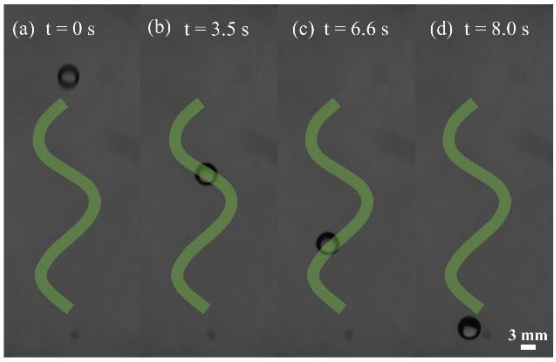

Figure - Passive actuation of a water droplets along a wavy illuminated stripe achieved at the surface of LIS/LiNbO3 crystals via light-induced phenomena.

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Unlocking Single-Particle Multiparametric Sensing: Decoupling Temperature and Viscosity through Upconverting Polarized Spectroscopy

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Upconverting particles (UCPs), renowned for their capability to convert infrared photoexcitation to visible light, are extensively used as imaging probes. Furthermore, their responsiveness to diverse external stimuli holds promise for their application as remote multiparametric sensors, capable of swiftly characterizing medium properties in a single assessment. However, the utility of UCPs in multiparametric sensing is impeded by crosstalk, wherein distinct external stimuli induce identical alterations in UCP luminescence, hindering accurate interpretation and yielding erroneous outputs. Overcoming crosstalk requires pioneering strategies in upconverting luminescence analysis. In this study, we present a breakthrough: an optically trapped $NaYF_4:Er^{3+}$ upconverting spinner makes possible simultaneous and dependable readings of temperature and viscosity. This achievement is realized by disentangling thermal and mechanical measurements—employing the luminescence of thermally coupled Er^{3+} ions for thermal sensing,[1] while leveraging the polarization of luminescence from non-thermally coupled Er^{3+} ions to determine viscosity.[2] Through a series of proof-of-concept experiments, we validate the capability of a single UCP to perform unbiased, simultaneous temperature and viscosity sensing, thereby opening avenues for advanced sensing applications.

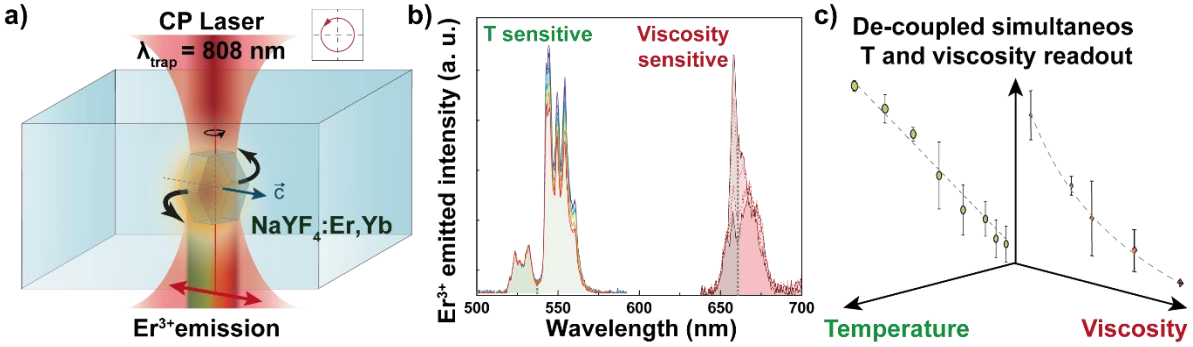

Figure – **a)** Schematic diagram of a rotating UCP within an optical trap when the trapping beam is circular polarized. **b)** Emission spectra of a single UCP, corresponding to the temperature calibration of the "green" bands and the time-dependent polarized "red" band sensitive to rotation and, consequently, viscosity. **c)** Temperature and viscosity calibration of a spinning UCP obtained from its emission spectra, avoiding crosstalk.

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Deciphering the role of Brownian motion in plasmonic enhancement in single colloidal upconverting nanoparticle

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Upconverting nanoparticles (UCNP) are essential in modern photonics due to their ability to convert infrared to visible light. Their main drawback is the low brightness, owing to the relatively low absorption coefficient of the lanthanide ions and their reduced quantum yield. This drawback can be solved by combining UCNPs with plasmonic nanostructures (PNSs). Plasmon-enhanced upconversion has been widely demonstrated in dry environments, where upconverting nanoparticles are immobilized so that the UCNP−PNS distance is controlled and fixed. Nevertheless, the situation becomes more complex if UCNPs are suspended in an aqueous medium. Brownian motion can introduce continuous fluctuations in the UCNP−PNS distance, competing with plasmon-enhanced luminescence.

In this study, we employ optical tweezers (OTs) for 3D manipulation of an individual UCNP in the proximity of Au plasmonic nanoparticles (PNPs), enabling the exploration of plasmon-enhanced upconversion luminescence in water. A continuous-wave 980 nm laser beam is focused within a microchamber containing the colloidal dispersion of UCNPs to create the optical trap and excite the upconverting luminescence. The base of the microchamber is a glass substrate deposited with Au PNPs. The magnitude of plasmon-enhanced luminescence in a single UCNP as a function of OT−PNS distance was studied. There are two differences between our results and those reported for static UCNP-PNPs systems. First, the plasmon-induced enhancement is moderate (20%). Second, our results arise from a long-range effect, extending up to UCNP-PNP separations as large as 1 μm. Comparison between experimental and numerical simulations evidence the key role of Brownian motion in limiting the plasmon-enhanced luminescence. The three-dimensional Brownian fluctuations of the upconverting nanoparticle leads to an “average effect” that explains the magnitude and spatial extension of luminescence. The findings contribute to the understanding of the complex interplay among plasmonic effects, optical trapping, and Brownian motion in colloidal systems.

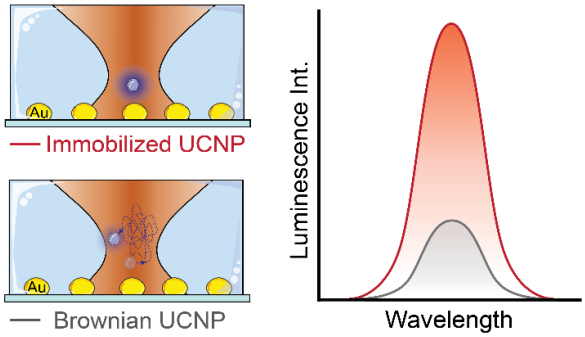

Figure – Different plasmon-enhanced luminescence between immobilized UCNP (simulation) and colloidal UCNP subjected to Brownian motion.

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Acknowledgments

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Microscale Optical Forces: Exploring Size and Electrostatic Influences

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Optical tweezers (OT) are a widely used tool in fields such as biology and physics as they facilitate the manipulation of nanometer and micrometer elements. Most of the particles used in optical tweezers (OT) with a biological interest usually have a micrometer radius, as well as being manipulated with lasers in the infrared range. Such particles lie in between the Mie Regime and the Rayleigh Regime, but neither is an accurate model for particles in the 1 to 10 micrometer range [2]. Furthermore, the optical forces acting on dielectric microparticles have only been related to parameters such as volume, and size has traditionally been identified as a key parameter, but it has now been found that electrostatic properties could be an important factor to consider [1].

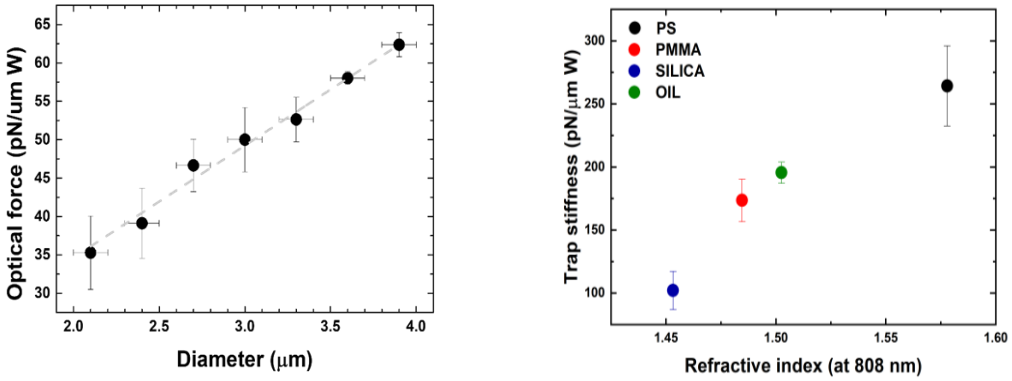

Figure 1. Optical force as a function of the diameter of particles.

For this reason, in this work we have designed a set of experiments that aim to test which parameters and properties are relevant when trapping a dielectric microparticle. Within the experiments, we will measure the trapping constant of particles of different materials, sizes, and also, we will measure the zeta potential of each sample.

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Submicro patterning in $LiNbO_3$ by Fe ion implantation for the assessment of novel type of photovoltaic optoelectronic tweezers

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In the last years, photovoltaic optoelectronic tweezers (PVOT) have emerged as a versatile multi-functional tool for a large variety of applications in different fields, such as optical manipulation and trapping of nano-objects [1], optofluidics [2], plasmonics [3] or biotechnology/biomedicine [4], to cite a few. The technique is based on the bulk photovoltaic effect. It is a singular phenomenon that appears in a few crystalline ferroelectric materials ($LiNbO_3$ clearly standing out) when properly doped (mainly Fe). By default, the available iron-doped $LiNbO_3$ crystals (Fe:LN) are homogeneously doped in bulk format. In addition, these crystals are much more expensive than the nominally pure LN.

The required optimum Fe atomic concentration for good PVOT performance is of the order of 1/1000. Fe implantation at the CMAM, UAM has been used to obtain such moderate concentrations, locally in a submicro pattern format to be exploited, in the implanted layer. We have used in-situ annealing during irradiation to prevent damage/disorder accumulation taking place at the first few microns beneath the surface [5].

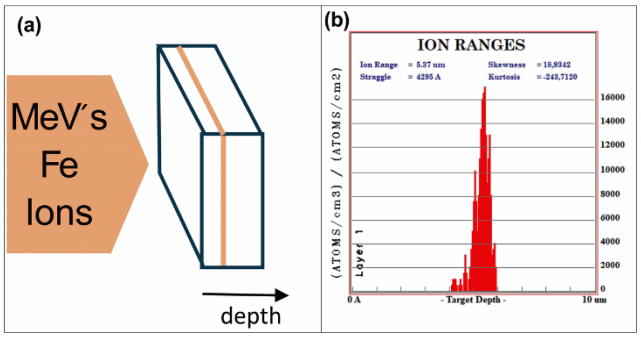

Figure – (a) Schematic 3D drawing, not to scale, for generating Fe doped lines (of mm-cm length) of submicron thickness by Fe implantation in a standard pure LN sample; and then using the polished perpendicular surface to the ion-implanted surface to study the PVOT performance. (b) SRIM calculations show the depth profile of the implanted Fe ions for the case of 30 MeV Fe ions. Most ions are implanted and concentrated in a thin layer of < 500 nm thickness.

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Harnessing Plasmon Resonances in Ni and Bi_2Te_3 Nanowire Networks for Enhanced Thermoelectric Performance

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Anodic aluminum oxide (AAO) templates were used in template-assisted electrochemical deposition, facilitating the creation of one-dimensional (1D) nanowire arrays with different densities of nanowires per area unit and three-dimensional (3D) nanowire networks composed of Ni and Bi_2Te_3. The optical properties of these materials were analyzed using spectroscopic ellipsometry. The results indicate that plasmon resonances are responsible for the distinct optical behaviors observed in both materials. Despite the different origins of the plasmons in each material, the position of the resonances appears to be dependent on the interactions between the nanowires [1]. Bi_2Te_3 is a thermoelectric semiconductor capable of converting temperature differences into electrical voltages, while Ni is a magnetic metal. It has been observed that 3D nanowire networks exhibit superior performance compared to films or 1D or bulk configurations [2-3]. In the case of Bi_2Te_3 nanostructures, the ability of the plasmon to induce a localized temperature increase can be harnessed to enhance the thermal gradient in these structures, thereby facilitating the fabrication of miniaturized thermoelectric generators, as proposed by other researchers [4]. The confinement of light produced by the plasmon resonance could potentially be used to increase the thermal gradient, resulting in an increase in the final power output.

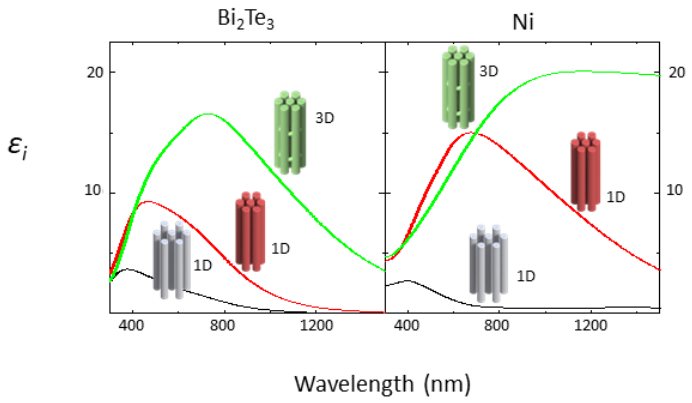

Figure – Experimental spectra of the imaginary parts of the in-plane effective dielectric constant of 1D nanowire arrays with 100nm inter-wire distance (black line, scheme in grey), 65 nm inter-wire distance (red line, scheme in red) and 3D nanowire-networks (green line, scheme in green) for Bi_2Te_3 (left) and Ni (right).

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Three-dimensionally nanostructured waveguides inside optical crystals for on-chip instrumentation by fs-laser nanolithography

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Optical waveguiding inside high quality optical garnet materials, such as sapphire and yttrium aluminum garnet (YAG), transparent from the UV (250 nm) to the mid-IR (5 μm), has great application for on-chip sensing instrumentation [1], such as harsh-environment resistant spectrometers, beam combiners for on-chip interferometry [2], and others. Besides sensing and spectral characterization, optical gain and laser generation is also a well-known application of doped sapphire and YAG crystals, with tunable emission from 750 to 1000 nm in the case of Ti:Sapphire, and high efficiency emission at laser lines of 946, 1030, 1064, 1319, 2010, 2080, 2900 and 2940 in the case of YAG doped with rare earth ions Nd^{3+}, Yb^{3+}, Tm^{3+}, Ho^{3+}, and Er^{3+}, for example, for which single and multimode laser-written waveguides were already seminally demonstrated a decade ago [3]. Coherent light generation in the form of supercontinuum is also a well-known application, for which no crystal doping is needed, but a precise control of the waveguide dispersion as well as of optical losses is required, for which the standard low index-contrast and low spatial precision laser-writing technique is not sufficient [3].

To achieve all of the above mentioned concepts on a single chip, we have recently developed a novel type of 3D embedded optical waveguides whose mode confinement and properties control is based on the sub-wavelength nanostructuring of the optical crystals such as sapphire and YAG, with 10 nm precision and high index contrast of air-to-dielectric [4, 5]. Our concept unifies the fields of nanophotonics with that of solid-state optics for the first time in a three-dimensional architectural design framework.

In this talk we will present the basics of our technique and we will showcase recent results on telecom waveguides design and fabrication, towards application on on-chip metrology instrumentation and integrated laser sources.

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Dimensional analysis of Kukhtarev equations for the photorefractive effect

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This study conducts a dimensional analysis of the Kukhtarev equations governing the photorefractive effect at low light intensity [1], While numerous studies have explored this phenomena [2], the dimensional analysis offers a unique perspective on the underlying physics governing the process. By applying dimensional analysis techniques [3], the equations are scrutinized to identify key dimensionless parameters that govern the photorefractive effect. This systematic examination aims to elucidate the fundamental non obvious relationships between various physical quantities involved in the process.

In parallel configuration, estimates are made for the diffusion length and local oxidation ratio. In perpendicular configuration, superficial diffusion of charge occurs, and there are chances of donor depletion. Simple dependencies are obtained for photoionization cross-section, recombination rate, carriers mobility, and time evolution. More complex dependencies are found for center density, photovoltaic length, and pattern size.

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Exploring the electric charge of tumour spheroids through their manipulation on photovoltaic ferroelectric platforms

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Optoelectronic ferroelectric platforms have been widely used for the manipulation of micro/nano-objects thanks to the bulk photovoltaic effect (PVE) [1]. These kind of optic manipulation takes advantage of the light-induced electric fields generated in some ferroelectric crystals, being particularly strong in $LiNbO_3$:Fe. Recently, a method to manipulate aqueous solution micro-droplets using these optoelectronic platforms have been developed [2]. It allows the manipulation of bio-materials such as DNA and sperm, homogeneously dispersed inside the droplet [3]. In this work we report the application of this technique to the manipulation and characterization of non-homogeneous droplets containing one multicellular spheroid, i.e. a 3D cell model whose metabolism is close to the one of tissues [4]. Two cell lines of human cancer have been used: U-87 MG and MCF-7.
Hybrid droplets (1-mm-diameter), consisting of cell culture medium with one distinguishable spheroid (diameter between 350 and 500 μm) are suspended in the air-paraffin interphase (see figure 1). When light illuminates the ferroelectric substrate, the migration of the hybrid droplet is achieved under the influence of the light-induced electric field.
The results show a change in the migration behavior of hybrid droplets compared with that of only cell culture medium (even as strong as a complete reversal of the movement) that depends on the face of the ferroelectric substrate being illuminated. Careful experiments with water, cell culture medium, and hybrid droplets have been conducted. Their analysis, to the light of a developed model, demonstrates a negative charge for the spheroids and allows estimating its charge density.

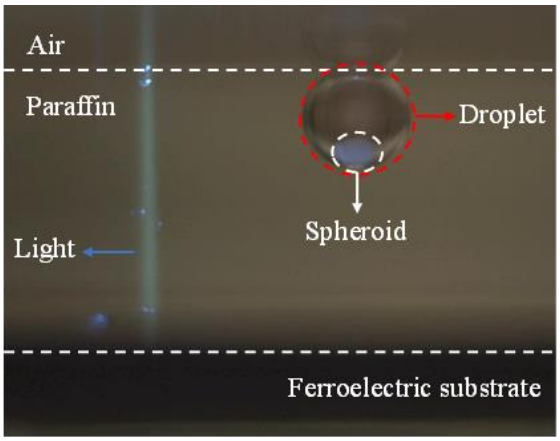

Figure 1: *Schematics of the PV ferroelectric platform showing the hanging droplet containing the spheroid. The ferroelectric substrate is illuminated with a laser beam that generates a PV electric that manipulates the droplet.*

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Imprinting micro-patterns of photovoltaic charge onto non-photovoltaic dielectric substrates

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Unlike metals or semiconductors, dielectric materials allow for the storage of charge patterns for long times thanks to their low electrical conductivity. These charge patterns have many applications: electrostatic assembly of micro/nanoparticles (e.g. laser printers), spatial modulation of wettability, manipulation of liquid droplets, etc. In that context, $LiNbO_3$ is an outstanding platform where one can generate tailored space-charge distributions by optical and/or thermal stimuli, exploiting the bulk photovoltaic effect and/or the pyroelectric effect. Here, we demonstrate a novel technique for transferring photovoltaic charge patterns from Fe:$LiNbO_3$ to different passive dielectric substrates, such as glass, quartz or various polymers. The method resembles the operation of a stamp: 1) first, the Fe:$LiNbO_3$ crystal is illuminated with the desired light distribution, hence producing an electric charge pattern correlated with the light distribution; 2) the crystal is brought into contact with another dielectric substrate; 3) they are separated. As a result, a mirror replica of the original charge pattern is transferred, which has been employed for the electrophoretic/dielectrophoretic assembly of micro/nanoparticles (see Figure 1). In this work, we successfully showcase two flexible schemes to print arbitrary charge distributions: scanning laser beams and structured illumination generated by a spatial light modulator. These results establish the foundation of a versatile simple method for electrostatic charge patterning, tentatively called “photovoltaic charge lithography”.

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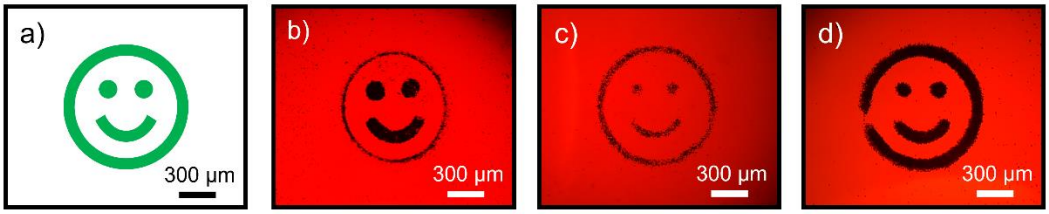

Figure 1 – a) Light pattern generated by a spatial light modulator. b)-d) Electrophoretic particle patterns made of positively charged toner microparticles. Image b) corresponds to the pattern on the +*c* face of a *z*-cut Fe:$LiNbO_3$ crystal. c) and d) correspond to the patterns on BK7 glass after contact for b) 5 min and c) 16 min with the −*c* face of a *z*-cut Fe:$LiNbO_3$ crystal.

Anomalous small polarons mobility in defective oxides: the case of congruent lithium niobate

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Charge transport phenomena play a key role in determining the figure of merit of many polar oxides for different applications including electronics, sensors, resistance to optical damage in nonlinear optical applications and integrated optics, holography, photovoltaics and photocatalysis [1].

In these materials the charge carriers are self-localized small polarons moving by thermally activated random hops on the crystal lattice. In the case of free polarons moving on a regular lattice, the standard theory for normal diffusion can be applied and simple expressions for the mobility of the charge carriers are available [2]. However, many oxide materials of technological interest are characterized by a large concentration of substitutional or extrinsic defects. They act as “traps” for the polarons which, if captured, shall remain on the defective site for very long times. In these circumstances the standard normal diffusion approach is no longer applicable and obtaining an explicit expression for the charge mobility is challenging.

We analyze this problem in the framework of a switching diffusion model [3] where polaron transport is considered to occur either by hopping transport on regular sites, or by direct hopping among defective sites. The two transport modes are related via a coupled diffusion equation which is characterized by some effective transformation rates among the two species.

The theory is verified by Monte Carlo simulations in the technologically important case of congruent Lithium Niobate for which the rate constants are obtained.

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Small polaron trapping kinetics in iron-doped congruent lithium niobate

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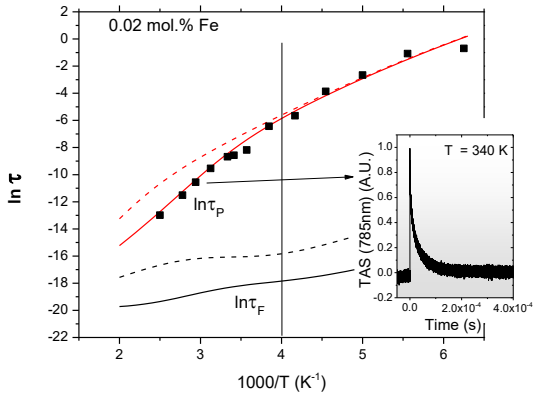
Iron-doped lithium niobate (LN) is one of the most used ferroelectric oxides in the realization of photorefractive and holographic devices due to its large electro-optical and bulk photovoltaic coefficients [1]. In all these applications the kinetic behavior of charge carriers from excitation to trapping determines the electrical conductivity and other charge transport properties of the material. It is nowadays well accepted that charge carriers in LN are small polarons moving by thermally activated hopping among different sites [2]. At visible wavelengths the polarons are emitted by Fe2+ donor centers and, after a thermally activated random walk, they are captured by deep traps ready to repeat the cycle. However, real materials are characterized by a high density of intrinsic (NbLi) and extrinsic (Fe2+/3+) defects which have the capability to trap polarons for long times. A formal description of the trapping kinetic from microscopic modelling is therefore very complex and, up to now, could be tackled only by MonteCarlo simulations [3]. In this contribution we present an analytical approach based on coupled kinetic equations. The transformation between the different species of polarons is described by effective rate constants which can be calculated taking into account both the rate of transformation and the diffusion time from polaron mobility. We provide explicit solutions for the trapping kinetics of polarons and their lifetimes. The temperature and concentration dependences of the observed quantities are analyzed. Finally, our results are used to fit experimental decay kinetics and lifetimes obtained by Light Induced Time-resolved Absorption spectroscopy (TAS) [2].



Experimental bound polaron lifetimes (black dots) measured by TAS at different temperatures in a 0.02 mol% Fe:LN sample and theoretical calculation (red line). The inset is an exemplary LIA decay.

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Optical control of ferroelectric liquids on ferroelectric solid substrates

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In this talk I will report on the optical control of the electromechanical instability of ferroelectric liquid droplets exposed to the photovoltaic field of a lithium niobate ferroelectric crystal substrate. The ferroelectric liquid is a nematic liquid crystal in which almost complete polar ordering of the molecular dipoles generates an internal macroscopic polarization locally collinear to the mean molecular long axis.

Upon entering the ferroelectric phase, droplets irradiated by an unfocused beam undergo an electromechanical instability and disintegrate by the explosive emission of fluid jets. The regions of jets emission can be controlled by focusing the light beam in areas close to the droplet's edge. Once emitted, the fluid jets can be walked by moving the beam up to millimeter distance from the mother droplet. Reverting the lithium niobate substrate, jets become thinner and show the tendency of being repelled by the beam instead of being attracted, thus offering an additional tool for their optical manipulation. Coating the ferroelectric substrates with fluorolink and decreasing the droplet size, the same focused light beam can be used to obtain optically controlled droplet motion. Ferroelectric droplets are again either attracted toward the center of the beam or repelled, depending on the side of the lithium niobate exposed to light irradiation. Moreover, moving the beam results in walking the ferroelectric droplet over long distances on the substrate.

We understand these effects as due to the coupling between the polarization of the ferroelectric droplet and the polarization photoinduced in the irradiated region of the lithium niobate substrate. Indeed, the effect is not observed in the conventional nematic phase, suggesting the crucial role of the ferroelectric liquid crystal polarization.

The reported results may pave the way to intriguing applications of ferroelectric nematic fluids related to manipulation, actuation, and control of soft, flexible materials.

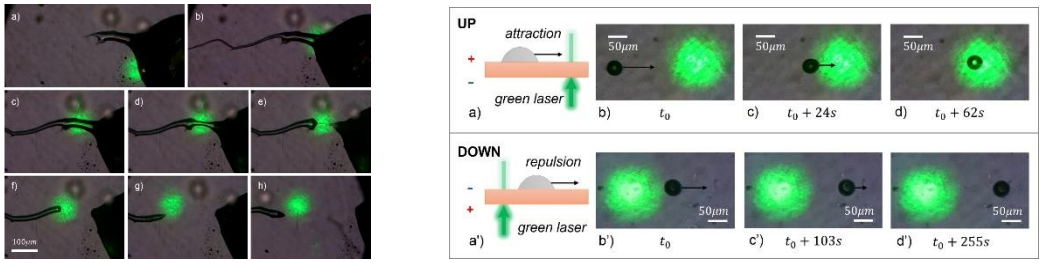

Figure 1: Example of optical manipulation of ferroelectric fluid jets and optical control of ferroelectric droplet motion

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