Photorefractive Photonics and Beyond

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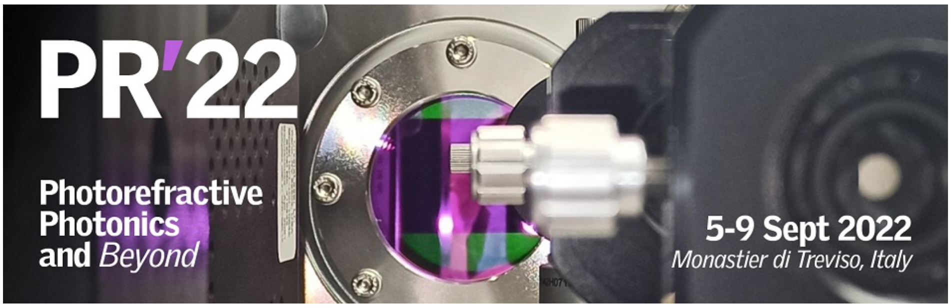

Book of Abstracts

Contents

Signal processing and photonics / 44

Learning in Holographic Convolutional Neural Nets

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We show how the array of convolutional adaptive interconnections needed for deep learning can be physically implemented and learned in an all-optical multistage dynamic holographically-interconnected architecture using thick Fourier-plane dynamic holographic photorefractive crystals. This optical architecture is self-aligned, phase-calibrated, and aberration compensated by using photorefractive phase conjugate mirrors to record the dynamic-holographic Fourier-plane interconnections in each layer.

Signal processing and photonics / 14

Neural networking and machine learning based on photorefractive solitonic waveguides: novel all-plastic Photonic Artificial Intelligence

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Often, when speaking of artificial intelligence, we think of software systems capable of learning-memorizing-reasoning. All AI codes run on traditional computers, which suffer from architectures not optimized for neural computing: in fact, they are based on traditional von Neumann geometry, for which processing and memory areas are physically separated. Unlike computers, the brain uses a unified geometry (neuromorphic paradigm), whereby memory and computation occur in the same physical location. However, it is possible to create neuromorphic hardware systems for example using light. In the photonics field, one possible and efficient way is to use integrated circuits based on soliton waveguides, ie channels self-written by light. By exploiting photorefractive nonlinearity, light can write waveguides and subsequently modify them based on the information propagated within them. This feature makes this technique extremely promising as it introduces neuroplasticity into hardware systems, that is, the characteristic of biological brain of modifying itself plastically based on the transported information. The work proposed here introduces the soliton X-junction as an elementary unit (neuron) for complex neural networks. Solitonic X-junctions can learn in both supervised and unsupervised ways by unbalancing the junction according to the information carried. By exploiting this phenomenon, complex solitonic networks can store information as propagation trajectories and use them for reasoning. In fact, they can compare unknown data with the stored ones and eventually recognize them. Using the photorefractive nonlinearities in different materials, it is possible to create different types of memories with different peculiarities.

Signal processing and photonics / 47

Programming Nonlinear Optical Propagation as an Optical Computer

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The ever-increasing need for processing large volumes of data is currently met with electronic processors. However, their limitations such as high power dissipation necessitate new modalities for computing. Optics is a promising contender for lower power operation. However, to achieve computing with the efficiency of light, creating and controlling nonlinearity optically stands as the next milestone. As the medium for this task, multimode fibers are promising candidates, since they can provide useful nonlinear effects while maintaining parallelism and low loss in a small form factor on the order of micrometers. In this presentation we investigate methods for programming these spatiotemporal nonlinearities by wavefront shaping, to control and optimize the performed optical computation. We use a surrogate model which links the various parameters in the system (light intensity, illuminating beam position and wavefront control) to the corresponding performance on a given task. Then, an iterative search algorithm based on a response surface model looks for the optimal set of parameters by creating and refining the surrogate model. This method efficiently programs the optical computer based on light propagation inside multimode fibers with minimal utilization of the digital computer. Inference can be performed even fully optically with accuracies on a similar level to digital neural networks on image classification tasks.

Signal processing and photonics / 70

Optical signal detection beyond the quantum limit: a case study from gravitational astronomy

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The newborn field of gravitational wave astronomy is gaining speed and after the first detection in 2015, gravitational waves coming from almost a hundred compact binary coalescences were detected between 2015 and 2020. Among all GW detections, more than two third were detected in the last observation run (O3). This was possible only thanks to the various upgrades implemented in between observation runs. One of such upgrade, which has already proven extremely effective, is the implementation of squeezed state of light to reduce the quantum noise limit of the interferometer. The central piece of squeezed state production is an Optical Parametric Oscillator (OPO). In this talk I will present the status of the quantum noise reduction techniques applied to GW astronomy and the prospects of future generation detectors.

Signal processing and photonics / 13

Addressable and erasable photonic neurons using solitonic X-junctions in lithium niobate films

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We show that undoped $LiNbO_3$ films constitute an attractive photosensitive medium to form reconfigurable optical functions controlled by pyroelectric effect. The present work illustrates this potential through the formation light-induced tunable X-junctions capable of fulfilling the function of optical neurons.
The $LiNbO_3$ films is fabricated from a photonic grade $LiNbO_3$ wafer gold-bonded to a silicon wafer with an intermediate silica buffer layer. After grinding and polishing, it forms an 8µm thick slab $LiNbO_3$ waveguide. This planar configuration is exploited to demonstrate the realization of photoinduced X-junctions generated by self-confined crossing CW beams of µw power. Further to inscription, the memorized structure allows two optical input signals to be mixed and redirected with a chosen ratio to the two outputs. A salient point of the demonstration reveals that this ratio is dictated by the power ratio between the two incoherent writing beams. The planar configuration offers a very good control of the propagating beams and of their coupling along with the possibility of erasing the structure using light. Other advantages of the slab configuration are response time up to two orders of magnitude faster than in $LiNbO_3$ bulk and the compactness of the devices made.
To conclude, our work shows that $LiNbO_3$ films, offering the possibility of inducing reconfigurable optical functions, constitute a valid configuration for the realization of neuromorphic circuits. By analogy to biological neurons, soliton formed x-junction neurons in LiNbO3 films can increase and decrease their synaptic strength depending on the entries similarly to what happens in biological tissue.

Signal processing and photonics / **43**

All-optical switching on plasmonic-lithium niobate metasurfaces

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Ferroelectric crystals can modify their optical properties by producing photo-excited carriers when exposed to moderate laser power. This change stems from the direction-dependent photovoltages developed along the c-axis of the ferroelectric crystal. Here, we harness the pyroelectric, photorefractive and photoelastic effects to induce reversible (pyroelectric and photoelastic) and irreversible (photorefractive) transmittance changes on plasmonic-lithium niobate metasurfaces.
We prepare two types of plasmonic-LiNbO_{3} metasurfaces by depositing either ~30 nm of copper (Cu) or Indium Tin Oxide (ITO) on commercially available x-cut congruent films of LiNbO_{3} (thickness ~100 µm). Next, we anneal the samples (from 400 oC up to 800 oC), thereby transforming Cu into CuO and increasing the transparency of ITO. At the same time, ions diffuse into the LiNbO_{3} crystals, creating deep and shallow traps. We subsequently deposit 50 nm gold films and fabricate photonic metasurfaces of subwavelength, periodic nanohole arrays.
We set-up a pump-probe experiment on a home-built microscope based on lock-in detection technique, thereby record transmittance changes induced on the plasmonic-lithium niobate metasurfaces at the probe laser beam (1064 nm), from the pump laser beam (532 nm).We present various configurations where the pyroelectric, photorefractive and photoelastic effects induce volatile and non-volatile transmission changes. The relative modulation depth of the probe beam exceeds 150% with up to 2 ms response time, induced by a few mW (<5mW) of the pump power.
Our results pave the way for a new type of compact, all-optical switching scheme for flat optics.

Signal processing and photonics / 15

Photorefractive soliton synapsis for Surface-Plasmon-Polariton circuits

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The realization of low-loss, high-speed all-optical interconnections is of great interest for possible photonic applications; having plastic interconnections will extend applications to the field of neural networks. To mimic biological neuroplasticity, interconnections should be able to be created, deleted, strengthened, and weakened due to the learning and reasoning purposes of neural networks. Traditional photonics suffers from limited integrability with respect to electronics, due to the difference in the size of the photonic and electronic wavelengths. Recently, a major improvement has been represented by the use of plasmonics, which limits light signals in nanometric dimensions. On the other hand, plasmonics is mainly linear, thus limiting the possibility of processing signals. In this study, the authors developed a novel Plasmonic-Solitonic hybrid photorefractive interconnection, capable of linking two metal circuits carrying Surface-Plasmon-Polariton (SPP) waves. The light transported in the form of SPP can generate a photorefractive soliton channel which in turn is re-coupled to a second nanostrip. Soliton coupling adds plasticity to plasmonic circuits which can now store information and can act as active neuromorphic systems. The photorefractive soliton channel satisfies the conditions of low loss, long-range propagation, and wide transmission band, fundamental characteristics for future applications. Here, the authors study the formation characteristics of the soliton, which can be addressed according to the applied bias field. Consequently, the re-coupling to a second plasmonic nanostrip is not constant but depends on the experimental conditions, perfectly simulating the sigmoid-like activation function as a replication of the action potential of biological neurons within the soma

Materials micro- and nano-engineering / 30

Multifunctional materials for emerging technologies

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This presentation focuses on structure property/relationships in advanced materials, emphasizing multifunctional systems that exhibit multiple functionalities. Such systems are then used as building blocks for the fabrication of various emerging technologies. In particular, nanostructured materials synthesized via the bottom–up approach present an opportunity for future generation low cost manufacturing of devices [1]. We focus in particular on recent developments in solar technologies that aim to address the energy challenge, including third generation photovoltaics, solar hydrogen production, luminescent solar concentrators and other optoelectronic devices. [2-40].

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Materials micro- and nano-engineering / 61

Optical response of LiNb_{x}Ta_{1-x}O3 solid solutions calculated from first principles.

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In the last decade, our knowledge of the linear and nonlinear optical response of LiNbO3 crystals has substantially improved [1]. Precise optical measurements on samples of well known composition allowed to distinguish, e.g., polaronic signatures, while refined ab initio models allowed to disentangle the various effects contributing to the measured spectra and to assign spectral signatures to determined structural features.
In this contribution, we review the actual knowledge of the linear and nonlinear optical response of LiNbO3 crystals from a theoretical point of view. The optical properties calculated with different approaches of different precision [2], ranging from the independent particle approximation to the GW-approach are shown and compared to experimental data. The role of intrinsic and extrinsic defects and temperature is discussed in detail [1,3]. Additionally, we discuss a few possibilities to tailor the materials optical response (e.g., the second harmonic generation) by structural strain or by tuning the crystal composition for specific applications. In this respect, LiNb_{x}Ta_{1-x}O3 solid solutions offer a further knob to realize crystals with optimized optical properties. The talk is concluded with an overview of actual research fields of theoretical materials science concerning the linear and nonlinear optical response of LiNbO3 and related materials.

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Materials micro- and nano-engineering / 33

MgO-LiNbO3 film: an appealing photorefractive medium

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LiNbO3 films constitute an attractive photorefractive medium offering the possibility of inducing reconfigurable optical functions either with beams guided in the film or with an illumination transverse to the film. Several additional motivations animate the study of the photosensitivity of LiNbO3 films. Performances such as sensitivity and response time are improved compare to bulk due to the specificity of the geometry that confines both light and charges in one dimension. Moreover, interaction between beams is facilitated by the planar arrangement, novel architectures are conceivable through the control of guided beams using an external writing beam and potential applications are expanded with the possibility of integration of photonic and electronic components considering LiNbO3 films on silicon.
To further illustrate this potential, we present surprising results on the photosensitivity of MgO-doped LiNbO3 films. We show that guided beams of few microwatts can self-focus efficiently by photorefractive effect triggered by pyroelectricity. The experimental observations are performed in a slab waveguide consisting of a 7µm thick LiNbO3 layer doped with 5%mol of magnesium oxide (MgO) adhered with a silica layer onto a silicon wafer. Despite the MgO doping, known to reduce the PR effect, the efficiency of the self-trapping is comparable with the one observed in undoped layers but with much faster response. Measurements show that milliseconds response time can be reached with power beam on the order of milliwatt at 532nm. The observed self-focusing dynamics is exploited to better comprehend the underlying physics.

Materials micro- and nano-engineering / 10

Pyroelectric field-assisted domain engineering in lithium niobate and lithium tantalate using femtosecond laser pulses

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Domain-engineered structures play an essential role in nonlinear optics for quasi-phase-matched parametric processes. Recently, we have discovered a pyroelectric field-assisted domain inversion approach that can be used to switch ferroelectric domains in magnesium doped lithium niobate without using an external applied electric field. The process works as follows. First, permanent defects are induced along the polar axis by focused femtosecond laser pulses. Then, the crystal is heated up above 200 °C. During cooling, the domain inversion is driven by a space-charge field that locally exceeds the threshold field of domain nucleation. After this heating-cooling cycle, ferroelectric domains are inverted below and above the defects that act as seeds. Domain inversion occurs if certain pulse energy and defect length are exceeded.

Here, we fabricate two-dimensional lattices of ferroelectric domains by patterning lithium niobate and lithium tantalate crystals with femtosecond laser pulses and then heating them to elevated temperatures. We investigate the effect of temperature and seed spacing on the number and size of inverted domains in magnesium-doped lithium niobate. To this end, we create 2D nonlinear photonic structures with periods of 15 µm x 6.3 µm. Čerenkov second-harmonic generation microscopy allows visualizing the generated ferroelectric domains and laser-induced seeds in 3D. Measurements with different electrical terminations of the crystal surfaces reveal the influence of surface charges during the domain formation process. Finally, we present the conversion efficiencies of quasi-phase-matched second-harmonic generation in our two-dimensional nonlinear photonic structures.

Materials micro- and nano-engineering / 20

Solution-deposited $BiFeO_3$ films: Photovoltaic effect & electro-optic response in dependence of doping & substrate stress

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Perovskite-structured bismuth ferrite ($BiFeO_3$, BFO) is one of very few 'true' multiferroic single-phase materials with both ferroelectric and antiferromagnetic ordering. With a Curie temperature above 1000 K, it is also a prime candidate for high-temperature applications. Photovoltaic conversion efficiencies of more than 10% were reported for above-bandgap illumination in epitaxial BFO films. However, domain walls are essential in this phenomenon; it is interface-dominated and not a 'bulk' photovoltaic effect. Photorefractive properties are suppressed by high dark conductivity, which makes it difficult to achieve fully polarized samples and limits the space charge field that can be obtained under illumination.
Here, we present highly (001)-textured polycrystalline BFO films prepared by spin-coating. Doping with Mn strongly reduces leakage current, resulting in properties rivalling those of epitaxial films. At the same time, light-induced charge transport at sub-bandgap photon energies is drastically increased by Mn-doping. Evidence is presented that this charge transport is a true bulk photovoltaic effect, the first such demonstration for a solution-deposited polycrystalline film. A variation of the substrate material creates different mechanical stress states in the films, which in turn modify the photovoltaic response. This phenomenon is based on an intrinsic piezo-photovoltaic effect rather than extrinsic domain-wall phenomena. An electrooptic effect can be observed and quantified in the polycrystalline films by a modified Teng-Man setup, but it is notably lower than that seen in BFO single crystals. Combining the information on light-induced and dark charge transport and the electrooptic properties, the suitability of the solution-deposited films for photorefractive investigations is assessed.

Materials micro- and nano-engineering / 36

Influence of substrate stress on the electro-optic effect in polycrystalline bismuth ferrite films

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With their linear electro-optic effect, i.e. the linear change in the refractive index under an electric field, complex ferroelectric oxides are an ideal candidate to control the propagation of light in the field of integrated optics.

The research focused on the integration of thin ferroelectric films for electro-optic applications is concentrated on a few promising systems such as barium titanate, with high electro-optic coefficients but strong temperature dependence, or lead zirconate titanate, which is more stable but subject to environmental legislation restrictions. An interesting alternative is bismuth ferrite (BiFeO₃), often used in photoferroelectric investigations. The high Curie temperature of BiFeO₃ (1100 K), its high birefringence together with its lead-free nature makes bismuth ferrite a candidate for electro-optic applications.

In this study, we focus on the effect of mechanical stress on the electro-optic properties of solution-deposited polycrystalline BiFeO₃ thin films. Low-leakage polycrystalline bismuth ferrite thin films were fabricated on c-cut sapphire, fused silica, and magnesium oxide substrates to induce different degrees of stress in the films. The electro-optic coefficients were measured using the Teng-Man technique. Two different electrode configurations were used: metal-insulator-metal (MIM) and interdigitated electrode configuration (IDE).

The films show stress values ranging from +0.93 GPa (tensile stress) on fused silica to -0.54 GPa (compressive stress) on MgO. High tensile stress enhances the in-plane polarization, enhancing the Pockels coefficient in interdigitated electrode geometry. These results give guidelines for the design and geometry of thin film-based electro-optic devices.

Materials micro- and nano-engineering / 42

Amplitude, phase, and polarization control of light wave with double phase meta-surface

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We propose a method for simultaneous control of three elements of light wave; amplitude, phase, and polarization by dielectric meta-surfaces based on the principle of double phase holography. Meta-surfaces consisting of one type of meta-atom can independently control only two of the three elements. In double phase holography, the intensity is modulated by the interference of light waves of two different phases. By applying this principle, a meta-surface consisting of two types of meta-atoms can control three elements simultaneously. We have demonstrated this principle by numerical calculations using the finite element method and the rigorous coupled wave equation. The meta-atom is assumed to be a Si rectangle on a SiO_2 substrate. The incident light wavelength was set to 1.06 μm. The length and orientation of the three sides of the rectangle are the design parameters. The phase of the scattered light is controlled by the difference between the resonance frequency of the meta-atom and the frequency of the incident light wave. The orientation of the rectangular body determines the polarization of the scattered light. It is shown that this can generate arbitrary amplitudes below a certain value, phases in the range of 0~2\pi, and all polarizations on the Poincaré sphere.

Holography, optical processing and imaging / 25

Cancer Holography for Personalized Medicine

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This paper reviews the uses of optical holography in cancer biology and personalized medicine. Holography of living tissue occurs in two stages: a coherence-domain stage with depth-selection through holographic interferometry (hologram writing), followed by a reconstruction stage (hologram readout). With its beginnings in photorefractive holography, the writing and the readout of cancer holograms were both in the optical domain through four-wave mixing. However, better performance is obtained by retaining the optical writing stage while relying on digital cameras to perform the holographic playback electronically—known as digital holography (DH). Interestingly, DH is the reverse of Gabor's original idea for holography that used electrons to expose film and only used optics for the hologram readout. Today, digital holography is the most commonly used technique for coherent optical imaging of biological samples.

An example of such medical-inspired holography is full-frame optical coherence tomography (OCT) that relies on digital holography, as does dynamic contrast OCT, also known as biodynamic imaging, to make phase-sensitive measurements of the Doppler spectra of light scattered from intracellular motions in living tissue samples. Full three-dimensional maps of cellular metabolism of active cancer tumors can be obtained using holographic Doppler spectroscopy. Applying anti-cancer drugs to these biopsy samples and measuring shifts in the Doppler spectra can help identify cancer patients who will benefit from alternative cancer therapies, thereby directing those patients to more effective treatments. Several recently-completed pilot human clinical trials will be described that test the clinical utility of cancer therapy selection using holographic Doppler spectroscopy.

Holography, optical processing and imaging / 46

Interferometric complex-field retrieval in photorefractive transient detection imaging

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A transient detection imaging system (TDI), also known as optical novelty filter, is an adaptive interferometric device that detects temporal changes in a scene while suppressing its static parts. Removal of background improves contrast and helps visualizing and measuring intensity and phase. Most TDI systems are based on photorefractive two-wave mixing. Previous works rely on conventional intensity measurements, where partial information about input signal phase changes are obtained by previous calibration.
We present our results on the TDI output complex-field and its relation with the input signal phase changes. The experimental setup is based on a single-frequency laser and SBN crystal. The laser beam is split into a signal, pump, and reference beam for interferometry. Signal and pump beams intersect at the nonlinear crystal, oriented to get strong energy transfer from signal to pump. Therefore, the output beam contains images only when the input signal beam changes. Output signal phase is retrieved from off-axis holographic Fourier technique which, compared to conventional intensity-based TDI, provides important additional features such as directionality of the phase change, higher resolution ($\lambda/30$), and differential-phase measurement for enhanced sensitivity without calibration.
We have evidenced the linear relation between input and output phases for the entire range from $-\pi$ to π in excellent agreement with our theory.
We believe that this work takes advantage of background suppression with high phase-sign sensitivity, especially important for low-power small-phase change signals sensors, and opens up new possibilities.

Holography, optical processing and imaging / 38

Defect detection in composite material by means of photorefractive vibrometry

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The use of composite materials for structural elements in high value structures and components (e.g. wind turbines blades, composite parts in aircrafts …) requires fast and reliable tools for assessing their structural integrity.
The inspection method proposed in this work is based on the detection of defect-induced elastic cross-modulation phenomena using a vibrometric scheme that makes use of photorefractive interferometry. This non-contact method is full-field, and aims at inspecting large areas at once and enable detection of defects in an early stage.
The novelty of the system lies in both the acoustic excitation and in the detection method. Two guided waves are sent along the sample: one of low amplitude and high frequency (probe) and one of high amplitude and low frequency (pump). The mechanical response of a damaged composite sample is, in general, not linear. Detection of acoustic frequency mixing caused by mechanical nonlinearity can thus evidence the presence of a crack or delamination defect.
We have exploited non-degenerate two-wave mixing in a photorefractive crystal to perform a full-optical lock-in detection and image the vibration pattern at the frequency of interest, the defect signature, without crosstalk from other vibrations, e.g. from the strong pump vibration, which was used to modulate the defect response to probe vibrations.
Using standard homodyne interferometry, frequency mixing between the modulation frequency and the probe frequency, resulting from the defect response would be indistinguishable from frequency mixing due to the nonlinear relation between the interferometer light intensity and the measured displacements. Heterodyne techniques, on the other hand, do not allow for full field detection. This work highlights that photorefractive interferometry allows for frequency selective detection of vibrations and enables to identify the modulated probing signal amid an intense vibration background.

Holography, optical processing and imaging / 48

Optical coherent detection through scattering media by two-wave mixing in liquid crystal light valves

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Coherent detection in optical beams requires measuring the optical phase with an interferometric setup, which implies superposing the optical wavefronts of the signal and reference beams. Because of its intrinsic nature, optical phase detection rapidly undergoes degradation if the interfering beams are not spatially uniform, as when propagating through scattering media. In this case a nonlinear medium can be employed instead of a conventional beam-splitter to recombine the reference and signal. Liquid crystal light valves (LCLV) are optically addressed spatial light modulators realized by associating a nematic liquid crystal with a photorefractive substrate. Here a LCLV is used to perform two-wave mixing (2WM) with a continuous reference (typical intensity of few mW/cm^2 in the green) and a very low intensity speckled signal beam. Thanks to its intrinsic nonlinear dynamics, the LCLV adjusts its properties following the phase and intensity changes of the interacting beams in the frequency bandwidth of its response. With the novel operating conditions of our LCLV at wavelength of 532 nm a sub-ms response time is measured, thus being compatible with a speckle decorrelation times also in the range of ms. Therefore, it is able to filter out low frequency modulations and noise effects. Based on these properties, optical coherent detection is achieved when the signal propagates through multiscattering media, as foam layers of various thicknesses. When an incident phase modulation is imposed on the speckled signal issued from the foam sample, this is transformed into intensity modulation after 2WM interaction in the LCLV. At the exit of the LCLV and due to Reference-Speckle signal two beam coupling, the modulation frequency is easily detected by measuring the intensity on the self-diffracted plane wave reference beam on a single detector.

Photorefractive hybrid systems / 69

Multiple Scenarios for Soft Matter Manipulation based on LiNbO3 Crystals

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Manipulation of soft matter, especially at micro and nanoscale, is of primary importance in many fields of science and technology. Novel scenarios have been opened in recent years by using platforms based on LiNbO3 crystals. Interestingly, the multifaced intrinsic properties of such ferroelectric crystal has driven the development of novel concepts in exploiting pyroelectric or photorefractive effects for manipulate liquids or polymers. Moreover, further developments have been achieved in manipulating or driving biological matter such as cells and bacteria on platforms based on LiNbO3 crystals thus opening the route to a new set of tools in biotechnologies. The next challenging step forward to achieve in such intriguing scientific arena will points toward the realization of intelligent platforms able to integrate multipurpose functionalities for manipulating soft matter at multiscale. Here we present an array of assay of demonstrations to show several handling modalities of liquid sample such as, self-assembling, liquid drop ejection, robotic-like multiplexed liquid manipulation, electrowetting-like tasks, pyro-EHD drop printing, pyro-EHD-spinning, and different example of microfabrication processes based on pyro-EHD polymer drawing, and more. Furthermore, a couple of examples of applications in using platforms based on LiNbO3 crystals for study and address live biological matters will also presented and discussed at the aim to revealing innovative scenarios in which such kind of platforms based on substrate-cell interaction based on electric surface charges could be a exploited in the future for driving and/or regulate biological processes.

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Photorefractive hybrid systems / 39

Light-shaped virtual electrodes on Fe:LiNbO3 to control confined droplets

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Non-centrosymmetric ferroelectric materials serve as optimal substrates for generating local evanescent electric fields for droplet manipulation. Upon illumination, net space charge distributions are induced in the material, acting as virtual electrodes for dielectrophoretic control of droplets. Droplet manipulation using this method is promising due to the high flexibility offered by optical modeling techniques, especially for lab-on-a-chip applications that require multiple functional operations, such as droplet blending, sorting, and mixing, on the same platform. Although the control of liquid droplets has been successfully achieved using virtual electrodes, the confinement of aqueous droplets in micrometer-sized channels, i.e., the most typical configuration in lab-on-a-chip, has never been studied. In particular, these materials have not yet been successfully integrated into microfluidic platforms.

Here, we present the integration in droplet microfluidic devices of Fe:LiNbO3, one of the most commonly used crystals for this application, because of its high photoinduced electric fields. C-cut crystals replace the classical slide used as the bottom layer of a PDMS microfluidic device, allowing photoinduction of the evanescent field within the microfluidic channels. Light patterning techniques were used to shape the electrodes to control the droplets within the channel in different ways, such as sorting or fusing. We use stripe-like electrode patterns to direct droplets along paths that differ from paths in normal Poiseuille flow in the micrometer channel. In addition, arrangements of stripe electrodes perpendicular to the droplet flow are exploited for an on-demand merging of successive droplets.

Photorefractive hybrid systems / 28

Light and thermally-induced charge transfer phenomena at ferroelectric crystal surfaces

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Lately, evanescent electric fields generated by the bulk photovoltaic (PV) effect and the pyroelectric (PY) effect have attracted significant interest for multiple applications (particle/droplet manipulation and trapping, droplet dispensing, electrowetting, orientation of liquid crystals, etc). In this context the ferroelectric surface plays a key role, and we have discovered a new interaction mechanism when ferroelectrics come into contact with other objects, exploiting the PV and PY effects. On one hand, in this work we present experimental evidence of a charge transfer between ferroelectric crystals and micro/nanoparticles in contact with their surface, driven by optical or thermal stimuli. We have thoroughly studied the influence of the type of particle (metallic or dielectric), crystal orientation, light intensity, wavelength and surrounding medium. Furthermore, although most experiments have been conducted with LiNbO3:Fe crystals, we have also tested the effect in other ferroelectrics (such as LiTaO3), thanks to the generality of the PY effect. On the other hand, we have taken this new mechanism one step further and demonstrated the feasibility of transferring PV/PY surface charge patterns to passive dielectric substrates. The procedure is simple and resembles the operation of a stamp: upon contact, part of the PV/PY charge is transferred and stored at the surface of the dielectric substrate. Those charge patterns have been exploited to massively trap and assemble micro/nanoparticles, obtaining very similar particle distributions on the active ferroelectric crystal and the passive substrate. Overall, this charge transfer phenomenon opens the way towards novel functionalities and applications of ferroelectric platforms.

Photorefractive hybrid systems / 64

A polarization-induced Rayleigh instability: Ferroelectric liquid droplets exploding on ferroelectric solid surface

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We present a study on the electrostatic behavior of ferroelectric liquid droplets exposed to the pyroelectric 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 by reducing the temperature from the nematic phase, the liquid crystal droplets become electromechanically unstable and disintegrate by the explosive emission of fluid jets. These jets are mostly interfacial, spreading out on the substrate surface, and exhibit fractal branching out into smaller streams to eventually disrupt, forming secondary droplets. We understand this behavior as a manifestation of the Rayleigh instability of electrically charged fluid droplets, expected when the electrostatic repulsion exceeds the surface tension of the fluid. In this case, the charges are due to the bulk polarization of the ferroelectric fluid which couples to the pyroelectric polarization of the underlying lithium niobate substrate through its fringing field and solid-fluid interface coupling. Since the ejection of fluid does not neutralize the droplet surfaces, they can undergo multiple explosive events as the temperature decreases.

Photorefractive hybrid systems / 21

Photoinduced Displacement of Ferroelectric Nematic Liquid Crystal droplets on the Surface of Lithium Niobate

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The recent discovery of nematic liquid crystal molecules showing a ferroelectric order has marked a breakthrough in liquid crystal science. In nematic liquid crystals the rodlike molecules align parallel to each other. However, the conventional nematic phase is not polar, as in average half of the molecules have their dipoles pointing in each of the two opposite directions associated to the director axis. On the contrary, ferroelectric nematic liquid crystals (FNLC) are polar fluids with alignment of their dipoles. In this work, we studied interaction of FNLCs with photovoltaic and/or pyroelectric fields generated on the surface of iron-doped lithium niobate crystals (LiNbO3:Fe) to induced large electric fields without requiring electrodes. When sessile droplets of a FNLC are placed onto the surface of an illuminated or heated x-cut LiNbO3:Fe crystal, intriguing dynamic processes occur. At first, the droplets change their shape from spherical to extended ellipsoidal. Then, they start to rapidly move preferentially parallel to the direction of the crystal's plus and minus c-axis. During this motion, several droplets merge into running streams extending towards the edges of the crystal. Finally, practically all liquid-crystalline material is transferred from the top surface to the side surface of the crystal. We will discuss the dependence of the described phenomena on the optical field intensity, polarization, and spatial profile, and on the temperature ramp (inducing pyroelectricity). These intriguing behaviors are reproducible and have been tested with two different FNLCs, whose ferroelectric phase exists above or at room temperature.

Optical analogues of complex phenomena / 40

Quantum-analogy-based solutions for robust photonics

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The equations describing the evolution dynamics of coupled few levels quantum system bear direct analogy with those describing several processes in classical wave optics, including the cases of evanescently coupled waveguides, polarization transformation optics, and nonlinear optical frequency conversion. This allows to exploit the same kind of robust approaches used in the quantum field in order to reach a specific target state. This talk will summarize some of our recent works in this context. The examples will involve adiabatic approaches for light transfer, mode conversion or broadband polarization selective beam splitting in waveguide optics, a simple and robust composite optical rotator for polarization optics, and composite approaches for broadband nonlinear optical frequency conversion based on segmented crystals. The usefulness of employing non-Hermitian systems involving dissipation for specific purposes will also be discussed.

Optical analogues of complex phenomena / 34

Synthetic Magnetism in Nonlinear Photonic Crystals

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The dynamics of nonlinear sum frequency generation is analogous to spin current dynamics in magnetic fields: the signal and idler complex amplitudes represent the two-dimensional spinor; the nonlinear coupling (governed by the undepleted pump and nonlinear modulation) represents the strength and direction of the magnetization; and the transverse Laplacian of the beams represent the kinetic energy. This analogy can be useful for broadband frequency conversion, for accumulation of geometric phase and its application for non-reciprocal and asymmetric beam focusing and for spin-dependent deflection, representing the nonlinear-optics analogue of the Stern-Gerlach effect. The recent breakthrough that enables now to modulate the nonlinear coefficient in all the three dimensions of the nonlinear crystal opens the door for the design and formation of skyrmionic nonlinear photonics crystals. These structures would give rise to an all-optical topological Hall effect, in which the deflection of light beams depends on the spectrum and propagation direction of the input light. Furthermore, this deflection can be optically controlled by the topological charge of the pump beam. Whereas these effects are observed with classical light beams, when a signal-idler frequency-superposition qubit is injected, new effects such as bunching of the two-photon state are revealed, thereby enabling new possibilities to control the spectral and spatial degrees of freedom of quantum light.

Optical analogues of complex phenomena / 35

Optical computation of the spin glass dynamics

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Optical computation is an emerging scheme in quantum transport, quantum simulation and machine learning. Computation exploiting light field can be performed in the time needed for a laser pulse wave-front to be shaped by a phase mask which can be as short as few femtoseconds: the calculation can performed at the "speed of light".
Spin glasses serve as prototype models, capable of providing both equilibrium and off-equilibrium nontrivial phenomenology while, at the same time, they are still hosting many open questions in modern statistical mechanics. Complex systems from diverse fields fall into the spin glass universality class: brain functions, random lasers, and quantum chromodynamics. Indeed, novel methods for the calculation of the equilibrium states and of the dynamics of a spin glass system are highly sought after.
By exploiting last-generation optical modulation devices, millions of light rays can be driven simultaneously between several states within microseconds, thus potentially providing a scalable optical platform that only needs to be built around the relevant computationally hard problem.
In a recent paper [M. Leonetti et al, PNAS 118(21), e2015207118 (2021)] we proposed an analog optical system to compute the dynamics of a given spin glass state. We observed that the overall intensity on a screen placed downstream of a strongly scattering medium shone with N coherent light rays can be formally written as a spin glass Hamiltonian, in which spin states maps on the light rays phase. We demonstrate the supremacy (speedup) of our approach with respect to digital computing.

Optical analogues of complex phenomena / 57

Optimized chaos properties from a laser diode subjected to phase conjugate feedback

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We analyze in details experimental measurements of chaos generated by a laser diode subjected to phase-conjugate feedback realized using a SPS photorefractive crystal in a CAT configuration. In addition to the typical figure of merit, ie, chaos bandwidth, the corresponding spectral flatness and permutation entropy at delay is analyzed. The experiments reveal that chaos, with a bandwidth up to 30 GHz, a spectral flatness up to 0.75, and a permutation entropy at delay of up to 0.99 can be generated. These optimized performances are observed over a large range of parameters and have not been achieved in the conventional optical feedback configuration. Interestingly, when the pump current is reduced, the chaos bandwidth is also reduced while keeping the spectral flatness and the permutation entropy. Our experimental findings are in qualitative agreement with the presented numerical simulations produced using the Lang-Kobayashi model.

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Poster session - in presence / 51

The impact of self-trapped excitons for the photophysics of lithium niobate

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Various manifestations of small polarons strongly affect the linear and nonlinear optical properties of the oxide crystal lithium niobate ($LiNbO_3$, LN). While related transient absorption phenomena in LN have been extensively studied in recent decades, a sound microscopic picture describing the blue-green (photo)luminescence of lithium niobate single crystals is still missing. In particular, almost nothing is known about: (i) the luminescence build-up and (ii) its room temperature decay.
We present here the results of our systematic experimental study using nominally undoped and Mg-doped LN crystals with different Mg concentration. Picosecond luminescence was detected by means of femtosecond fluorescence upconversion spectroscopy (FLUPS) extended to the inspection of oxide crystals in reflection geometry. Two distinct luminescence decay components on the picosecond time scale are revealed. While a short exponential decay is present in each sample, a longer non-exponential decay clearly depends on the crystal composition. Since transient absorption spectroscopy excludes geminate small polaron annihilation as microscopic cause of the luminescence, both decay components are discussed in the context of self-trapped exciton (STE) transport and decay.

Poster session - in presence / 54

Insight to small polaron kinetics in lithium tantalate

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The formation, transport and relaxation kinetics of small polarons with strong coupling have been studied intensively in lithium niobate (LN) over the last decades. The gained knowledge helped to understand the (non-)liner optical and photoelectric properties of LN on a microscopic level. The question of the transferability of these findings to other, comparable ferroelectric crystal systems has been addressed only to a limited extent.
In this contribution, we apply the small polaron approach to lithium tantalate (LT) with the goal to highlight similarities with the model system LN, but also to uncover properties being related with the individual material properties of LT, such as the inverted sign of birefringence. For this purpose, optical and nonlinear optical experimental findings - in particular obtained by means of steady-state and dynamic spectroscopy - are determined and analyzed for LT and compared with LN. The data are used to perform numerical studies for the polaronic hopping transport, that yield characteristic relaxation times of the small polaron survival propability as well as insight into the defect-modulated migration properties. A first driving result is the variation of the polaron binding energies in comparison to LN that has a strong effect on the emergent polaron behavior in LT. In particular migration and relaxation characteristics are substantially altered between the two materials and show a dominating contribution of small polarons bound to intrinsic defects even at elevated temperatures for LT. The consequences of these findings for high-temperature applications as well as the interplay with ionic transport features for temperatures $T > 500$ K are discussed.

Poster session - in presence / 32

Nonlinear Optical Effect of Natural Dyes Extracted from Hibiscus Sabdariffa with its Application as an All-Photonic Switching

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Introduction- There is an important interest and research work being undertaken by various research groups worldwide on natural dye applications due to its friendly environment and the viability and the high potential of these dyes to be used as optical materials for industrial and scientific applications. Indeed, there is a needing interesting in developing green novel hybrid photonics. All-photonic devices, in which photons instead of electrons are used as information carriers, represent the wave of the future in all-optical communications and information processing, that is required to modulate the signal light by using a pump laser beam. But, the interaction between photons is only possible in an optical material. Natural dyes can be introduced as new optical materials. The nonlinearity effect can be used for the design of all- photonic devices. In this stage, all-photonic devices can be used as a core element in constructing on-chip all-optical switch networks [1-4].

Experimental- Natural dyes extract of Hibiscus Sabdariffa (Hs) has been used for dyeing natural materials. Hs and Hs/PVA freestanding film were prepared under a simple physical method. This method is called the simple aqueous extraction method [5] (more detail will be described in the text). In this contact, we have presented and built pump-probe technique to demonstrate the possibility of realizing the all-photonic switching of Hs and Hs/PVA freestanding films.

Results and discussion- The absorption spectra of the sample freestanding films was measured using UV-visible spectrophotometer in the range of 200-800 nm. It was observed that the sample have absorbance peak at 550 nm. In addition, we studied the effect of nonlinear optical response for Hs and Hs/PVA freestanding films. Here, different nonlinear optical parameters such as the nonlinear refractive index n2 and nonlinear absorption β were determined. From the absorption coefficients α and the nonlinear optical parameters n2 and β of these dyes, two all-optical figures of merit $W=n2I/\alpha\lambda$ and $T=\beta\lambda/n2$ (I is the intensity of laser beam and λ the wavelength of laser) has been given to assess the possibility of using the natural dyes in all-photonic devices. Note that, it is shown that the all-figures of merit for Hs/PVA are higher and optimal values as compared to the Hs dye at input power. The result confirmed that the Hs/PVA can be a promising material for using to fabricate all-photonic devices.

To achieve high performance all-photonic devices of the natural dyes, different parameters are needed [1]. These parameters are the low input power, high switching contrast (SC), large modulation depth (MD), and fast switching time (ST). The devices with high MD and SC and fast ST with optimum power for Hs/PVA were achieved.

Conclusions- The results confirmed that the presented and built pump-probe technique was effective and able to pump the natural dyes and control the parameters (MD, SC, and ST). Natural dyes extracted from the Hibiscus Sabdariffa were used as natural photonic media for all-photonic devices. The all-photonic devices based on Hs/PVA have shown the best performance. The obtained results could open the way for further and future prospective studies among natural dyes with nanomaterial or other dyes in developing all-photonic devices and using as sensitizers for solar cell devices.

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Poster session - in presence / 49

Electronic balls and photonic clubs in photogalvanic lithium niobate: a first principles approach

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The photogalvanic effect (PGE) consists in the spontaneous production of a bulk electrical current density in a polar material when the latter is illuminated [1]. This effect triggers several phenomena which are at the basis of important applications such as photorefraction, photovoltaic energy conversion in photoferroelectrics, photocatalysis and so on [2,3,4].
Despite the fact that a microscopic understanding of the PGE is nowadays quite achieved, it still relies on a few phenomenological parameters. In particular the thermalization length, describing the absolute average distance from the emitting site at which a photo-excited charge self-localizes into a polaron, cannot be obtained from experiments and at the same time it is the critical parameter ruling the photogalvanic properties of a given material.
In this work we present a mean-field approach [5] to describe the energy loss of the photoemitted charge interacting with the phonon bath of the material, which allows us to compute the thermalization length. Our results are applied to the technologically important case of lithium niobate [6]. Using our method we can reproduce the wavelength dependence of the PGE and compare the obtained results with experimental data [7].

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Poster session - in presence / 55

NIR-to-NIR-imaging via polar oxide nanoparticles

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Polar oxide nanoparticles like LiNbO3, KNbO3 or NaNbO3, are of increasing interest as multimodal markers in biological environment thanks to the their pronounced electro-optical, piezo-electrical, pyro-electrical, photorefractive and nonlinear optical effects. For instance, the latter one allows for a particular type of multiphoton imaging (non-bleaching, non-blinking, high-contrast, etc.) where the established fluorescent nanomarker fails. The further effects are promising for the context of optogenetics, e.g. in the framework of the manipulation of the cellular environment via the electrostatic field.

The possibility to trigger two or more of these effects simultaneously make polar oxide nanoparticles a unique biocompatible marker platform. From the scientific viewpoint, an advantage is the comprehensive know-how on the photophysical effects gained over several decades in bulk single crystals. It provides an outstanding basis for the study and application of these nanoparticles in this emerging field of application.

In this presentation we focus on the nonlinear optical characterization of polar oxide nanoparticles - and in particular on second and third harmonic generation. The analysis reveals that the harmonic emission can be continuously tuned to every wavelength in the UV/VIS, but also NIR for pumping up to 2400 nm. These results find their more important applications in-vivo imaging. Indeed, in the IR region the tissue shows reduced light scattering and absorption potentially permitting to perform deep-tissue imaging with the lowest light-induced damage. It is interesting to notice that the use of infrared light beyond 1700nm is not possible with other nanomarkers, offering a unique solution for NIR-to-NIR imaging.

Poster session - in presence / 60

Optical response of the newly discovered hexagonal phase of Ta2O5 (calculated) from first principles

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Ta2O5 is known as a relatively chemically inert material with high density and high refractive index. It has low absorption and is therefore usually employed in optical coatings for applications from near-UV to near-IR, e.g. for mirror coatings in gravitational-wave detectors.

Experimental studies of thermically produced nanocrystals in amorphous Ta2O5 thin films indicate a new crystalline phase of Ta2O5. These crystals were characterized by Grazing Incidence X-Ray Diffraction (GIXRD). The phase has a hexagonal structure with cell parameters of around 7.2 Å and 3.8 Å. The unit cell includes four Tantalum and ten Oxygen atoms as shown in Fig.1.

This new phase is modeled from first principles in the framework of the Density Functional Theory (DFT) as implemented in VASP [1]. In this work we present, besides the ground state structural properties, the optical response of the newly proposed hexagonal Ta2O5 phase. The optical properties are calculated with different approaches of different precision, ranging from the independent

particle approximation to the GW-approach. Additionally, we compare the optical responses of the new hexagonal phase with those of known phases of Ta2O5, e.g. orthorhombic and monoclinic phases.

First results indicate remarkable differences between the investigated phases regarding their linear optical responses. Therefore, it should be possible to differentiate between crystal structures of Ta2O5 by optical measurements, e.g. by comparing their absorption spectra.

In addition, we analyze non-linear optical properties of the hexagonal phase, e.g. THG.

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Poster session - in presence / 59

Optical response of strained LiNbO3 crystals from first principles

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As X-ray measurements have shown, domain walls in $LiNbO_3$ exhibit the structure of compressed bulk material [1]. Hence, knowledge of the optical response of $LiNbO_3$ as a function of compression can help to characterize the domain walls of $LiNbO_3$ and yields information about their optical signatures.

In our work, we model linear and non-linear optical properties of $LiNbO_3$ in dependence on uniaxial compressive strain in x-, y- and z-direction from first principles using time-dependent density functional theory (TDDFT) [2]. This includes the calculation of the energy dependent second (SHG) and third harmonic generation (THG). We find changes for all components of the second- and third-order polarizability tensor χ^2 and χ^3. In particular, for $|\chi^2_{zzz}|$ we obtain a linear increase with applied compression in z-direction. Due to the threefold rotational symmetry, $LiNbO_3$ has four independent χ^2 elements [3]. However, compression in x- and y-direction reduces the symmetry, lifting the degeneracy of identical χ^2 components. Additionally, from the calculated dielectric tensor the refractive index and birefringence as a function of compression is obtained. Knowledge of both these properties under compression is particularly important for the application of Ti waveguides.

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Poster session - in presence / 58

Composition dependent optical properties of LiNb_xTa_(1-x)O3 solid solutions

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Lithium niobate (LN) and lithium tantalate (LT) are ferroelectric crystals with a wide range of applications, extending from piezoelectric sensors to integrated photonics. Their structural similarities enable the combination of these materials to $LiNb_xTa_{1-x}O_3$ (LNT) alloys. As the optical absorption edge depends on the stoichiometry, it can be used to determine the crystal composition non destructively.
\\
Here, we use special quasi-random structures to simulate LNT crystals with different compositions. These structures mimic an ideal random alloy, even when periodic boundary conditions are employed. Furthermore, we use the Li-vacancy model as well as the Nb-antisite model [1] to simulate congruent LN crystals, as they are commonly used in experiments.
\\
We calculate the first order dielectric tensor of these materials by combining density-functional theory with the indepent particle approximation. A clear correlation between the absorption edge and the Li-concentration of LN can be seen, as it has been described in [2]. Modifications of the electronic band structure, can be attributed to the absence of Li-2s states near the fundamental band gap.
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Poster session - in presence / 9

Three modes of the nonstationary holographic current excitation in a gallium oxide crystal

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Monoclinic gallium oxide β-Ga_2O_3 demonstrates an interesting combination of physicochemical parameters which advance its application in modern electronics and optics. The crystal with the band gap of ~ 4.8 eV is transparent in the range from visible to near UV light, that is why the material is suitable for the implementation of solar-blind detectors of deep ultraviolet radiation. The material is characterized by the high breakdown field (6-8 MV/cm), moderate electron mobility and good thermal stability, which make it very engaging for production of radio frequency and power field-effect transistors, as well as Schottky rectifiers.
Recently we applied the non-steady-state photo-EMF technique for characterization of β-Ga_2O_3 crystal in the green spectral region. In this research we continue the investigations of β-Ga_2O_3 at $\lambda = 457$ nm. The material demonstrates insulating properties and high transparency for the chosen wavelength, but this, however, does not prevent the dynamic space-charge grating formation and the holographic current observation for various external electric fields - zero, dc and ac ones. These recording modes correspond to the non-local and local response of a photosensitive medium, thus their joint investigation is of great importance for a better understanding of photoelectric phenomena and utilization scopes for the studied material. The holographic current amplitude is measured and analyzed versus the frequency of phase modulation, spatial frequency and electric field value. The main photoelectric parameters such as specific photoconductivity, sensor responsivity and diffusion length of carriers are determined for the blue region of spectrum.

Poster session - in presence / **53**

NLO characterization of harmonic LNT nanoparticle pellets by means of nonlinear diffuse fs-pulse reflectometry

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Lithium niobate tantalate solid solutions ($LiNb_{1-x}Ta_xO_3$, LNT) represent a promising material system for nonlinear photonics and quantum technologies. It is because their nonlinear optical and photophysical properties can be selectively tuned by composition ($0 < x < 1$) from the properties of the edge compositions lithium niobate (LN, x = 0) and lithium tantalate (LT, x = 1). So far, the exact relationship between composition and material properties, and especially with respect to the nonlinear optical properties, is poorly understood. One of the reasons is the availability of LNT bulk crystals with high optical quality. Thus, it is particularly unclear so far whether LNT crystals can be used for frequency conversion at all.
To address this question, we have studied LNT nanopowder samples [provided by the Institute of energy Research and Physical Technologies, Clausthal. See also: Vasylechko et al., crystals **2021**, 11, 755] using the method of nonlinear diffuse fs-pulse reflectometry. The advantage of this method is the possibility to obtain a quantitative measure, called 'harmonic ratio' about the frequency conversion properties of materials that are only available as powder samples. Thus, the fulfillment of a phase matching condition below a characteristic particle size is not required.
The paper shows the methodological requirements for this type of studies, the procedure of sample preparation, the obtained results for LN, LT and LNT crystals and explains the determination as well as the impact of the 'harmonic ratio' as a qualitative quality factor of the powder samples. The influence of the particle properties (size distribution, pellet thickness, etc.) but also of the pulse parameters (pulse duration, pulse peak intensity, etc.) is discussed. The results are compared with data from X-ray structure analysis. The possibility to tune second harmonic emission within the visible and near-infrared spectral range is successfully demonstrated.

Poster session - in presence / **27**

Real-time manipulation of microparticles in aqueous media by photovoltaic optoelectronic tweezers operating at high light intensities

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Photovoltaic optoelectronic tweezers (PVOT) have emerged as a powerful tool for the manipulation of a wide variety of micro/nano-objects (particles, liquid droplets, bubbles or biological material) based on the electric fields induced by the bulk photovoltaic effect, often using LiNbO3:Fe crystals. Nevertheless, the manipulation of such objects in aqueous media has remained mostly elusive so far, due to the fast screening of electrostatic fields in water. Even in the case of ultrapure Milli-Q water, with a resistivity of 18 MΩ·cm at room temperature, the photovoltaic electric fields are screened in around ~100 µs, thus hindering the proper functioning of PVOT. However, water is ubiquitous in biological environments, where it plays a vital role. Therefore, the successful operation of PVOT in water is of remarkable interest for potential applications in biotechnology or biomedicine, among

others. In this work, we show that it is feasible to employ PVOT in distilled water by using simultaneous light excitation with high intensities (around ~1 kW/cm2). At such intensities, the screening time of water is not negligible compared with the photovoltaic buildup time, allowing for the generation of an evanescent electric field. (which persists as long as light excitation is maintained). When light is switched off, the evanescent field rapidly fades away, allowing us to carry out dynamic real-time manipulation, very constrained in nonpolar liquids due to the long lifetime of the electric fields in the dark. Fruitful results with both z-cut and x-cut LiNbO3:Fe crystals have been accomplished, achieving a long-sought milestone for PVOT.

Poster session - in presence / 31

High-Performance Co-Doped Photorefractive Sn2P2S6 Crystals

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The Sn2P2S6 crystals are known as efficient photorefractive materials, that can be efficiently modified by their doping. Our recent works are directed to a search for the new efficient dopants and their combinations, which are provided by two methods: growth in the presence of two types of the impurities, and by the indiffusion of the metals (Cu, Ag) into previously grown samples. In the communication, we present the results of the complex investigations of the optical and photorefractive parameters of the various co-doped Sn2P2S6 crystals.
It was found that the most promising for photorefractive applications is the co-doping of Sn2P2S6 by Cu+Sb. The main advantage of this composition is the single-exponential dynamics of the photorefractive response when the formation of the space-charge grating occurs practically without the compensation processes that are usually observed in other doped Sn2P2S6 crystals. The experimental results correlate with ab initio calculations of the electron spectra in the Sn2P2S6 with two defects (Cu and Sb), showing that they both probably are forming the single defect electron level in the gap. These co-doped crystals also demonstrate a high enough two-wave mixing gain at 633 nm, which allows realizing various photorefractive schemes on their base. This is illustrated by studying the performances of two optical schemes: the dynamic interferometer based on the two-wave mixing, and the semi-linear oscillator scheme with high efficiency and low generation threshold compared with other doped Sn2P2S6 compounds.

Poster session - in presence / 68

Optofluidic platform for the manipulation of water droplets on engineered LiNbO3 surfaces

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The actuation of liquid droplets on a surface has important implications in many industrial applications and microfluidics. The reproducible motion of water droplets on solid surfaces is very difficult to achieve because of the presence of surface defects. Bioinspired liquid-infused surfaces (LISs),

made of textured materials imbibed with a low surface tension oil, exhibit various unique properties attributed to their liquid-like nature. In particular, they enable low friction droplet motion.
In this work, droplet actuation is achieved by exploiting the photovoltaic effect of iron-doped lithium niobate (Fe:LiNbO3): when the crystal is illuminated, charges of opposite sign accumulate on the two faces of the crystal. This effect allows to create virtual and reconfigurable electrodes, that can be exploited to achieve droplet manipulation. The face of LiNbO3 in contact with the droplets is coated with the LIS to create a low friction surface. We have realized LISs impregnating a porous Teflon filter with a fluorinated oil using a dip-coater to ensure high reproducibility. This process allows one to obtain very slippery hydrophobic surfaces for prolonged use. Their performances are tested by analyzing the motion of repeated sequences of water droplets with different volumes and deposited on a sample tilted at different angles; it is found the LIS can be used safely for the motion of thousands of droplets. In this way, sessile water droplets having volumes of microliters, corresponding to millimeters in size, can be easily actuated, guided, merged and split by the projection on the crystal of suitable static or dynamic light patterns.

Nonlinear light-matter interaction and applications / 50

Polar oxide nanomaterials - an emerging playground in photophysics

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The manifold photophysical properties of polar oxide crystals have driven the research field of photorefraction for decades to a large extent. With the availability of nanoscale polar oxide model systems, the question arises to what extent the acquired knowledge remains applicable for crystals with dimensions on length scales of micro- and nanometres, i.e. in the order of magnitude of the photovoltaic transport length. A number of phenomena can be predicted from the application of knowledge from nanosciences, such as the disappearance of second-order photophysical effects with the collapse of spontaneous polarization at crystallite sizes on the sub 5-nm length scale (size effect).

However, there are also phenomena that so far have no analogue in other model systems, such as the self-localization of charge carriers with strong coupling as small polarons and their hopping-like transport in strongly confined structures. Questions about the rising influence of the nanocrystals' surface on the self-localization or the lifetime of polarons as a function of the crystallite size have not been studied, nor have the properties of the photogalvanic effect - up to the photorefractive effect - in nano- and microstructured polar oxide material systems.

The talk gives an overview of: (1) selected examples of progress in the synthesis of polar oxide nanomaterials of the last years, (2) specifically developed methods for nonlinear optical characterization of respective samples, (3) phenomena unambiguously resulting from the effect of length scale reduction and (4) perspective application areas.

Nonlinear light-matter interaction and applications / 56

Small polaron hopping in Fe:LiNbO3 from microscopic modelling to macroscopic observables

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Lithium niobate is nowadays one of the most used ferroelectrics oxides in the realization of optical modulators, waveguides and optical sensor due to its large acousto-optical, electro-optical and nonlinear optical coefficients. Further tailoring of these applications requires a deeper scientific insight to the relation between the microscopic structure and the macroscopic observables.
In this framework, it is already accepted that the photophysical charge transport properties can be understood to a large extend in terms of small polaron hopping. Carriers are photo-generated from deep donor centers in the first step and subsequently emitted with a preferential direction in the conduction band. Here, they lose energy by interaction with the lattice and condensate into a new state, self-localizing in the structure via distortion of the local ionic environment, i.e. a polaron is formed. According on which site the charge is localized at, different types of polarons can be distinguished. Each of them can later move by thermal assisted hopping among different sites, until a deep trap is encountered.
Despite this advanced level of understanding, there is still a lack of knowledge on the relation between the macroscopic observables such as polaron mobility and lifetime with the basic polaron hopping processes. In this contribution we try to fill this gap by combining experimental results with numerical analysis based on Monte Carlo methods.

Nonlinear light-matter interaction and applications / 52

Time resolved sum-frequency generation in harmonic LiNb1-xTaxO3 (LNT) nanoparticle pellets

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Harmonic nanoparticles (HNPs) are of wide spread interest in the context of material science applications due to their large nonlinear optical (NLO) tensorial elements and their broad spectral tunability [1]. Regarding the investigation of time-dependent phenomena, however, a detailed knowledge of the pulse propagation in such a strongly scattering medium is required. This has so far only been investigated to a limited extend [2]. In an attempt to close this vacancy, we herein present an experimental investigation of the temporal evolution of ultrashort pulses inside HNPs.

This is enabled by means of nonlinear diffuse fs-pulse reflectometry measurements combined with a pump-probe scheme to monitor the time-resolved sum-frequency generation of two differently coloured, ultrashort pulses inside densely packed HNP pellets [3,4]. Special emphasis is devoted to the comparison of LNT solid solutions in varying compositions. We discuss the effects of different size distributions and NLO properties on the pulse propagation inside the pellets.

In addition, numerical studies on the pulse propagation due to multiple scattering inside the media are performed to consolidate the experimental results, on the one hand, and allow to make predictions with regard to particle size and wavelength dependencies, on the other hand [4].

These results can be utilized for the employment of HNP pellets as a novel tool for fs-pulse characterization (e.g. chirp determination).

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Nonlinear light-matter interaction and applications / 17

Slowdown of nanosecond light pulses without distortion in a SPS crystal

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Slow light has been observed in several physical systems, including optical fiber, and photorefractive (PR) media. The ability to slow down light pulses is a fascinating phenomenon with important applications, such as optical telecommunications. For that, it is essential that the slow light phenomenon has a large bandwidth, so that it can respond quickly to the short light pulses that will carry the data. However, in the PR crystal, only light pulses of the order of milliseconds or seconds have been slowed down, and because of the high dispersion, they are broadened at the output of the PR crystals [1], leading to loss of information.

Recently, we have demonstrated that the two-wave mixing (TWM) effect in the pulsed regime can slow down nanosecond light pulses in a PR SPS crystal [2]. This is possible only if the laser intensity is high enough to reduce the crystal response time to the value of the input pulse duration. Here, we show that by optimizing the TWM in the pulsed regime, nanosecond light pulses can be slowed down without suffering from broadening. For a coupling strength of 5 and response time of 32 ns, pulses of 20 and 70 ns can be delayed respectively by 2 et 15 ns.

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Nonlinear light-matter interaction and applications / 41

Polarization dependent second-harmonic generation in cascaded optically poled fibers

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Commercial Ge-doped silica fibers can be converted into frequency doublers, despite the lack of quadratic nonlinearity of the glass, by employing optical poling. With this technique, injecting high-intensity fundamental frequency pulses into the fiber generates photoinduced currents leading to a static electric field resulting in an effective second-order nonlinearity that satisfies the quasi-phase-matching condition. For instance, a poled 1 m long Ge-doped fiber can generate the second-harmonic (SH) of 1064 nm pulses with an average conversion efficiency of about 1%. However, the conversion efficiency is limited by the difficulty of preserving the polarization of the fundamental light used during the poling process over the entire fiber length. Also, a limitation comes from the short extent of the poled region obtained by the optical poling, which is typically around 60 cm, regardless of the actual length of the fiber undergoing the poling process. Our experimental work demonstrates that these limitations can be partially overcome by resorting to a circularly polarized fundamental field to independently pole a number of fiber sections and then by cascading poled fiber segments. The segments can be cascaded either by splicing using a fusion splicer or by connectorizing the fibers and then mating the connectors. Although the SH power is a quadratic function of the propagation

distance within a single segment, we observed that the SH obtained by cascading a small number of segments (up to 5) grows approximately linearly with their number.

Nonlinear light-matter interaction and applications / 18

Controllable waveguiding structures induced by diffracting Bessel beams in a nonlinear medium

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Due to their unique profiles and fascinating propagating phenomena unconventional beams like Airy beams are good candidates for photo-inducing waveguiding structures in a photorefractive medium. Bessel beams (BBs) share similar features with Airy beams, such as diffraction-free, multi-lobes profiles, and self-trapping property under nonlinear conditions. Thus, several studies on waveguides induction using non-diffracting BBs under weak nonlinearity have been developed [1]. Instead, our recent work unveiled that diffracting BBs propagating under high nonlinear conditions provide more advantages and opportunities for the light-induction of waveguiding structures.
In our work, we experimentally and numerically demonstrate that only one single diffracting BB can induce complex 3D waveguides with up to 9 outputs in a biased photorefractive SBN crystal. By tuning parameters such as the incoming BB size, the applied electric field, the input beam power, and the background illumination, our optical platform enables all-optical control of the output intensity levels and tailors the stability of each channel.
Furthermore, we demonstrate that the truncation and the order of the incoming BB are also two crucial parameters for adjusting the number of inputs/outputs channels [2]. Finally, numerical results of two counterpropagating BBs are also presented. These results show advantages of using two BBs to obtain higher guiding efficiency, more complex waveguiding configurations and consequently further possibilities for all-optical interconnects.

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Nonlinear light-matter interaction and applications / 45

Conical diffraction cascades and interplay with linear and nonlinear material properties

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Internal conical diffraction is a well-known singular phenomenon observable whenever a tightly focused wave is incident with its wavevector along one of the two optical axes of an optically biaxial crystal. The effect gives rise to a vector type wave with the Poynting vectors associated to each linear polarization component lying on a slanted cone surface with circular base. The number of these

cones can be multiplied by a factor 2^{N-1} if a cascade of N biaxial crystals with perfectly aligned optical axes is considered. However, as it will be discussed in this contribution, a dramatic change in the shape of the conical diffraction vector beams can be achieved if a proper manipulation in wavevector space is performed between the different crystals in a cascade. Highly peculiar non-circularly shaped vector beams can be obtained, some of which associated to a reversed curvature as compared to the one proper to circles. While the main effect is due to the material birefringence, conical diffraction in both single step and cascaded configurations is influenced also by other linear and eventually nonlinear optical properties of the involved crystals (optical activity, photoinduced effects, …). Such an interplay is discussed in the case of photorefractive $Sn_2P_2S_6$ crystals, as compared to standard materials commonly used for conical diffraction, such as centrosymmetric $KGd(WO_4)_2$.

Signal processing and photonics / 65

planary session

Poster session - in presence / 37

Nonlinear Optical Effect of Natural Dyes Extracted from Hibiscus Sabdariffa with its Application as an All-Photonic Switching

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Nonlinear Optical Effect of Natural Dyes Extracted from Hibiscus Sabdariffa with its Application as an All-Photonic Switching
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Introduction- There is an important interest and research work being undertaken by various research groups worldwide on natural dye applications due to its friendly environment and the viability and the high potential of these dyes to be used as optical materials for industrial and scientific applications. Indeed, there is a needing interesting in developing green novel hybrid photonics. All-photonic devices, in which photons instead of electrons are used as information carriers, represent the wave of the future in all-optical communications and information processing, that is required to modulate the signal light by using a pump laser beam. But, the interaction between photons is only possible in an optical material. Natural dyes can be introduced as new optical materials. The nonlinearity effect can be used for the design of all- photonic devices. In this stage, all-photonic devices can be used as a core element in constructing on-chip all-optical switch networks [1-4].

Experimental- Natural dyes extract of Hibiscus Sabdariffa (Hs) has been used for dyeing natural materials. Hs and Hs/PVA freestanding film were prepared under a simple physical method. This method is called the simple aqueous extraction method [5] (more detail will be described in the text). In this contact, we have presented and built pump-probe technique to demonstrate the possibility of realizing the all-photonic switching of Hs and Hs/PVA freestanding films.

Results and discussion- The absorption spectra of the sample freestanding films was measured using UV-visible spectrophotometer in the range of 200-800 nm. It was observed that the sample have absorbance peak at 550 nm. In addition, we studied the effect of nonlinear optical response for Hs and

Hs/PVA freestanding films. Here, different nonlinear optical parameters such as the nonlinear refractive index n2 and nonlinear absorption β were determined. From the absorption coefficients α and the nonlinear optical parameters n2 and β of these dyes, two all-optical figures of merit W=n2I/αλ and T=βλ/n2 (I is the intensity of laser beam and λ the wavelength of laser) has been given to assess the possibility of using the natural dyes in all-photonic devices. Note that, it is shown that the all-figures of merit for Hs/PVA are higher and optimal values as compared to the Hs dye at input power. The result confirmed that the Hs/PVA can be a promising material for using to fabricate all-photonic devices.

To achieve high performance all-photonic devices of the natural dyes, different parameters are needed [1]. These parameters are the low input power, high switching contrast (SC), large modulation depth (MD), and fast switching time (ST). The devices with high MD and SC and fast ST with optimum power for Hs/PVA were achieved.

Conclusions- The results confirmed that the presented and built pump-probe technique was effective and able to pump the natural dyes and control the parameters (MD, SC, and ST). Natural dyes extracted from the Hibiscus Sabdariffa were used as natural photonic media for all-photonic devices. The all-photonic devices based on Hs/PVA have shown the best performance. The obtained results could open the way for further and future prospective studies among natural dyes with nanomaterial or other dyes in developing all-photonic devices and using as sensitizers for solar cell devices.

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Holography, optical processing and imaging / 8

Photorefractive holography for optical reconstruction of structured light

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This work presents the photorefractive holography possibilities of the optical reconstruction of structures light. In PRH, the hologram of a non-diffracting beam is optically constructed ('recording') and reconstructed ('reading') in a nonlinear photorefractive medium. The experimental realizations of many types of the structured light, for instance: non-diffracting beams, vortex beams and othes structured light, are made in a photorefractive holography setup using a photorefractive crystal as the holographic recording medium. The results are in agreement with the theoretical predictions and are presenting excellent prospects for the implementation of this technique in dynamical systems with applications in optics and photonics.

Materials micro- and nano-engineering / 66

Plenary session

67

Special session