FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

European Commission

SPINONICS MSCA Individual Fellowships

Online workshop on structured light and its applications

November 7-8th 2022

organized by the Institute of Applied Physics, Friedrich Schiller University Jena, Germany

Organizers

Dr Jisha Chandroth Pannian

Dr Alessandro Alberucci

Prof Dr Stefan Nolte

Institute of Applied Physics
Friedrich-Schiller-Universität Jena

MAX PLANCK SCHOOL of photonics

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA Abbe Center of Photonics

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FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

European Commission

MSCA SPINONICS Individual Fellowships

Workshop on **Structured light and its applications**

7-8th November 2022

Virtual meeting organized by the Institute of Applied Physics, Friedrich Schiller University Jena, Germany

Invited Speakers

Andrea Alù, **Plenary talk (CUNY, USA)**

Alessandro Alberucci
(UniJena, Germany)
Andrea Blanco-Redondo
(Nokia Bell Labs, USA)
Jeroen Beeckman
(UGhent, Belgium)
Ileana-Cristina Benea-Chelmus
(EPFL, Switzerland)
Jennifer Dionne
(Stanford, USA)
Natalia Litchinitser
(Duke Univ, USA)
Lorenzo Marrucci
(Univ of Naples, Italy)
Stefan Nolte
(UniJena, Germany)
Thomas Pertsch
(UniJena, Germany)

When: 7-8th Nov 2022
Where: Online
Deadline: 10th Sept 2022

Organizers

Jisha Chandroth Pannian
UniJena, Germany
Stefan Nolte
UniJena, Germany
Alessandro Alberucci
UniJena, Germany

The Friedrich Schiller University Jena is organizing a two-day workshop on structured light and its applications. The workshop aims to foster exchange of ideas and disseminate the state of the art in the field of structured light. By including different aspects of the vast field of structured light, the goal is to provide a comprehensive view on this exciting topic, to nurture new ideas by the meeting of specialists in different sub-fields, and eventually to pave the way to new collaborations between researchers with complementary expertise.

The workshop is intended both for established and young researchers -PhD students, early stage researchers and highly motivated Master students- who want either to learn how to exploit all the degrees of freedom of a light beam for their own research, or to find new ideas to pursue along their academic career.

We invite submissions in the general area of structured light with topics including but not limited to:

Sub-wavelength design of photonic devices

Optical angular momentum and its manipulation

Structured beams for optical tweezing

Complex polarization states for information processing in the classical and in the quantum regime

Geometric phase in optics

Spin-orbit interaction in photonics

Tunable beam shaping using liquid crystals

Optical metasurfaces for beam shaping

Nonlinear optics with structured beams

Light-matter interaction with structured beams

To register fill out the Google Forms using this link or through the QR code.

Participation in the following forms are possible: Oral presenter, Poster presenter or Attendee.

Oral and Poster presenters should submit a 300 words abstract after registering.

Best Poster award sponsored by SPIE-OPTICA student chapter

Website: https://www.iap.uni-jena.de/sla

Contact : jisha.chandroth.pannian@uni-jena.de

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Online Workshop on Structured Light and its Applications

https://uni-jena-de.zoom.us/j/63769750845

Meeting ID: 637 6975 0845

Passcode: 989399

GatherTown link for poster presentation and networking

https://app.gather.town/app/EwNZfrvjk16XymuU/StructuredLight

		November 7 Monday	November 8 Tuesday
0855 - 0900		**Welcome**	
0900 - 1040	0900 - 0930	**Lorenzo Marrucci**, Università di Napoli Federico II, Italy Photonic quantum walks with structured light for quantum simulations	**Jeroen Beeckman**, UGhent, Belgium Liquid crystal technology for geometric phase optics
	0930 - 0950	**Jer-Shing Huang**, Leibniz-IPHT, Jena Chiral Structured Illumination Microscopy	**Vincenzo D'Ambrosio**, Università di Napoli Federico II, Italy Ultra-sensitive measurement of transverse displacements with photonic gears
	0950 – 1005	**Niladri Modak**, IISER Kolkata, India Emerging aspects of optical beam shifts	**Praveen Kumar**, Chiba University, Japan Dual-pass phase modulation approach to generate structured light
	1005 – 1020	**Muhammad Waqar Iqbal**, Université de Lorraine Structured vector beams via conical diffraction cascade	**Grant W. Henderson**, University of Strathclyde, UK Structuring ultracold atoms with light
	1020 – 1035	**Vittorio Aita**, King's College London, UK Focused complex beams interacting with strongly anisotropic metamaterials	**Sinuhé Perea Puente**, King's College London, UK Passive structured metasurface for anomalous penetrating transmission through an opaque material
1040- 1100		Coffee Break	
1100 - 1230	1100 - 1130	**Ileana-Cristina Benea-Chelmus** EPFL, Switzerland Gigahertz speed electro-optic metasurfaces	**Thomas Pertsch**, UniJena, Germany Controlling light by nanostructured metasurfaces for applications ranging from UV to IR
	1130 - 1150	**Bruno Piccirillo**, Università di Napoli Federico II, Italy Generating polarization monstar disclinations based on a geometric approach	**Spencer Jolly**, ULB, Brussels Spatio-temporally structured light
	1150 – 1205	**Shreyas Ramakrishna**, UniJena Germany Photo-excitation of atoms by cylindrically	**Venugopal Raskatla**, NIT Warangal, India

		polarized Laguerre-Gaussian beams		Speckle-based Recognition of Orbital Angular Momentum Modes
	1205 - 1230	3 minutes Poster Talk		
1230 - 0230		**Poster presentation @GatherTown** - Lunch Break - Networking		
0230 - 0345	0230-0315	**Andrea Alù**, CUNY, New York Nonlocal metasurfaces	0230-0300	**Stefan Nolte**, UniJena, Germany Structured light for ultrashort pulse materials processing
	0315-0345	**Natalia Litchinitser**, Duke Univ, USA Topology of light and darkness in engineered optical media	0300-0330	**Andrea Blanco-Redondo**, Nokia Bell Labs, USA Topological quantum nanophotonics
			0330-0345	**Stree Vithya Arumugham**, UniJena, Germany Waveguides based on spin-orbit interaction
0345 - 0400		Coffee Break		
0400 - 0540	0400-0420	**Filippo Cardano**, Università di Napoli Federico II, Italy Ultra-long quantum walks via spin-orbit photonics		**Maria Del Mar Sanchez Lopez**, Universidad Miguel Hernández, Spain Tailoring depolarization spatial patterns with a liquid-crystal SLM
	0420-0440	**Raouf Barboza**, Università Politecnica delle Marche, Italy Geometric Phases and beam structuring with liquid crystals photonics		**Battulga Munkhbat**, DTU Fotonik, Denmark Nanostructured transition metal dichalcogenide multilayers for advanced nanophotonics
	0440-0455	**Sandra Mamani**, City College CUNY, USA OAM Multipoles Polarized Light-Matter Interaction		**Verónica Vicuña-Hernández** Università di Napoli Federico II, Italy Orbital angular momentum broadening in Poincaré beams
	0455-0510	**Amala Raj**, Indiana University Bloomington, USA Orbital Optical Trapping at Atmospheric Pressure		**Sebastian Linss**, UniJena, Germany Wave-optical simulation of macroscopic dielectric metasurfaces
	0510-0540	**Jennifer Dionne**, Stanford Univ, USA Emerging nanophotonic platforms for environmental and human health monitoring: Re-imaging the conventional microbiology toolkit		**Alessandro Alberucci**, UniJena, Germany Influence of geometric phase on the propagation of optical waves
0540-0545				**Best poster award** **Concluding Remarks**

Poster Presentations – Day 1

Felipe Almeida, Pontifícia Universidade Católica do Rio de Janeiro	Optical Bottle Beam
Mouli Hazra, Institute of Optics and Quantum Electronics, UniJena	Nonlinear polarization holography of metal nanolayer
Esther Nabadda, Universidad Miguel Hernández de Elche, Spain	Retrieving the phase distribution of structured light beams by a self-interferometric technique
A. Ustinov, Institute of Solid State Physics, UniJena	Linear and second-order response of metamaterial-inspired resonant waveguides hybridized with transition metal dichalcogenides
Sharareh Jalali, Urmia University, Urmia, Iran	Study of the superposition of optical vortex beams
S Ashutosh, Department of Physical Sciences, IISER, Kolkata, India	Non-separability and classical entanglement through optical beam shifts
Aiham Rostom, Institute of Automation and Electrometry SBRAS, Novosibirsk, Russia.	Beyond the weak value: optimal post selected quantum metrology
Zhan-Hong Lin, Leibniz Institute of Photonic Technology, Jena, Germany	Plasmonic elliptical nanoholes for chiroptical analysis and enantioselective optical trapping

Poster Presentations – Day 2

Athira Kuppadakkath, UniJena, Germany	Effect of gradual heating on quasi-BIC dielectric metasurface
Andrea Vogliardi, University of Padova, via Marzolo 8, 35131 Padova, Italy	Metaoptics for the controlled generation of orbital angular momentum vector Beams
Rohit Kumar, Indian Institute of Technology Patna, Patna	Observation of narrow EIT linewidth in Rubidium – 85 atomic system at room temperature vapor medium in presence of structured coupling beam
J. L. M. Villanueva, Universidade Federal de Itajubá, Brazil.	Influence of the electrolyte and etch-stop time upon the optical response of 1D-porous silicon photonic crystal structures
M. C. Alonso Casimiro, Instituto Nacional de Astrofísica, Óptica y Electrónica, Mexico	Generation of periodic and quasi-periodic two-dimensional non-diffractive beams with inhomogeneous polarization
Dixith Manchaiah, Indian Institute of Technology Patna, Patna	Interplay of polarizations and vortex in a cascade EIT system of 87 Rb atomic vapor medium
Jeetendra Gour, UniJena, Germany	Fabrication of sub 5-nm plasmonic nano-gap structures for extreme confinement of optical fields
Sebastian Beer, UniJena, Germany	Investigation on surface lattice resonance enhancement of SHG in plasmonic metasurfaces

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Ultra-long quantum walks via spin-orbit photonics

Filippo Cardano, Universita di Napoli Federico II, Italy

Processing quantum information encoded into spatial modes of light proved instrumental for a number of quantum applications. In the context of quantum simulation, dynamical evolutions of particles in complex lattices have been realized in different platforms, where photonic modes are judiciously coupled to let the optical field evolve like the target system. This in turn has led to the observation of many interesting phenomena, like exotic topological phases, localization effects or non-Hermitian physics. Here we introduce a photonic setup that allows to generate quantum walks in the space spanned by optical modes carrying quantized transverse momentum. The action of the evolution operator is realized via light propagation through patterned devices yielding space-dependent polarization transformations. Based on the concept of Pancharatnam-Berry phases, these transformations allow to shape the field wavefront and polarization structure, so as to mimic the effect of the target evolution. This modulation is achieved through birefringent liquid-crystal metasurfaces, made of a micrometric layer of liquid-crystal material having patterned optic axes. These provide a generalization of well-known q-plates. By engineering metasurfaces having fastly varying optic axes, we can generate long evolutions (equivalent to hundreds of time-steps) via a few optical elements, thus keeping optical losses at minimum. In standard setups, indeed, the number of resources scales at least linearly with the number of simulated time-steps, thereby introducing an exponential attenuation of traveling photons. In our experiment, we successfully realize up to 320 time-steps quantum walks, going far beyond state-of-the-art implementations of this dynamics. To demonstrate the potential of our platform, we generate disordered quantum walks to realize maximal entanglement between the two natural partitions of the system, which was earlier investigated theoretically but not achieved experimentally hitherto. Our work is part of a larger effort to leverage structured light and its accurate manipulation for photonic quantum technologies.

Photonic quantum walks with structured light for quantum simulations

Lorenzo Marrucci, Università di Napoli Federico II, Italy

Chiral Structured Illumination Microscopy

Shiang-Yu Huang,[a] , Jiwei Zhang,[a,b] Ronny Förster,[a] Christian Karras,[a] Ankit K. Singh[a], Rainer Heintzmann,[a,c] and Jer-Shing Huang,[a,c,d,e,*]

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[b]*MOE Key Laboratory of Material Physics and Chemistry under Extraordinary Conditions, and Shanxi Key Laboratory of Optical Information Technology, School of Physical Science and Technology, Northwestern Polytechnical University, Xian 710129, China*
[c]*Institute of Physical Chemistry and Abbe Center of Photonics, Friedrich-Schiller- Universität Jena, Jena 07743, Germany*
[d]*Research Center for Applied Sciences, Academia Sinica, 11529 Taipei, Taiwan*
[e]*Department of Electrophysics, National Yang Ming Chiao Tung University, 30010 Hsinchu, Taiwan*

The ability to fast image chiral domains at sub-diffraction limited resolution is valuable for understanding the spatial distribution of chiral species and may find applications in drug design, material sciences, and biomedical imaging. Existing chiral domain imaging methods suffer from diffraction-limited resolution, low throughput, or weak contrast due to the weak chiral-light matter interaction. Here, a chiroptical microscopy method, called "Chiral Structured Illumination Microscopy (Chiral SIM)", is proposed to fast image fluorescent chiral domains at sub-wavelength resolution [1-3]. Operation of Chiral SIM is based on the combination of three photonic techniques, namely structured illumination microscopy, fluorescence-detected circular dichroism, and optical chirality engineering. Different from typical SIM, where the intensity of the illumination is spatially structured, Chiral SIM modulates the optical chirality, $\frac{-\varepsilon_0 \omega}{2} \Im\left(E^{¿} \cdot B\right)$, of the illumination field. Since optical chirality is proportional to the circular dichroism of chiral species [4], Chiral SIM generates the moire patterns in the fluorescence image due to circular dichroism-dependent fluorescence. With image reconstruction algorithm, Chiral SIM restores the high spatial frequency information of the chiral domains and thereby reconstructs the image of fluorescent chiral domain at wub-wavelength resolution (Fig.1). The theoretical framework of chiral SIM is presented with demonstration using numerical simulations. The possibility and limitations of applying nanostructures [5] to provide structured optical chirality of illumination at spatial frequencies far beyond that of diffraction-limited interference patterns are also discussed.

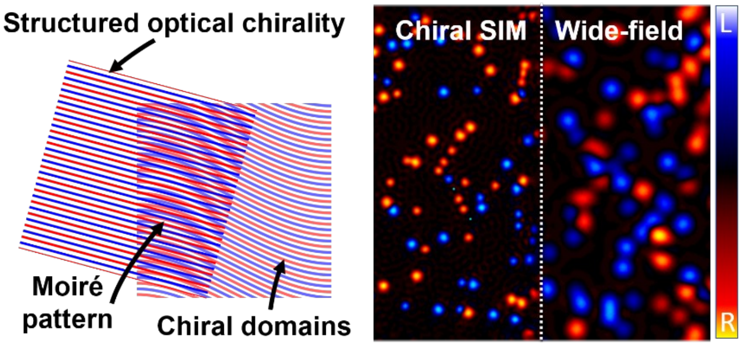

Fig. 1. Illuminating samples with fluorescent chiral domains using illumination with spatially structured optical chirality leads to morie pattern (left) and allows for fast imaging chiral domains at sub-wavelength resolution (right)

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Gigahertz speed electro-optic metasurfaces

Ileana-Cristina Benea-Chelmus, EPFL, Switzerland

Generating polarization monstar disclinations based on a geometric approach

Bruno Piccirillo[1,2*], Veronica Vicuña-Hernández[1], Filippo Cardano[1], Pegah Darvehi[1], Lorenzo Marrucci[1,3], Andrea Rubano[1,3]

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The ability of structuring spatial and polarization modes of the optical field has proven to be crucial in the development of a wide variety of applications in multiple domains, ranging from fundamental science to micro-manipulation, material processing, classical and quantum communications, classical and quantum metrology, to cite a few [1]. Within this framework, polarization singularities play a prominent role due to the fact that both spatial and polarization degrees of freedom are concomitantly controlled. They are embedded into polarization disclinations and can be generated as non-separable superpositions of singular spatial modes and orthogonal polarization states. Polarization disclinations are categorized according to the net topological charge I_C with respect to the embedded singular points, and by the symmetry of the radial sectors into which the whole disclination patterns can be partitioned. In symmetric disclinations, the number N of radial lines – straight lines radiating from the singularity – is given by [2]

$$N = |2(I_C - 1)|, I_C \neq +1. \quad (1)$$

Symmetric disclinations with $I_C > 0, \neq +1$ are named *lemons* and those with $I_C < 0$ are named *stars*. Asymmetric disclinations including radial sectors, bounding curved lines radiating from the singularity, are named *monstars*. Monstars have been up to now prepared using three helical modes in a non-separable superpositions with left- and right-circular polarization states [2,5]. We here propose a different approach, in which monstars are generated by superposing the fundamental TEM_{00} mode, in a circular polarization state of specified handedness, with a Gaussian beam having a periodically modulated helical phase [3, 4], in a circular polarization state of opposite handedness. We have implemented such approach by using liquid crystals-based Spatially Varying Axis Plates (SVAPs) [6] (Fig. 1).

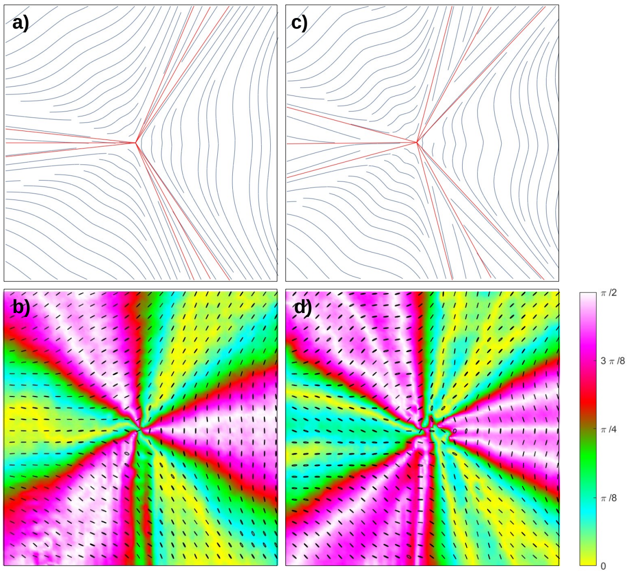

Fig. 1. Numerical simulations and experimental measurements of two Modulated Poincaré Beams patterns. In the first column **a)** and **b)**, the amplitude modulation is below threshold and the pattern is symmetric. In the second column **c)** and

d), the amplitude modulation is high enough to produce a monstar pattern. False color encodes the orientation of the polarization relative to the radial direction. Radial lines are along the yellow colors.

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Nonlocal metasurfaces

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In this talk, I will discuss our recent research activity on metasurfaces based on highly nonlocal features, stemming from long-range resonant interactions, lattice phenomena and broken symmetries. Different from conventional metasurface approaches, nonlocality offers tailored spectral control, both temporally and spatially, combined with largely enhanced light-matter interactions. We achieve these features by combining quasi-bound states in the continuum leveraging broken symmetries with geometric phase variations in engineered metasurfaces, tailoring at will the supported eigenwaves. The resulting metasurfaces support sharp responses selective to the impinging wave properties, effectively realizing a platform for efficient dispersion engineering and to realize ultrathin transparent films that highly reflect light only when illuminated by selected polarization, frequency and wavefront spatial distribution of choice. The demonstrated responses of nonlocal metasurfaces open exciting opportunities for analog signal processing, augmented reality, secure communications, optical modulators, tailored thermal emission, and enhanced light-matter interactions for nonlinear and quantum optics.

Topology of light and darkness in engineered optical media

Natalia Litchinitser, Duke University, USA

Geometric Phases and beam structuring with liquid crystals photonics.

Raouf Barboza
Dipartimento Scienze e Ingegneria dei Materiali e dell'Ambiente e Urbanistica, Università Politecnica delle Marche, 60131 Ancona, Italy

In optics, the phase of propagating light has been commonly known to be dependent on the optical path length. However, due to its vectorial nature, light experiences, beside the path dependent phase (dynamical phase), a phase that is termed geometric phase. The latter is due to the evolution of the degrees of freedom of light such as: propagation direction (wave-vector), Rytov-Vladimirskii-Berry (RVB) phase; and polarization state, Pancharatnam-Berry (PB) phase [1]. To access PB phase effects, the state of polarization of a propagating beam is transversally modulated via space-varying anisotropic structures, and pioneering demonstrations were achieved using sub-wavelength gratings [2] and templated uniaxial liquid crystal layers [3]. For thin elements behaving locally like half-wave plates, the geometric phase is $2\sigma\theta$, with θ the angle of the optical axis and σ the handedness of the input beam. Thus, with relatively thin optical elements, a broad range of polarization and phase structuring functionalities can be provided by designing the appropriate template of the optical axis.

With the use of liquid crystal light valves, optical vortices can be generated via the induction of umbilical defects, the latter providing the required azimuthal pattern of the effective optical axis [4,5]. By changing the uniaxial liquid crystal layer to cholesterics, an uncommon geometric phase can be observed due to the strong chiral reflection [6].

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Emerging nanophotonic platforms for environmental and human health monitoring: Re-imaging the conventional microbiology toolkit

Jennifer Dionne, Stanford University, USA

How can we enhance and extend healthspans of life on our planet? It is estimated that 20% of an average human lifespan is spent in a diseased state. Meanwhile, nearly one million animal and plant species are threatened with extinction - many of which are crucial to planetary health. Plant disease is estimated to cause a 40% loss in yield across major food crops, and disease transmission from livestock to humans accounts for over 2 million deaths annually. Climate change will only exacerbate these problems, as unprecedented warming, flooding, and drought have displaced ecosystems and escalated vector, food and water-borne diseases. The decreased health of ecosystems will have devastating consequences for our food security, economies, and quality of life. Transformative new capabilities for molecular detection and control are needed to address these challenges - particularly capabilities that are scalable, equitable, and inform actionable outcomes.

Here, we present our efforts to develop photonic sensors suitable for field-deployment that enable early disease onset, help inform optimal treatment, and uncover new biological pathways associated with personal, population, and ecosystem-level health. First, we combine Raman spectroscopy and deep learning to accurately classify bacteria by both species and drug susceptibility in a single step. With a convolutional neural network (CNN), we achieve species identification and antibiotic susceptibility accuracies similar to leading mass spectrometry techniques. We show how this technique can be applied to rapid tuberculosis detection, as well as to waste-water monitoring of bacterial pathogens. Next, we describe resonant nanophotonic surfaces that enable detection of genes, proteins, and metabolites with femtomolar sensitivity. These metasurfaces produce a large amplification of the electromagnetic field intensity, increasing the response to minute refractive index changes from target binding; simultaneously, the light is beam-steered to particular detector pixels. By combining metasurface design with acoustic bioprinting for functionalization, we develop chips that detect gene fragments, proteins, and metabolites on the same platform. We discuss integration of these sensors with workflows in Stanford’s Clinical Virology Laboratory, as well as with autonomous underwater robots from Monterey Bay Aquarium Research Institute (MBARI) for real-time phytoplankton detection.

Liquid crystal technology for geometric phase optics

Jeroen Beeckman, UGhent, Belgium

Ultra-sensitive measurement of transverse displacements with photonic gears

Vincenzo D’Ambrosio, Universita di Napoli Federico II, Italy

Accurately measuring mechanical displacements is essential for a vast portion of current technologies. Several optical techniques accomplish this task, allowing for non-contact sensing even below the diffraction limit. Structured light can be a resource for enhanced sensing purposes as for instance in the ``photonic gears''. This technique enables a boost of the sensitivity in roll angle measurements thanks to a bidirectional mapping between the polarization state and a properly tailored vectorial mode of a paraxial light beam [1]. Similarly, ultra-sensitive measurements of a transverse displacement can be performed by mapping it into the polarization rotation of a laser beam [2]. By exploiting this technique, dubbed ``linear photonic gears'', we measured, in ordinary ambient conditions, the relative shift between two objects with a resolution of 400 pm. We argue that a resolution of 50 pm should be achievable with existing state-of-the-art technologies. Our single-optical-path scheme is intrinsically stable and it could be implemented as a compact sensor, using cost effective integrated optics.

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Controlling light by nanostructured metasurfaces for applications ranging from UV to IR

Thomas Pertsch, University of Jena, Germany

In this talk I will cover basic concepts of resonant light-matter interaction at nanostructured surfaces. I will also cover several application examples, where such metasurfaces and the underlying photonic nanostructures open new doors to interesting science and applications.

Spatio-temporally structured light

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Abstract :

Spatiotemporally-structured light is ultrashort light bursts that have some structure that makes their electric field non-separable in space and time (or space and frequency), which can result in novel structures and characteristics. Spatiotemporal structure can either be deleterious in high intensity experiments, or can be used to tune and control light-matter interaction. We will first review the field and provide theoretical background on how to describe various types of spatiotemporally structured pulses. We will especially focus on how they propagate and focus in free space. We will then discuss both how to generate spatiotemporally structured light via various methods (refractive optics, SLMs, metasurfaces, etc.) and how they can interact with physical systems. Lastly, we will discuss new descriptions of light that is both spatiotemporally and polarization structured, and how these new and exotic light pulses could lead to interesting new physics.”

Structured light for ultrashort pulse materials processing

Stefan Nolte, University of Jena, Germany

Topological quantum nanophotonics

Andrea Blanco-Redondo, Nokia Bell Labs, USA

Tailoring depolarization spatial patterns with a liquid-crystal SLM

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We present the proof-of-concept of a technique to generate beams with tailored spatially-varying polarization state (SoP) and degree of polarization (DoP) [1]. It is based on sequentially addressing two phase masks to a pixelated liquid-crystal spatial light modulator (SLM), in a time interval that is chosen to be the exposure time of our detector. The polarization properties of the output beam are verified by imaging the SLM screen onto a polarization camera and applying Mueller matrix imaging polarimetry.

In this situation, the SLM behaves as a depolarizing sample whose effective Mueller matrix is the averaged sum of two linear retarders with spatially-varying retardances $\phi_A(\mathbf{x})$ and $\phi_B(\mathbf{x})$, with $\mathbf{x}$=(x,y) being the spatial coordinates in the SLM. This effective Mueller matrix is expressed as the product of a depolarizer and a retarder. An intuitive geometrical explanation of the action of these matrices over an input state of polarization (SoP) is provided in the Poincaré sphere. We show that the effective SoP of the output beam is governed by the averaged retardance, while the DoP is governed by the retardance semi-difference. Various cases featuring spatial control of the DoP are realized to show the potential of the method, including beams with a spirally-shaped depolarization pattern. In all cases the measured polarization parameters agree very well with the expected results. This technique could be useful in the field of structured light, where introducing the DoP as an additional parameter and being able to tailor it spatially, might lead to new designs of vector beams. Also, in testing imaging polarimeters, laser beam shaping and biomedical imaging, where depolarization effects have proven to be a relevant channel of information.

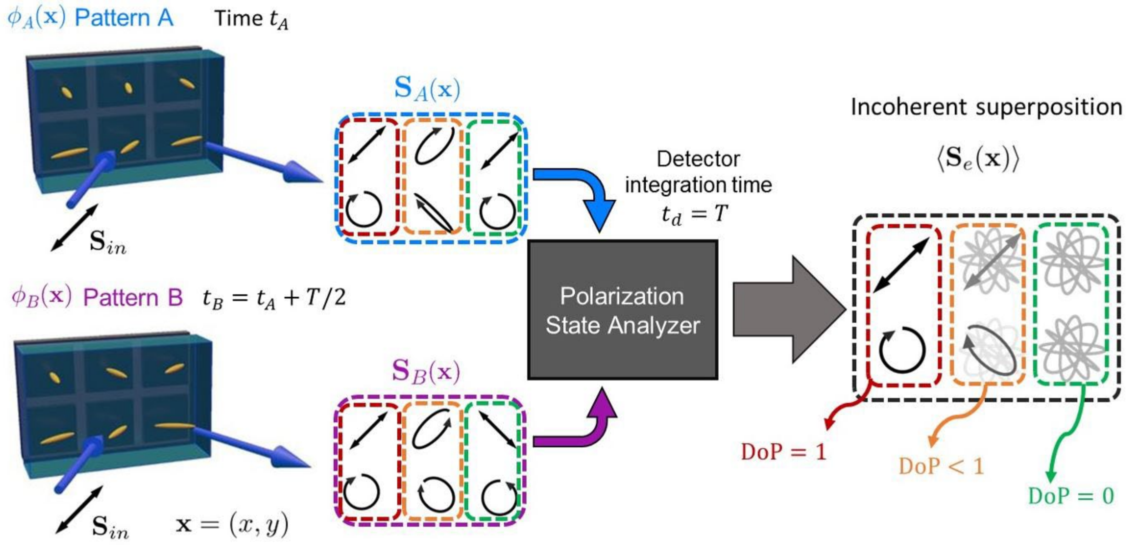

Figure 1. Scheme of the operation principle to generate spatial patterns of the degree of polarization.

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Nanostructured transition metal dichalcogenide multilayers for advanced nanophotonics

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Influence of geometric phase on the propagation of optical waves

Alessandro Alberucci, University of Jena, Germany

Emerging aspects of optical beam shifts

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The reflection and refraction of real optical beams at interfaces deviate from Snell's law when the cylindrical symmetry is broken. In such a scenario, the beam, exhibits polarization-dependent longitudinal and transverse deflections. These so-called Goos-Hänchen (GH) and Imbert-Fedorov (IF) beam shifts have evoked recent intensive investigations. In this presentation, we briefly summarize some of our recent and ongoing studies on different consequences of optical beam shifts both from the perspective of fundamental interest and applications.

a. We demonstrate the inherent non-separability of longitudinal and transverse beam shift. Such non-separability leads to a classical position-position entanglement from a simple partial reflection of a Fundamental Gaussian beam.
b. We demonstrate an intriguing giant optical beam shift in a tilted polarizer system analogous to the IF shift in partial reflection around the Brewster's angle of incidence. A regulated control of both the magnitude and direction of the shifts are demonstrated further by wisely tuning the input polarization and the corresponding orientation angles.
c. We further indicate the possibility to study the physics of PT symmetric system in optical beam shift set-up.

Structured Vector Beams via Conical Diffraction Cascade

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Structured light has gained wide attention owing to its applicability for investigating fundamental physical phenomena as well as several application prospects. Vector beams possessing spatially varying polarization across the beam cross-section are one type of such structured light beams, whose peculiar polarization distribution enables them to be utilized in several modern photonics applications[1]. Vector beams can be generated naturally by the phenomenon of conical diffraction (CD) in an asymmetric biaxial crystal. 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[2]. 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[3]. 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 $KGd(WO_4)_2$.

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Focused complex beams interacting with strongly anisotropic metamaterials

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Thanks to structured light, the field distribution of a laser beam can be engineered at an always-increasing degree, allowing for numerous exciting applications and new ways for light to interact with matter. In this work we analyse both theoretically and experimentally the two sides of the interaction between Cylindrical Vortex Beams (CVBs) and strongly anisotropic metamaterials, characterising the extinction properties of the sample and the influence that these have on the beam propagating through it. We developed a semi-analytical model to describe the propagation of focused CVBs through an anisotropic slab based on an effective medium theory and we mainly applied it to the case of radial and azimuthal polarisation states. Our Epsilon-Near-Zero metamaterial is fabricated with a self-assembly technique that allows for an easy scalability of its size and customisation of its optical properties. Varying the focusing condition, the sample can show a strong sensitivity to the angle of incidence and the state of polarisation of the incoming beam. The interplay between the non-locality properties of our metamaterial and the customisable longitudinal field achievable with different polarisation states is fundamental in the understanding of this new kind of interaction. Moreover, the effect of said interaction on the modal content of the beam has been investigated, showing that the strong dichroism of the anisotropic metamaterial reveals a non-negligible variation in the set of Laguerre-Gauss modes contained in the beam. Linear, radial and azimuthal polarisation states have been tested for metamaterials with different anisotropy parameters for a better characterisation of the interaction. In all the cases considered, experimental results show a good agreement with the theoretical and numerical predictions, proving the great potential of anisotropic metamaterials as a platform for light manipulation.

Keywords: Cylindrical Vector Beams, Anisotropic Metamaterials, Longitudinal Fields, Tight Focusing

Photo-excitation of atoms by cylindrically polarized Laguerre-Gaussian beams

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Laguerre-Gaussian beam [1] can have cylindrical polarization in addition to circular, linear or elliptical polarization. A cylindrically polarized Laguerre-Gaussian beam is also known as a vector Laguerre-Gaussian beam ([2],[3]). In this work, we present a theoretical model to analyze the interaction of atoms with cylindrically polarized Laguerre-Gaussian beams. In particular, we analyze the excitation process of atoms with a single valence electron by cylindrically polarized Laguerre-Gaussian beams. The analysis is performed within the framework of first-order perturbation theory and by expanding the vector potential of the Laguerre-Gaussian beam in terms of its multipole components. For cylindrically polarized Laguerre-Gaussian beams, we show that the (magnetic) sub-components of the electric-quadrupole field vary significantly in the beam cross-section with beam waist and radial distance from the beam axis. In addition, we calculate the total excitation rate of electric quadrupole transition ($4s\ ^2S_{1/2} \rightarrow 3d\ ^2D_{5/2}$) in a mesoscopic target of Ca$^+$ ion. These calculations show that the total excitation rate is sensitive to the beam waist and the distance between the centre of the target and the beam axis. Our results [4] explicitly show that the cylindrically polarized Laguerre-Gaussian beam is more efficient in driving electric quadrupole transition in the mesoscopic target than the circularly polarized Laguerre-Gaussian beams.

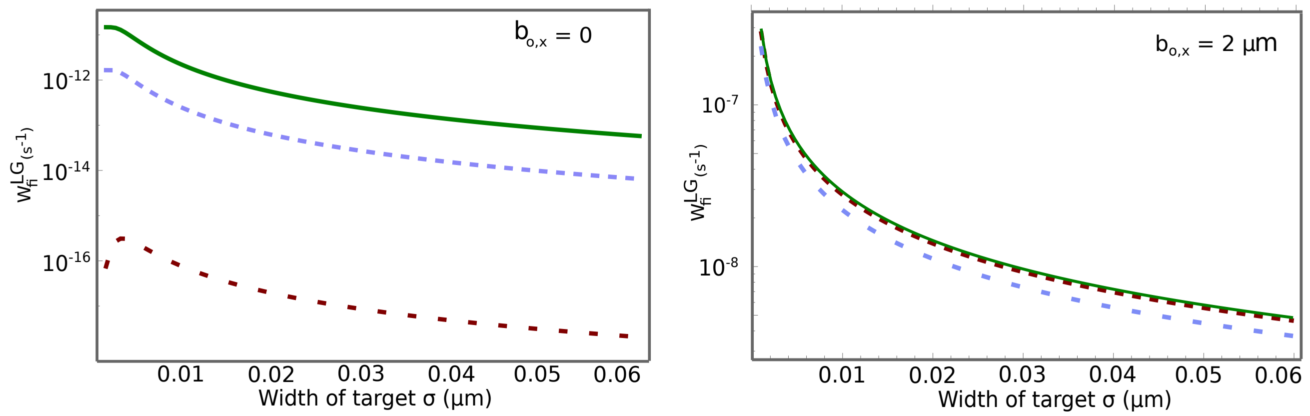

Fig. 1: Log plot of the total rate of excitation $W_{fi}^{LG}(s^{-1})$ for electric quadrupole transition between 4s $^2S_{1/2} \rightarrow$ 3d $^2D_{5/2}$ levels of Ca$^+$ ion driven by LG beam is plotted as a function of width of the target σ for azimuthal (green solid line), radial (brown dashed line) and circular polarization (blue dotted line). In the top figure the target is placed on the beam axis $b_{o,x} = 0$ and in the bottom figure the target is displaced from the beam axis by $b_{o,x} = 2\ \mu m$. In both the plots, the radial index p and beam waist w_o is kept fixed at 0 and $2.7\mu m$ respectively.

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OAM Multipoles Polarized Light-Matter Interaction

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Abstract:

The light-matter is investigated in two important optical processes of Raman scattering and Transmission. We explore two light's salient degrees of freedom such as polarization (spin angular momentum—SAM) and wavefront (orbital angular momentum—OAM). During the light-matter interaction, the structured OAM light studied can have multiple poles of OAM, which travel in a material that has a certain topological structure. These multipole moments can be involved with the matching up with the symmetry of the material and the light maximizing and enhancing the optical process. The multipole moment interaction can be represented through an expansion based on the value of OAM (L) and the structure of the material represented by: the first term—Monopole (L=0); the second term—Dipole (L=1); the third term—Quadrupole (L=2); the fourth term—Octopole (L=3); the fifth —Hexadecapole (L=4) moment.

Our experimental results show for first time a large increase of Raman intensity in the spectra of certain vibrational bonds in organic liquids and a decrease of other bonds relative to Gaussian (L=0) beams. For example, methanol liquid sample shows changes for circularly polarized OAM Raman ranging from 4.5% to 66.8% for different vibrational modes. In addition, we present results of the transmission study in a cerebellum tissue at two different oxygen levels— control (21% oxygen) and hypoxia (7% oxygen). The results indicate some degree of OAM and polarization dependency more for the control than for the hypoxia samples and an increase in transmission with respect to the OAM value (L).

In conclusion, the experimental observations for the two major optical processes studied—Raman and transmission are attributed to the structure and topology of the multipoles of a given beam when interacting with an organic liquid and bio-media sample and the matching up of their respective multipole moment distribution for its interaction.

Orbital Optical Trapping at Atmospheric Pressure

Amala Raj, William L. Schaich, Bogdan Dragnea

Optical trapping is a well-known non-contact analytical technique that has found applications in numerous scientific areas, from single particle characterization to ultra-precise sensing. Compared to single beam optical tweezers, counter-propagating dual-beam traps offer enhanced trap stiffness in the direction along which the laser beams propagate, since the instabilities due to radiation pressure are absent in the latter. By adding a transverse offset between the counter-propagating beams in a dual-beam trap made of a pair of focused near-IR laser beams, the optical force field in the trap can be tailored to induce sustained periodic orbital motion of a dielectric microsphere. The key features of particle dynamics were evaluated as functions of the transverse offset between the laser beams, the axial offset between the foci and the optical power, both experimentally and theoretically[1]. We find that the power spectral distribution of scattered light from an orbiting particle manifests spectral features with narrow linewidths ($\frac{\delta\nu}{\nu} \approx 10^{-3}$), nearly two orders of magnitude narrower than the peaks associated with Brownian oscillator motion in traditional traps in air, which makes them better candidates for trapping-based sensing applications. With the help of numerical analyses employing ray optics, we discuss how the orbital trapping technique can be further modified to enhance its sensitivity to the changes in the physicochemical properties of a trapped particle and its surrounding medium. The evolution of orbital frequencies can be a useful signature in analyzing the kinetics of surface reactions on particles and microdroplets levitated in a controlled environment. Hence, we predict that this new experimental scheme could find application as a standalone, *in-situ* single-particle technique to explore reactions relevant to atmospheric chemistry.

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Dual-pass phase modulation approach to generate structured light

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Structured light has gained attention because of the remarkable properties arising from the shaping of optical fields. The association of helical wavefront with the angular momentum of light and optical singularity has brought many applications of structured light in the areas of light-matter interactions. The large degree of freedom brought by structured beams is also an attractive feature for applications in optical communications. Different types of structured beams with unique properties have been reported. Vectorial light beams have non-uniform polarization distributions. Light beams that carry both phase and polarization singularity are also known as vector-vortex beams. They are of interest for applications in optical manipulation, material processing, and information optics. Efficient methods for their generation and detection are crucial. Different methods have been reported for their generation, such as using q-plates and metasurfaces. However, very few techniques have been reported for generating high-order vector-vortex beams. Therefore, we have proposed a compact experimental set-up to produce high-order vector-vortex beams based on the technique of dual-pass phase modulation. A liquid crystal spatial light modulator with calibrated phase response has been used to enable on-axis phase modulation. Simulation and experimental results have been presented.

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Structuring ultracold atoms with light

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A persistent current, when formed within a Bose-Einstein condensate (BEC) as an azimuthal rotation of atoms, has the benefit of both quantised circulation and topological protection, with significant applications towards matter-wave interferometry. Using a numerical model based on coupled nonlinear Schrödinger and Gross-Pitaevskii equations, we demonstrate the formation of azimuthally rotating atoms when far-red-detuned light carrying orbital angular momentum (OAM) propagates through a co-propagating BEC.

When the light is red-detuned the atoms are attracted to positions of optical intensity, and we demonstrate the transfer of OAM to the BEC, with the BEC forming a ring-like intensity distribution with a uniform azimuthal rotation of the atoms; an atomic persistent current which avoids additional trapping requirements. We demonstrate that the rotational motion begins shortly after the optical vortex beam is incident on the BEC and characterise its speed. We also report on subsequent fragmentation dynamics leading to coupled light-atom soliton formation, with the number of structures given by twice the magnitude of the OAM. Our model provides a novel means of rotational dynamics within a BEC avoiding external traps, and a realisation of atomic transport in a highly controllable manner.

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Passive metasurface structured metasurface for anomalous penetrating transmission through an opaque material

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Propagation through a medium that would normally block, absorb, interfere or distort the passage of incident electromagnetic waves is a sought-after phenomenon, offering the intriguing promise of "seeing through walls” by controlling the intensity of the transmitted beam with, for example, the engineering of the incident beam or using parity-time-symmetry in evanescent waves. Here, we introduce a passive metasurface for improved transmission of light across optically opaque materials with a varying transmission phase and amplitude simultaneously. Initially, we present the ideal case with an infinite spatial dependent optic metasurface that induces a perfect transmission along a lossy material to later use vectorial Bessel beams to locally obtain a similar condition, obtaining an improvement of almost double field inside the material in a localised area, with potential applications to improved wave transmission inside buildings or biomedical laser selective ablation.

Keywords— ***Polarization-loss locking, near-field photonics, lossy propagation, Bullseye metasurface, passive metasurface,***

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Speckle-based Recognition of Orbital Angular Momentum Modes

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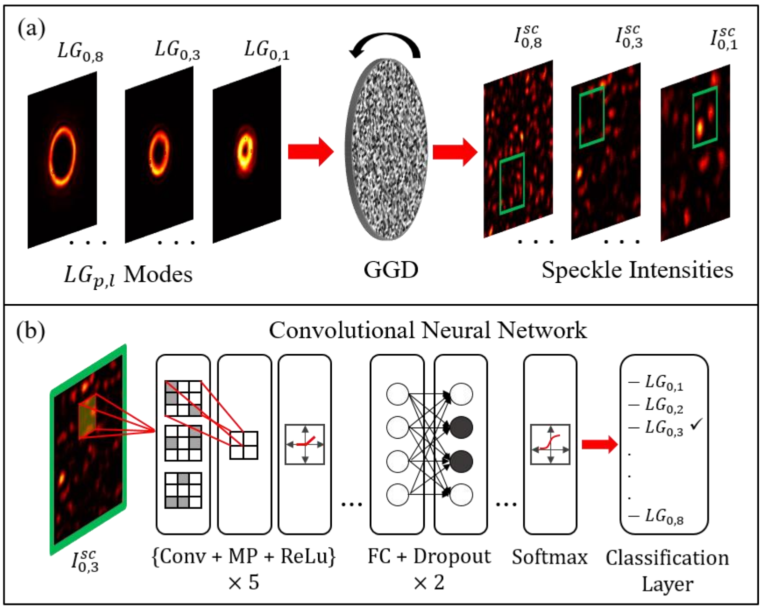
Abstract:

Orbital Angular Momentum (OAM) beams – structured light with a spatial degree of freedom due to the helical phase front – have emerged as a potential candidate for increasing the bandwidth and the information-carrying capacity of communication links as they have infinite orthogonal states on propagation[1]. The real challenge lies in the detection of these OAM modes as they are prone to distortion on propagation. Artificial intelligence has given a promising aid to boost the performance of communication systems by replacing physical components such as mirrors, beam splitters, etc with Machine Learning and Deep Learning Models, leading to a reduction in complexity and alignment constraint[2]. But still, the current state of the art needs to capture the entire modal field for authentic prediction.

To resolve this issue, a speckle-based recognition method is proposed where instead of capturing the entire modal field, any region of the speckle field having a sufficient number of speckle grains is enough for measuring the OAM mode[3]. Alexnet[4], a Convolutional Neural Network is used to develop an OAM classification model. The speckles are generated by passing OAM modes through Ground Glass Diffusor (GGD) and then a randomly selected region of 512×512 pixels from the captured intensity patterns is used for developing the model. The speckle structure formed at the detector does depend on the inhomogeneity size of GGD, therefore, for more robustness and generality, the network is trained on a cumulative dataset containing speckle patterns generated by three different GGDs and accuracy of $> 96\%$ is achieved for the classification of eight OAM modes with topological charge $l = 1$ to 8.

Here, the core idea behind this speckle-based learning is to make the model learn the underlying features of speckle distribution. Hence, the new dimensions of OAM modes can be studied by exploiting the feature learned by this CNN.



(a) Generation of speckle patterns by illuminating the OAM modes on Ground Glass Diffusor. **(b)** A region of 512×512 pixels (shown in the green box in (a)) is randomly selected and fed to the CNN.

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Waveguides based on spin-orbit interaction

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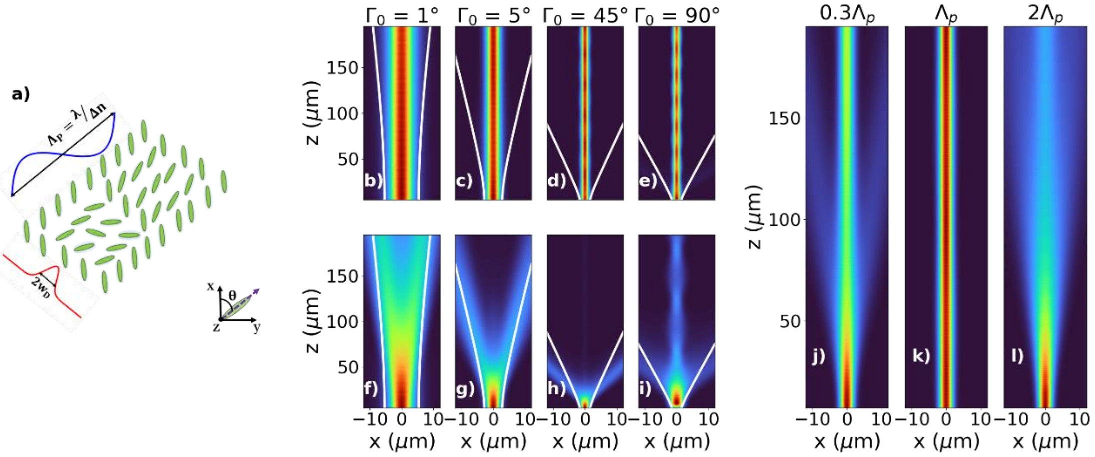
A waveguide based on spin-orbit interaction confines light in the absence of a refractive index gradient. It employs geometric phase (GP) or Pancharatnam-Berry Phase (PBP)[1,2] instead of dynamic phase, to balance the natural diffraction of light. A PBP is gained when polarization of light evolves, geometrically represented as a path on the Poincare sphere (PS). Natural candidates for the investigation of the PBP are anisotropic media, where light polarization varies along propagation due to the different values of the two refractive indices associated with the two eigenwaves. In an anisotropic material of length corresponding to a half-wave plate (HWP), for a circularly polarized (CP) input, the PBP is two times the local rotation of the optical axis. Furthermore, the sign of the imposed phase delay depends on the beam helicity. Thus, when the optic axis of the anisotropic medium is rotated along the beam cross-section, PBP is responsible for a strong spin-orbit interaction, i.e., the intensity strongly depends on the input polarization. However, PBP in an anisotropic medium - homogeneous along the propagation direction does not accumulate along propagation due to a null transversal PBP gradient. Therefore, the rotation of optic axis is also modulated periodically at each HWP distance to enable accumulation. This mechanism is demonstrated experimentally in Refs. [1] and [2] in a discrete linear case and in a continuous nonlinear case, respectively. We study the properties of the guided beam in the PBP waveguide, both theoretically and numerically. We derive numerically the quasi-modes of the waveguide and demonstrate that the quasi-modes are completely structured with a point-dependent polarization owing to the strong spin-orbit interactions in the PBP waveguide. We also measure the resilience of the waveguide, by varying its longitudinal modulation period and by changing the wavelength of the input beam in a phase-matched waveguide. We observe that the confinement of the waveguide is robust for up to 40% variation to the phase-matched condition.



(a) Illustration of a continuously modulated PBP waveguide (b-i) Intensity distribution of a quasi-mode (b-e) RCP, (f-i) LCP; propagating in a PBP waveguide with $w_D = 3\ \mu m$ and increasing Γ_0 as stated above each column. The white lines indicate the extent of natural spreading of light in a homogeneous material. (j-l) Propagation of a quasi-mode in a PBP waveguide with $w_D = 5\mu m, \Gamma_0 = 15°$ and different longitudinal modulation period, as stated above each column.

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Orbital angular momentum broadening in Poincaré beams

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Abstract: We present a theoretical study and experimental measurements of the broadening of the orbital angular momentum (OAM) spectrum due to spin-orbit modulation to generate asymmetric polarization singularities in Poincaré beams produced by Pancharatnam-Berry phase optical devices.

1. OAM spectrum of Poincaré beams produced by engineering the Pancharatnam-Berry phase

Topological polarization singularities in complex beams have generally been produced by a non-separable superposition of base modes in an orthogonal state of polarization [1–3]. In particular, asymmetric dislocations have been generated when the asymmetry reaches a threshold value. In the superposition of modes carrying OAM, the asymmetry is given by an asymmetric vortex that is formed by two modes ℓ in the same state of polarization and opposite topological charge, plus the superposition of a plane wave with an orthogonal state of polarization [4]. We present the case in which this coherent superposition is carried out by Free-Form Dark-Hollow modes (FFDH) produced by the Pancharatnam–Berry geometric phase elements Spatially Variant Waveplates (SVAPs) [5]. In our previous work [6] we presented polarization singularities produced with the Spatially Variant Waveplates (SVAPs) in which the superposition was performed by Free-Form Dark-Helical (FFDH) modes with orthogonal polarization to produce high-order singularities in polarization. FFDH modes are a special class of beams generated by adding an extra-phase factor to a uniform carrying Orbital Angular Momentum (OAM) beam. This phase factor comes from the symmetry properties of a designed curve and FFDH beams inherit its properties shaping intensity, polarization, and OAM. In this work, we show how the OAM power spectrum is broadened due to phase modulation. An ℓ-charge m-order FFDH mode does not carry a well-defined OAM and its spectrum includes multiple indices reflecting the m-fold rotational symmetry of the generating curve. Then, the OAM spectrum of an ℓ-charge m-order FFDH beam turns out to include the components with indices $\ell \pm hm$. We performed the modal decomposition with digital holograms on a phase-only spatial light modulator (SLM). The measurements of the set of modal expansion coefficients yield the amplitude and phase of the modes that compose the FFDH beam generated by the SVAP device. The number of modes and their power weight depend on the characteristics of the SVAP as topological charge q and the assigned parameters of the closed curve ρ. We measured the modal amplitudes c_l and the intermodal phases $\Delta\phi_l$ between modes showing how the spectrum can be broadened as the device SVAP is designed to break the rotation rate symmetry of its optic axis distribution generated by the phase modulation.

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Wave-optical simulation of macroscopic dielectric metasurfaces

Sebastian Linss, Dirk Michaelis, and Uwe D. Zeitner

With diffractive optical elements (DOEs) it is possible to manipulate the propagation of light in an almost arbitrary way. We propose a novel method for the wave-optical simulation of DOEs like metasurfaces or computer-generated holograms (CGHs) [1]. Furthermore, we present an ultrafast simulation method that determines the optical field directly form the geometrical structure based on a machine learning approach [2]. Designing a DOE usually starts with the determination of a phase profile, which can be experimentally realized by an array of pixels that contain specific sub-wavelength microstructures, e.g. rectangular pillars, chosen to yield a certain transfer function. To design those, rigorous methods like the finite-difference time-domain method (FDTD) can be used. It is assumed that the transfer function of a respective pixel in the DOE is the same as in a periodic arrangement, which is called local periodic approximation (LPA). This approach can produce useful designs for small deflection angles or numerical apertures. For higher angles coupling effects between neighboring pixels occur, making each pixel's transfer function dependent on its surrounding, especially for low-index structures.

Rigorous methods including the neighbor-coupling are only reasonable for small elements, but the application of the finite-difference beam propagation method (BPM) allows fast and accurate calculations. We adapted the BPM to be as accurate as necessary with minimal numerical effort to allow the simulation of large area elements.

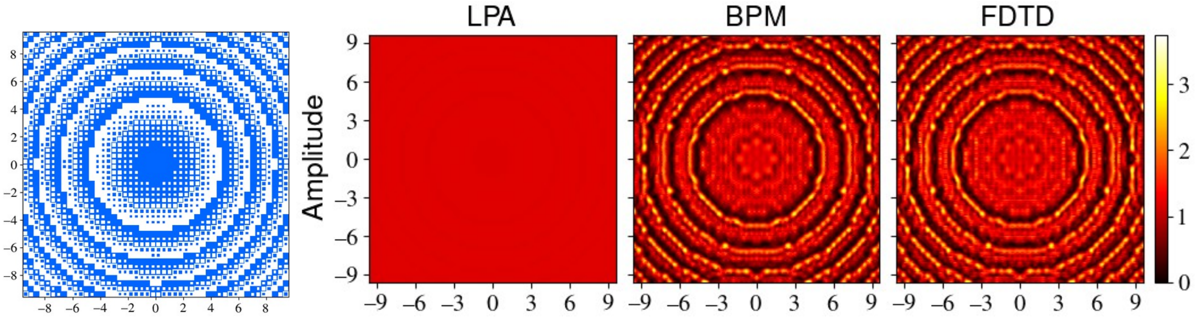

Fig. 1: Structure of the metalens (left) and amplitude of the electric field behind it, simulated with LPA, BPM, and FDTD. The axis labels show the position in µm.

A metalens based on effective-medium metasurfaces has been simulated. A comparison shows high conformity to a rigorous FDTD simulation, while the LPA produces deviating results (see fig. 1). The runtime of the BPM was up to 700 times smaller compared to FDTD. Thus, it becomes possible to analyze whole elements to a much higher accuracy than with the LPA within a reasonable runtime.

Meta-surfaces are often composited of a finite number of fundamental structures that can be characterized by a parameter, e.g. the size of a quadratic pillar. We simulated random elements by the BPM and used the results to generate a regression model. It is able to calculate the field behind a certain structure purely based on the geometry parameters. The field is approximated by a low-order polynomial, which is sufficient to accurately predict the farfield distribution. We call this approach polynomial field approximation (PFA).

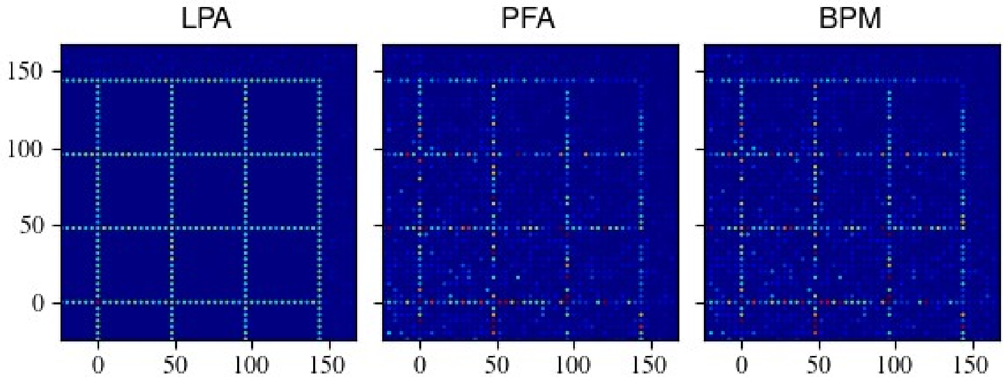

Fig. 2: Farfield distribution of a grid-projection CGH, simulated by LPA, PFA, and BPM. The axis labels show the number of the diffraction orders.

Different CGHs have been designed to compare their farfield calculated by different methods. A high correlation between the PFA and BPM could be obtained, while the LPA is not able to model variations in the target order intensities (see fig. 2). The PFA can almost reproduce the accuracy of the utilized training data, which might be created by different methods as well. Once trained, the calculation can be another 100 times faster than the BPM. So even the usage for wave-optical design of entire elements becomes feasible.

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Optical Bottle Beam

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Tightly focused light beams can be used to hold and move dielectric particles for which the refractive index is greater than the one of its surrounding medium, as first demonstrated by Arthur Ashkin. These so-called Optical Tweezers have applications in various fields, ranging from biology to quantum information. When the refractive index of the particle is smaller than that of its surrounding medium, dielectric particles are repelled from the peak intensity in the light field. Together with structured light beams, such repulsive force can be exploited to produce a dark optical tweezer, where dielectric particles can be trapped in a minimum of light intensity surrounded by a bright region. In this talk we shall explore this idea and introduce our Optical Bottle Beam (OBB) trap. We will discuss our work-in-progress towards implementing the OBB tweezer, its characteristic non-harmonic trap potential and force calibration methods. Diverse applications of the OBB dark tweezer, from biology to quantum optomechanics, will be discussed.

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Nonlinear Polarization Holography of Metal Nanolayer

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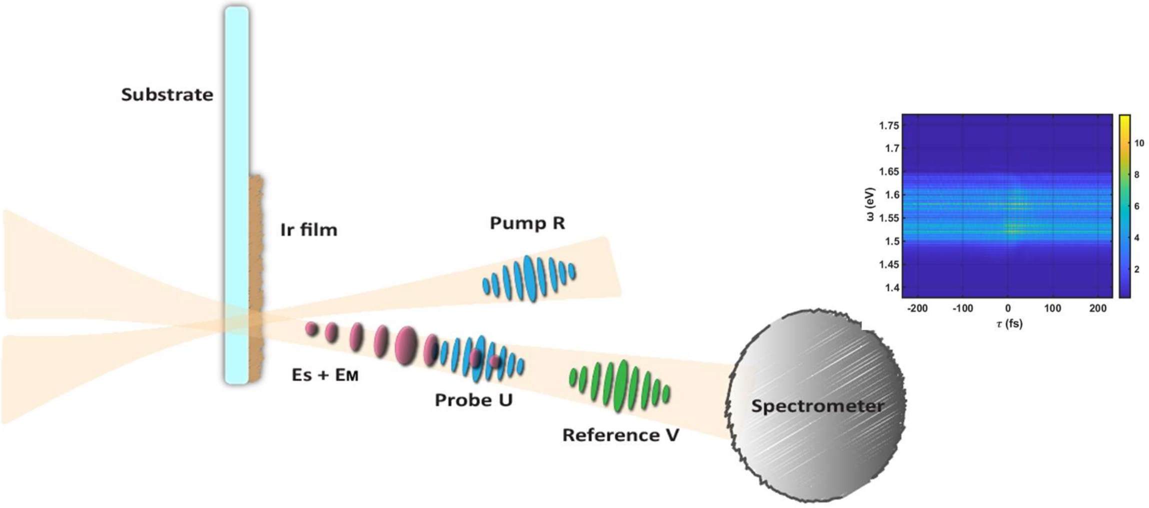
Real-time access to nonlinear polarization enables a wide range of applications such as optical switching, light harvesting, sensing [1], and so on. Previously, an attosecond streak camera was used to measure nonlinear polarization experimentally in an optoelectronic method [2]. Our current focus is on obtaining real-time nonlinear polarization responses from Iridium metal nanolayers using all optical methods.

Our method is similar to the time domain equivalent of spatial holography. A pump probe setup with nearly colinear geometry has been created. When the pump R and Probe U overlap, the nonlinear response Es (for substrate) and E_M (for metal) emerge. An additional pulse V is used as a reference. All pulses are 800 nm NIR, and the probe has a FWHM of 30 fs. First, we record the spectrogram at various time slices. After that, the time domain hologram was digitally reconstructed. We employ an analytical pulse retrieval method based on Cross Phase Modulation (XPM) Scan [3]. Once the pulse U has been reconstructed, the real-time nonlinear response can be calculated.

This method provides information about how nanoscale iridium responds to an intense laser pulse in the fs timescale. This paves the way to ultrafast light matter interaction control in solids, as well as future applications in petahertz electronics. We gratefully acknowledge the support of the Deutsche DFG 1375 NOA.



(Left) Experimental Setup for XPM Scan (Right) Recorded Trace at various delay (Ʈ) between U & R.

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Retrieving the phase distribution of structured light beams by a self-interferometric technique

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Complex optical fields featuring spatial distribution of the intensity and phase can be generated by encoding complex holograms on a spatial light modulator (SLM). Laguerre-Gauss beams and Hermite-Gauss beams are paradigmatic examples. In most cases, the successful generation of the complex hologram is verified by regarding the light intensity distribution in the far field. When the phase distribution is of interest, it is measured typically with a wave-front sensor or through an external interferometer that are added to the system generating the structured light, thus increasing the complexity of the setup.

We present a technique that combines an encoding method to display complex-valued holograms onto a phase-only SLM with a phase-shifting interferometric (PSI) technique for experimentally evaluating the generated complex-valued optical fields [1]. We demonstrate an efficient common-path polarization interferometer based on the SLM itself, not requiring any external additional element. The same setup can be used to simultaneously display the complex hologram and to apply the phase-shifting values required to retrieve the phase distribution of the vector beam. A simple rotation of a polarizer allows to change from the intensity configuration to the interferometer configuration. The continuous phase modulation provided by the SLM allows using arbitrary phase bias values, so different classical PSI algorithms can be applied to recover the phase information. The validity of the technique is confirmed by the experimental realization of different examples of complex light beams based on the coaxial superposition of Laguerre-Gaussian beams. In each case the experimental intensity and phase distributions in the far field reproduce very well the theoretical results.

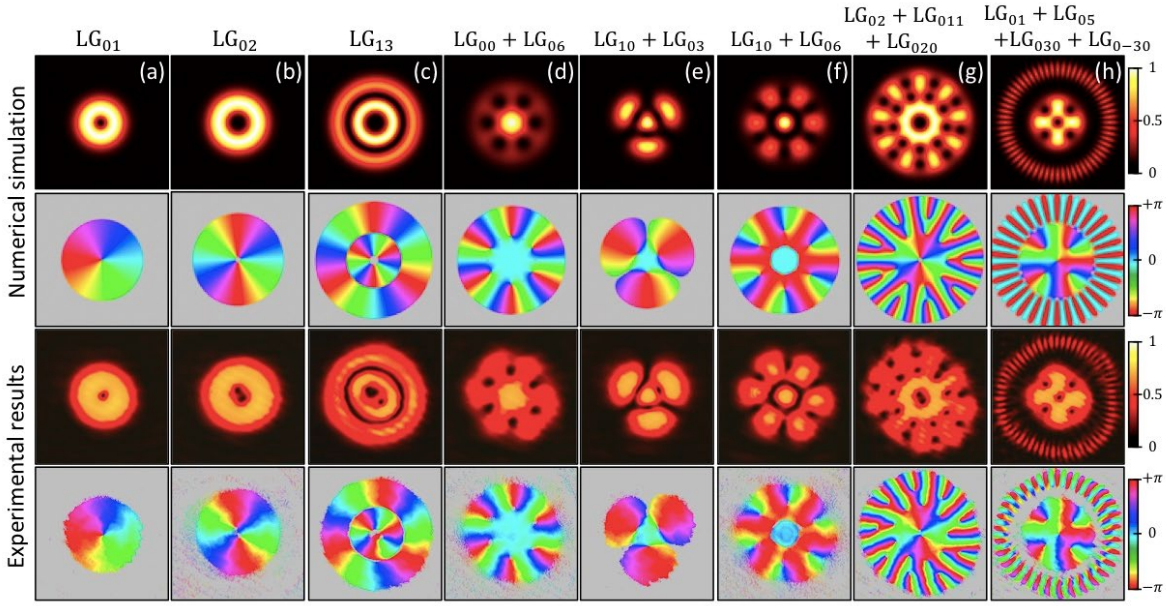

Figure 1. Intensity and phase distributions of different superpositions of Laguerre-Gaussian beams.

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LINEAR AND SECOND-ORDER RESPONSE OF METAMATERIAL-INSPIRED RESONANT WAVEGUIDES HYBRIDIZED WITH TRANSITION METAL DICHALCOGENIDES

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Two-dimensional transition metal dichalcogenides (TMDCs) are renowned for their intriguing optical properties [1-3]. Nevertheless, their extremely small thickness sufficiently limits the light-matter interaction strength. A way to overcome this challenge are resonant nanostructures [4, 5].

In this work, we propose resonant hybrid waveguides (WGs) for modulation of the linear transmission as well as second-harmonic (SH) generation intensity in the planar geometry. The hybrid WG composed of a chain of Mie-resonant all-dielectric nanodisks and a TMDC film on top of it allows for the strong localization of the electro-magnetic field in the volume and near the surface of the structure and, thus, increased interaction of propagating light with TMDC film.

The experimental linear transmission of a silicon WG with nanodisks under the excitation with the Gaussian beam at the wavelength range λ = 1260-1360 nm is in a good agreement with numerical calculations (Fig. 1). The transmission peak, corresponding to the excitonic resonance in SH regime, should enhance SH emission efficiency and allow for noticeable change in linear transmission and SH signal intensity upon monolayer TMDC refractive index modulation. The inset in Fig. 1 displays the scanning electron microscope (SEM) image of a silicon WG.

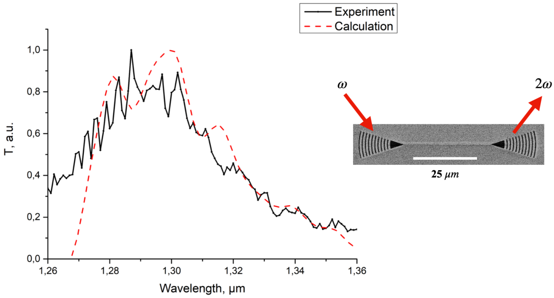

Fig. 1. Experimentally measured and numerically calculated transmission spectra of the WG sample with the SEM image of its structure and schematic of excitation with fundamental wavelength and SH signal out-coupling.

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Study of the Superposition of Optical vortex beams

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Abstract- This study introduces and demonstrates the superposition of optical vortex beams. Optical vortices are attracting more and more attention because they carry orbital angular momentum (OAM) associated with the phase distribution of $\exp(i\iota\varphi)$, where ι is the topological charge. An important characteristic of an optical vortices is topological charge. Actually, in this paper, we used of Spiral Zone plate and present new method to generate superposition of optical vortex beams.

A variety of beam shapes and structures such as on-axis and off axis optical vortices, optical lattice, optical wheels, and multi -spot, light-arm are generated at the focal plane, inside and outside that can carry integer and fractional topological charges.

Keywords: Diffraction, Optical vortices, Ring lattice shapes, Fresnel Zone Plate, Beam Shaping.

EFFECT OF GRADUAL HEATING ON QUASI- BIC DIELECTRIC METASURFACE

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Dielectric metasurfaces have applications in wavefront shaping, sensing, and imaging. We investigate the effect of temperature on a hydrogenated amorphous silicon metasurface structure, which can support bound states in the continuum states. Here we quantitatively analyze the variations in the resonance wavelength and the Q-factor due to gradual heating. We believe that our study would be helpful for sensing applications at high temperatures and other applications which can cause localized heating of the metasurface. The effect of temperature on two types of metasurface structures designed to have resonance at 683 nm (type 1) and 823 nm (type 2) are demonstrated in figure 1. The resonance wavelength shift and the reduction in Q- factor is associated with the increase in the refractive index of a.Si:H. Thus the temperature induced changes in the optical properties of the a.Si:H can affect the resonance in the metasurface. These results also indicate the possibility of tuning the resonance wavelength using temperature while compromising the Q factor.

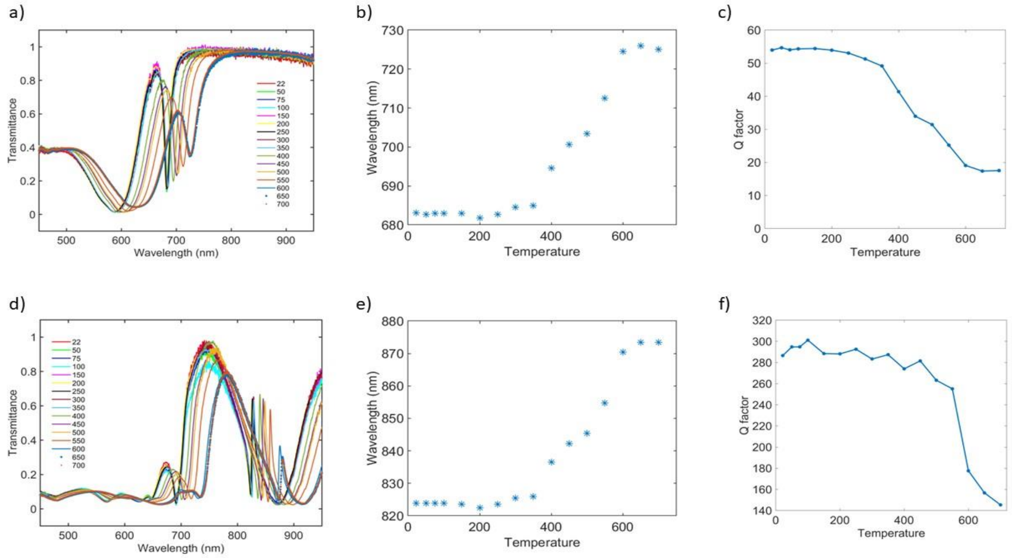

Fig.1: a) Transmission spectra of the type1 metasurface measured at different temperatures. b) Resonance wavelength of the type 1 metasurface as a function of temperature. c) Q factor of the type 1 metasurface as a function of temperature. d) Transmission spectra of the type2 metasurface measured at different temperatures. e) Resonance wavelength of the type 2 metasurface as a function of temperature. f) Q factor of the type 2 metasurface as a function of temperature.

Beyond the weak value:
Optimal postselected quantum metrology

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The weak value of an operator is a complex quantity that used to describe the pre- and postselected quantum ensembles. It is highly controversial due to the fact that it is not bounded by the possible eigenvalues of the corresponding operator. For instance, a spin of a spin-$\frac{1}{2}$ particle can turn out to be 100 [1], or “one photon can act like many” [2]. Nevertheless, the obtaining of the anomalous weak value is regarded as a powerful technique in the quantum interferometry nowadays.

The postselection on a quantum state is a result of merging between the components of the quantum superposition, thus, it is a quantum interference effect. For any quantum interference, there exist two main types of phases that one has to consider carefully: the dynamical and *geometric phases*. The dynamical phase controls the cosinusoidal variation of the interference pattern, while the *geometric phase* shifts this variation.

Depending on the *geometric phase shift* it is possible to provide optimal quantum-mechanical description for the pre- and postselected quantum ensembles. Using single photons, it is easy to show that [3]: i) the postselection on the quantum system is a specific type of quantum erasers, ii) a single postselected photon can impart a π phase shift to the other photon interacting weakly with it in a nonlinear optical medium, and iii) a pair of photons, initially prepared in a product state, can be entangled in a non-maximally entangled state which can be used as a resource for optimal parameter estimation.

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PLASMONIC ELLIPTICAL NANOHOLES FOR CHIROPTICAL ANALYSIS AND ENANTIOSELECTIVE OPTICAL TRAPPING

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Here, we propose using elliptical nanoholes on an extended gold film as a simple yet effective achiral platform to demonstrate chiroptical analysis [1]. For a linearly polarized light, a well-designed elliptical nanohole can simultaneously generate chiral near-field for chiroptical analysis and act as a nano-optical trap to capture dielectric and plasmonic nanospheres. The figure shows two distinct optical potential (U_{xy}) landscapes of the same elliptical hole upon illumination with different linear polarizations. The in-plane optical force (F_x and F_y) exerted on a polystyrene (PS) nanoparticle can trap (left) or repel (right) the particle according to its chirality (κ). This makes the platform powerful for enantioselective optical trapping. Using this achiral platform with linearly polarized illumination, false chiroptical signals due to nanostructures can be eliminated. Moreover, the compatibility of the platform with typical optical microscopes is greatly improved because the problems due to the distortion of circularly polarized light by the optics of a microscope are avoided. The platform is ideal for sensitive chiroptical analysis in combination with nanoparticles-based solid-state extraction and pre-concentration, which further enhances chemical selectivity and sensitivity.

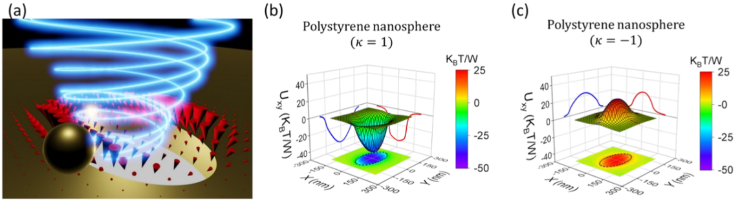

Fig. 1 (a) Schematic of the elliptical nanohole on the gold film. (b, c) Trapping potential contour maps of the in-plane optical force (F_x and F_y) exerted on a 20-nm chiral PS nanosphere. The chirality parameter κ is ±1. The red and blue traces on the *x*-*z* and *y*-*z* projection planes are the cross-sectional potential cut by $y = 0$ and $x = 0$ planes. The black dashed lines on the *x*-*y* projection planes mark the boundaries of the elliptical nanohole. The calculations were made for an injected power in the aperture of 1 W.

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Non-separability and Classical Entanglement through Optical Beam Shifts

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Abstract:

Optical beams with finite transverse extent show shifts in the respective longitudinal and transverse planes when undergoing reflection/transmission at any interface. The physics of beam shifts has correspondence to several conceptually rich physical phenomena involving the interference of matter or light waves, such as quantum weak measurements, spin-orbit interaction, slow and fast light, super oscillation, PT symmetry, etc. Due to their fundamentally different physical origins, these shifts have been treated in a separable manner in the literature so far. In this work, we demonstrate the inherent non-separability of these longitudinal (GH) and transverse (IF) optical beam shifts, which appear substantially in certain regions of the parameter space. We further show that this non-separability manifests as a classical entangled state whose degree of entanglement can be controlled through the experimental parameters. We anticipate that this unveiling of non-separability and classical entanglement in such simple optical beams will enrich the physics of beam shifts and analogous effects in other areas, act as an effective metrological tool, and provide a platform for developing entangled sources for communication and information processing purposes.

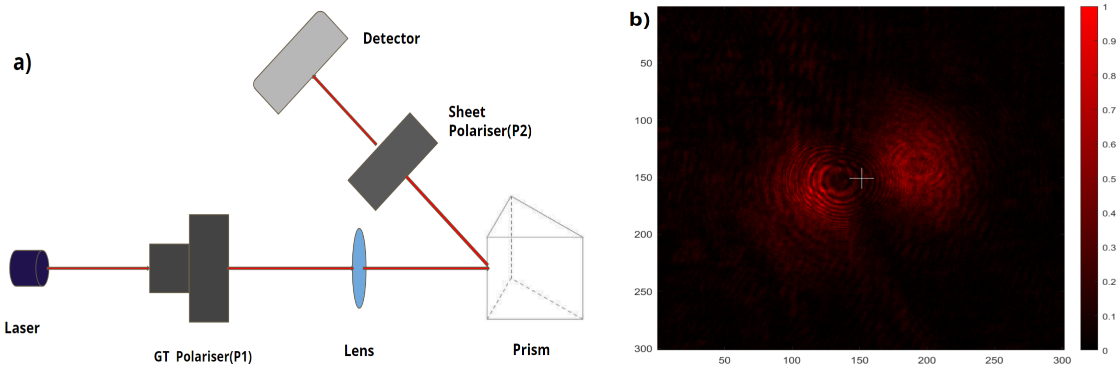

Fig. 1 (a) Experimental schematic to observe non-separability of GH and IF shift. Light source is a 632.8 nm line of a He –Ne laser (HNL225R, Thorlabs, USA). The polarisers P1 and P2 are used for pre-selection and post-selection respectively (b) The image of the beam near orthogonal post-selection. The beam showing a two-lobe pattern when represented in the x-y plane represents a position-position classically entangled state.

Metaoptics for the controlled generation of orbital angular momentum vector beams

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Moving from diffractive optics to metalenses novel tools for structuring light are provided for the integration in compact optical layouts. New metaoptics are designed for the light control in structured light beams implementing on-demand vectorial configurations. Different optical layout are achieved. We show metalenses that can generate focalized orbital angular momentum (OAM) vector beams.

Keywords: metalens, vector beams, orbital angular momentum

A metamorphosis is occurring in the design and fabrication of nanostructured optical devices. By encompassing two emerging fields, structured optics and structured light, the design of a new generation of metasurface optics is expected to provide the key-elements of future optical architectures based on the manipulation of the spatial degrees of freedom of light. In particular, beams carrying orbital angular momentum (OAM) have gained increasing interest with formidable applications in a wide range of fields, such as particle tweezing [1-2] microscopy [3-5], high-capacity communications [6-10] and security [11-13].

The ability to generate structured light with arbitrary controlled polarization in a compact optical path is a challenge of the last years in optics and photonics field. In this regard, our work proposes the design, fabrication, and characterization of new dielectric metaoptics able to generate high focused orbital angular momentum beams with on-demand different vectorial behaviors acting only on the input light's polarization. Furthermore, depending on the azimuthal angle of the linearly polarized light impinging the metasurface, it is possible both to explore different states of the Hybrid Poincaré Sphere (HPS) and focalize the beam at a prefixed point in space. Our metaoptics are designed as array of periodic subwavelength metastructures (the so-called meta-atoms) composed by silicon nanofins on a silicon substrate. Each meta-atom's nanorod acts like a half-wave plate that exploits both the geometrical and dynamical phases in a different way depending on its position on the entire optic. [14] The optical elements have been fabricated in the form of phase-only metasurfaces (meta-atoms) with high-resolution electron-beam lithography and characterized with a custom made optical bench.

The main objective of the work is the design of tiny high-resolution optics generating focalized structured beam and offering both an improvement in terms of the compactness of optical paths and an easily integration with other optical elements. In particular, the proposed metaoptics are suitable for the generation of vector beams for telecommunications, imaging, and security applications.

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Observation of narrow EIT linewidth in Rubidium – 85 atomic system at room temperature vapor medium in presence of structured coupling beam

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We have done electromagnetically induced transparency (EIT) spectroscopy for the Rubidium-85 atomic system at room temperature atomic vapour. We obtained the absorption spectrum for the EIT situation in presence of a coupling beam which is a superposition of Laguerre-Gaussian (LG) modes of equal and opposite angular momentum while the probe intensity profile is Gaussian in nature. From the obtained spectrum, we have found a significant reduction in the EIT linewidth in the case of a structured coupling beam compared to a normal Gaussian coupling beam profile. Semi classical model of light matter interaction is developed for the understanding of obtained experimental results which agrees qualitatively with obtained EIT spectrum. We have identified the reason for linewidth reduction as electric field inhomogeneity which is created by the structured beam. This linewidth reduction of EIT signal can find application in slow light generation, Quantum memory, etc.

Keyword: EIT; Structured beam; Linewidth; LG beam.

Influence of the electrolyte and etch-stop time upon the optical response of 1D-Porous Silicon Photonic Crystal structures

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Abstract

Photonic crystals (PC) are periodic structures having periodic refractive index through the entire structure. This structure allows the possibility of light manipulation just controlling the geometrical features of its unit cell [1,2]. The region where the light is inhibited through these structures is known as photonic band gap (PBG) and is characterized by the non-existence of photonic states there. However, the inclusion of a cavity in the middle of the periodic structure allows the existence of photonic states. Our purpose was the fabrication of 1D-PC using the porous silicon (PS) technology because of its low cost and easy handling. Nevertheless, drawbacks such as the interface roughness and the porosity gradient in-depth have to be solved to obtain high quality devices. For this task, we propose the inclusion of etch-stop times during the porous formation to improve the HF diffusion at the etching front. Two set of devices were fabricated by anodizing p^+-type silicon (100) having $\rho = 0.001\,\Omega.cm$ in solutions of HF:ethanol (3:7) (type I) and HF:H_2O:ethanol (3:3:4) (type II). For pore formation, current densities of $J_H = 50$ and $J_L = 5$ mA/cm^2 were applied periodically for $t_H = 7.1$ and $t_L = 11.2$ s in type I and during etching time of $t_H = 6.8$ and $t_L = 10.9$ s, to form periodic H (high porosity) and L (low porosity) layers in type II solution. Despite the solution, it was found that the optical response of these devices is strongly dependent on the etch-stop time between two adjuncts H and L layers, so that the PBG center is linearly redshifted. The fitting procedure of the optical response shows that this behavior is yielded by the increment of both silicon etching rate and effective refractive index (n_{eff}) of the H and L layers associated with the HF diffusion to the deepest region of the pores, as well as the HF consumption during pore formation, achieving a quasi homogeneous n_{eff} for higher etch-stop times for devices achieved in solution type II.

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Generation of periodic and quasi-periodic two-dimensional non-diffractive beams with inhomogeneous polarization

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In this work, two-dimensional periodic and quasi-periodic non-diffractive spatial inhomogeneous polarization optical fields are generated, numerically and experimentally, by the superposition of multiple plane waves with different polarizations states. For the experimental implementation of the fields, synthetic phase holograms are employed in conjunction with half-wave and quarter-wave retarder films as polarization modulators. The synthesis of the spatially inhomogeneous polarization optical fields is achieved by applying a 4f optical system to the phase modulation (phase hologram) of non-diffractive optical fields, displayed on a LC-SLM. The experimental results are in good agreement with numerical simulations. The interference patterns produced by different components of the fields were analyzed employing an analyzer near the output plane. The experimental setup employed is simple, robust, stable, and highly efficient.

Interplay of polarizations and vortex in a cascade EIT system of ^{87}Rb atomic vapor medium

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We investigate both experimentally and theoretically the effect of vortex coupling light with various polarizations on Electromagnetically Induced Transparency(EIT) resonances. Using the semi-classical density matrix approach, double hut model is developed and solved to establish theoretically that EIT peak height is enhanced due to effect of polarization. Furthermore, we observed two EIT peaks of F'' = 2 and F'' = 3 experimentally. Two photon transition probabilities are calculated for all the possible transition pathways to identify the experimentally obtained peaks at $\pi - \pi$ and $\sigma - \sigma$ probe-coupling configuration.

FABRICATION OF SUB 5-NM PLASMONIC NANO-GAP STRUCTURES FOR EXTREME CONFINEMENT OF OPTICAL FIELDS

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Squeezing light into nanometric volumes or confining it into nanometer-wide gaps in plasmonic metals can lead to extreme field enhancements, nonlinear optical effects, and optically induced electron tunnelling. However, it has not been readily accessible to experimentalists due to the lack of a reliable technology to realize uniform nano-gaps with sub-5 nm resolution. In this work, we use a combination of atomic layer deposition [1] and ion beam etching based planarization technique to obtain a reliable definition of the gap-size in a periodic gold grating.

In the paper, we introduce the technology process to realize structures with gap sizes in the sub-5 nm range and present our results demonstrating 3 nm wide, vertically oriented gaps in 1D grating structures in 30 nm thick gold films. The scanning electron microscope image in Fig. 1(a) shows a top view of the realized 1D nano-gap array. The scanning transmission electron micrograph in Fig. 1 (b) shows a high resolution bright field cross-section of the nano-gap confirming sub-5nm vertical gaps. The process is very flexible and we have also worked on its application for the realization of plasmonic nanostructures of various lateral geometries with sub-5nm gaps.

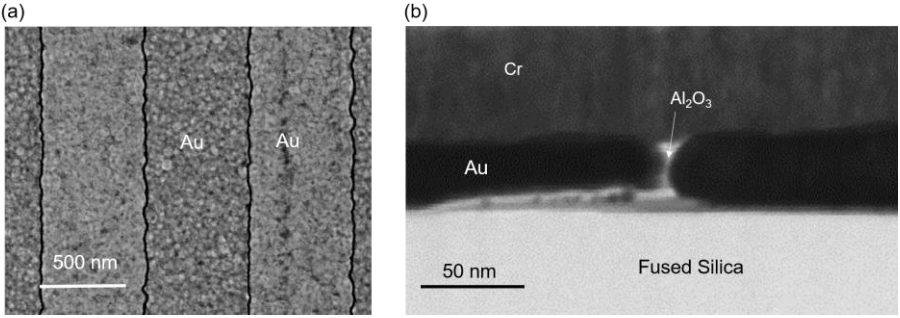

***Fig.1** (a) Top scanning electron micrograph of sub-5 nm nano-gap grating structures (Period=600 nm). (b)High resolution TEM image of the nano-gap cross-section.*

The fabricated nano-gap structures are intended to be used for the investigation of the nonlinear optical processes such as wavelength conversion [2], optically induced electron tunnelling and nonlinear resonance effects [3]. Further potential applications could be found in near field imaging, optical switching, etc.

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