Student Conference @ Spring School 2023

Tuesday, 28.03.2023

Morning Session 1 – Photonics, Chair: Daniele Ronchetti

Optoacoustic active cooling in waveguides
LAURA BLÁZQUEZ MARTÍNEZ

Microcavity-enhanced Investigation of Nanoparticle Dynamics
SHALOM PALKHIVALA

Towards smart and compact Optical Fiber Sensor Systems
ESTHER RENNER

Speeding up field-resolved spectroscopy by Compressed Sensing
KILIAN SCHEFFTER

Morning Session 2 – Sources, Chair: Lisa Härteis

Tuneable Spatially Entangled Photon-Pair Emission from a Nonlinear Metasurface
MAXIMILIAN A. WEISSFLOG

Compact femtosecond light source with flexible spectral control
ABDULLAH ALABBADI

Topological photonics
EMMANUEL NARVÁEZ CASTAÑEDA

Two-photon state engineering at nanoscale
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Optical Coherence tomography with extreme ultraviolet light
FELIX WIESNER

Developments for X-ray in-line holography at the GINIX
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Spatio-Temporal Wide-Field Imaging Based on Frequency Upconversion
DZIUGAS KIMBARAS

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HENRIK VON DER EMDE

MAX PLANCK SCHOOL of photonics

Laura Blázquez Martínez

Optoacoustic active cooling in waveguides

Abstract:

Brillouin-Mandelstam scattering describes the nonlinear interaction of two photons mediated by an acoustic phonon, a mechanical or density fluctuation present in any medium above absolute zero Kelvin. Two types of scattering can take place. Stokes, in which a phonon is created in the interaction, or anti-Stokes, in which a phonon is annihilated. In optical fibers, the acoustic phonons addressed in backward Brillouin-Mandelstam scattering are different for these two processes. Therefore, in order to achieve phonon cooling, there is no need to work in the resolved sideband regime, unlike with optomechanical cavities. Here, we experimentally demonstrate active optomechanical cooling of acoustic phonons using Brillouin-Mandelstam scattering in a chalcogenide glass photonic crystal fiber (PCF). We study the behavior of both Stokes and anti-Stokes resonances as a function of pump power. In a Stokes interaction, phonons are created, as the energy is transferred from the optical into the acoustic field. After a certain threshold, the regime of stimulated Brillouin scattering (SBS) is reached, proving the efficiency of the process. On the contrary, an anti-Stokes interaction removes energy from the acoustic field. The height of the Stokes resonance increases exponentially after the threshold of 15 mW pump power, giving a gain of g0= (1.32 ± 0.18) ·10-9 m/W. The anti-Stokes resonance, on the contrary, saturates in height after this threshold. Using the relation between phonon population and resonance linewidth nssn0=ΓmΓeff and the Bose-Einstein statistics \bar{n}=\ \ \sfrac{1}{{(e}^{h\Omega/k_BT}-1)}, the effective temperature of the resonant phonons (Ω) can be calculated. We report an effective temperature decrease of 219 K for 7.35 GHz anti-Stokes resonant phonons, from 293 K at room temperature to 74 K.

Esther Renner

Towards smart and compact Optical Fiber Sensor Systems

Abstract:

Optical Fiber Sensors (OFS) are well known for their advantages (e.g. immunity to EMI, chemical inertness and flexibility in size and setup). However, with climate change moving forward, it is getting more important than ever to have small and smart measurement systems, which are able to monitor our environment and renewable energy sources. Therefore, we investigate non-conventional approaches to make optical fiber sensors ready for the future, i.e. combination of multiple measurement principles in one measurement platform or implementation of digital twins for the sensor elements.

Shalom Palkhivala

Microcavity-enhanced Investigation of Nanoparticle Dynamics

Abstract:

The diffusion dynamics of nanoparticles and molecules in aqueous suspension are of interest in various scientific fields and for various applications. We implement a novel fibre-based Fabry-Perot microcavity with high finesse and integrated microfluidic channels to investigate single, unlabelled nanosystems. By measuring the dispersive shift of the fundamental and higher-order transverse resonance modes of a length-scanned cavity, silica nanospheres with a diameter of 50 nm could be tracked in three dimensions as they diffused through the cavity.To resolve the faster motion of even smaller particles, a locked cavity system is implemented, with an rms length stability of about 0.3 pm, or 4% of the resonance linewidth. The dynamics of 20 nm long gold nanorods could thus be measured with a high bandwidth limited by the detector itself. In addition, polarisation-split measurements of orthogonal cavity eigenmodes enable the further investigation of the rotation of anisotropic particles, allowing us to infer their angular orientation and trajectory of rotational diffusion. Furthermore, the dimensions of single nanoparticles could be estimated from their diffusion dynamics.The microcavity already shows a sensitivity which could detect single biomolecules such as viruses and ribosomes. We shall apply this sensing technology to investigate the diffusion, rotation and folding dynamics of bioparticles such as DNA.

Kilian Scheffter

Speeding up field-resolved spectroscopy by Compressed Sensing

Abstract:

Time domain spectroscopy, in particular, field-resolved spectroscopy has been a crucial tool for characterizing the transient electric field for decades. Here, upon light-matter interaction, a detailed description of the constituent and internal dynamics of the matter is encoded on the electric field of light. When short laser pulses are used, the response of the medium is temporally separated from the main excitation pulses. This response which is enriched with the entire spectroscopic information of the sample lasts from hundreds of femtoseconds to tens of nanoseconds and is analytically shown to be sparse in the frequency domain. To resolve the electric field and temporal decay of the transmitted or reflected transient, a short laser pulse probes the response at various temporal delays. By subsequent Fourier transformation, the full spectroscopic information is acquired. However, the measurement's speed is limited by i) the required number of sample points dictated by the Nyquist-Shannon criteria, and ii) the speed of the delay line. In this work, we overcome these limitations by Compressed Sensing and rapid scanning and demonstrate field-resolved spectroscopy in the terahertz spectral range on vapor water molecules. We report on the reconstruction of absorption frequencies in the time domain beyond the Nyquist-Shannon limit. Our approach is enabled by developing a randomly sampling, rapidly scanned delay line, which speeds up the measurement time by three orders of magnitude allowing for sensitive, real-time sample analysis.

Sources

Maximilian A. Weissflog
Tuneable Spatially Entangled Photon-Pair Emission from a Nonlinear Metasurface

Abstract:
Entangled photon-pairs generated through spontaneous parametric down-conversion (SPDC) have evolved into an indispensable resource for various quantum communication, imaging, sensing and computing schemes. While photon-pair sources are so far mostly based on bulk-optical nonlinear components, resonant nonlinear metasurfaces with sub-wavelength thickness have recently been demonstrated as a new platform for photon-pair generation.
However, the tunability of spatial photon emission in multiple directions remained an open challenge. Here, we experimentally demonstrate that by tuning the optical pump one can control the emission angle of photon-pairs generated from a metasurface with nonlocal optical resonances in a wide range from quasi-collinear to non-collinear. Practically, we use a Lithium Niobate (LN) thin film covered by a SiO2 grating that supports high-Q nonlocal resonances with strong angular dispersion in the telecom wavelength range. We further show photon-pair emission with comparable efficiencies in transmission, reflection, and counter-propagating directions – a property hardly achievable with conventional bulk components. Specifically for the counter-propagating configuration, we find that the generation rate of pairs from the metasurface is enhanced by orders of magnitude compared to an unstructured LN film of equal thickness. We anticipate that such unique features can facilitate applications of metasurface photon sources for quantum sensing and imaging.

Abdullah Alabbadi
Compact femtosecond light source with flexible spectral control

Abstract:
We report a compact and passively stable optical parametric oscillator for direct generation of sub-40 fs pulses, five times shorter than the 200 fs pump oscillator. By employing an intracavity all normal dispersion feedback fiber, we achieved low-noise and coherent broadening beyond the parametric gain bandwidth limitation. We demonstrate spectral coverage from 1.1 to 2.0 μm with excellent passive power and spectral stability below 0.1% rms and a footprint smaller than 14×14 cm2.

Emmanuel Narváez Castañeda
Topological photonics

Abstract:
Topology is the branch of mathematics that studies the global properties of an object under continuous transformations. Although topological physical phenomena in material systems has been widely studied in fermionic systems since the discovery of the Quantum-Hall effect, their photonic analogs are at the moment a topic of constant and rapidly expanding interest, due their potential for different applications. Such applications include, but are not limited to: photon sources, topological lasers and highly efficient generation of non-linear effects. On this note, we make a presentation highlighting the basics of topological photonics. We begin by introducing the concept of topological invariants in material systems: the Chern number and how non-trivial topological materials give rise to what are known as topological edge-states. Said states bring structural protection guided light and have interesting characteristics which differentiate them from other light states, such as their chirality and single-directionality. We also expose different models used to generate materials with a non-trivial Chern number via different symmetry breakages, and thus allow for the existence of photonic edge states in 1D and 2D platforms. Finally, we present how these concepts can be translated into different applications, particularly to the scope of our project, which consists of the generation of entangled photons with topological protection in a Silicon on Insulator platform.

Vitaliy Sultanov
Two-photon state engineering at nanoscale

Abstract:
Miniaturized sources of quantum light are in the spotlight of quantum research. They are vital for investigating light-matter interaction at the nanoscale and realizing quantum technologies with integrated photonic circuits. One of the leading trends is "flat optics", including ultrathin layers down to a thickness of several atomic layers and metasurfaces. Miniaturized two-photon sources are mainly based on the process known as spontaneous parametric down-conversion (SPDC) of the decay of one photon into a pair of entangled daughter photons. The unique feature of SPDC occurring at the nanoscale is the relaxed momentum conservation, or phase-matching condition. Relaxed process restrictions give unprecedented flexibility in quantum state engineering in position-momentum, time-frequency, and polarization, as well as the freedom of the nonlinear material choice that is impossible in conventional SPDC with bulk materials. Photon pairs generated via non-phase-matched SPDC possess an ultrabroad frequency-angular spectrum that can be further shaped utilizing geometric resonances. In this talk, I would like to give a sneak peek into our recent investigation of nanoscale two-photon sources and the unique properties of generated two-photon light. The talk starts with the experimental demonstration of an extremely broad frequency spectrum of two-photon light and a tunable two-photon polarization state available in an ultrathin nonlinear layer. Then it passes to the idea of using geometrical resonances in metasurfaces for two-photon state engineering in space, frequency, and polarization.

Imaging

Felix Wiesner

Optical Coherence tomography with extreme ultraviolet light

Abstract:

In this presentation, I will discuss the use of optical coherence tomography (OCT) with extreme ultraviolet (XUV) light. Lab-scale High Harmonic generation sources produce broadband XUV radiation which enables axial imaging with nanometer resolution. In XUV coherence tomography the depth structure of the sample is encoded as interferences in the reflected spectrum. However, missing phase information needs to be recovered by phase retrieval. We developed a one-dimensional, three-step phase-retrieval algorithm which enables artifact-free reconstruction. The recovered amplitude and phase can be further processed to obtain spectrally resolved field reflectivities of individual sample interfaces. Due to electronic resonances in the XUV spectral range, elements can be identified based on characteristic features in the reflectivity. Furthermore, the reflectivity in the XUV spectral range is highly sensitive to sample impurities on the nanometer scale. XUV coherence tomography can be used for the detection and characterization of internal oxide layers as well as the determination of interface roughness. In my talk, I will give a general introduction on the method and its underlying principles, followed by an overview of its potential applications, e.g., the characterization of encapsulated graphene layers.

Paul Meyer

Developments for X-ray in-line holography at the GINIX

Abstract:

X-ray holo-tomography is used to analyse the 3d microstructure of biological samples. The coherent illumination available at a synchrotron source allows for example to distinguish individual neurons within a tissue. A new adaptation of the experimental method uses additional information from coherently scattered photons to improve the resolution and applies a more realistic empty-beam correction. This talk will give an introduction to holo-tomography and show preliminary results of the new method.

Henrik von der Emde

MINSTED nanoscopy enters the Ångström localization range

Abstract:

Super-resolution techniques have achieved localization precisions in the nanometer regime. Here we report all-optical, room temperature localization of fluorophores with precision in the Ångström range. We built on the concept of MINSTED nanoscopy where precision is increased by encircling the fluorophore with the low-intensity central region of a stimulated emission depletion (STED) donut beam while constantly increasing the absolute donut power. By blue-shifting the STED beam and separating fluorophores by on/off switching, individual fluorophores bound to a DNA strand are localized with $\sigma = 4.7$ Å, corresponding to a fraction of the fluorophore size, with only 2,000 detected photons. MINSTED fluorescence nanoscopy with single-digit nanometer resolution is exemplified by imaging nuclear pore complexes and the distribution of nuclear lamin in mammalian cells labeled by transient DNA hybridization. Because our experiments yield a localization precision $\sigma = 2.3$ Å, estimated for 10,000 detected photons, we anticipate that MINSTED will open up new areas of application in the study of macromolecular complexes in cells.

Student Conference @ Spring School 2023

Wednesday, 29.03.2023

Morning Session 1 – Strong fields, Chair: Weizhe Li

Using big scary lasers for plasma-based particle acceleration
MORITZ FOERSTER

Strong-field ionization of atomic targets beyond dipole approximation
RESAD KAHVEDZIC

An in-situ method for the reconstruction of ultrashort and ultrabroadband synthesized light transients
MAXIMILIAN KUBULLEK

Enhancing soft x-ray diffraction by photoionization-induced manipulation of electronic populations
DANIELE RONCHETTI

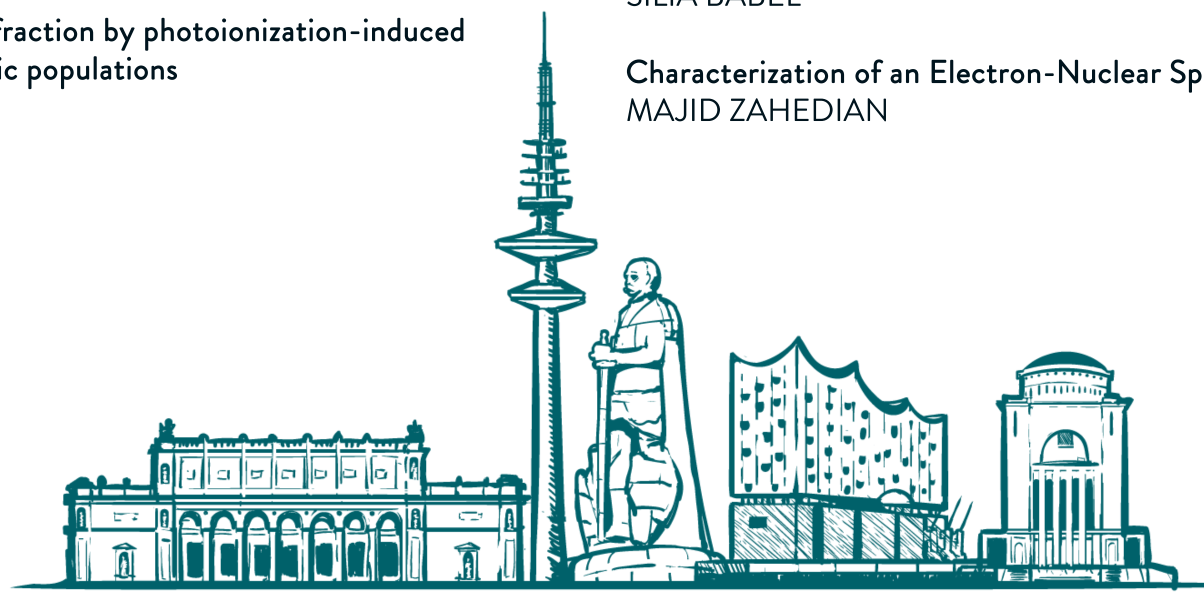
Morning Session 2 – Quantum Optics, Chair: Leon Lohse

Towards high-dimensional vector classification with quantum frequency combs
MERITXELL CABREJO PONCE

Bi-photon correlation time measurements with a two-colour broadband SU(1,1) interferometer
FRANZ ROEDER

Hong-Ou-Mandel Interference in LNOI
SILIA BABEL

Characterization of an Electron-Nuclear Spin Quantum Register
MAJID ZAHEDIAN



MAX PLANCK SCHOOL of photonics

Strong fields

Moritz Foerster

Using big scary lasers for plasma-based particle acceleration

Abstract:

In this contribution I will try to give a small and hopefully interesting insight into my daily work with one of the largest lasers in the country. The ATLAS3000 Titan Sapphire Laser System can generate laser pulses with peak powers of up to 3 Petawatts. To do that, the machine has to be pretty damn big. And that's why such a laser comes along with all kinds of technical challenges.
If you shoot light out of such an infernal machine onto or into matter, you immediately create plasma. And then it gets interesting. The charged particles that make up such a plasma can interact in many different ways with the electric and magnetic fields of the laser. If you do the whole thing cleverly, you can transfer a significant portion of the laser energy to electrons and thus accelerate them. My job is to master these processes as well as possible and to give the electrons the properties that could make them interesting for applications one day.

Resad Kahvedzic

Strong-field ionization of atomic targets beyond dipole approximation

Abstract:

Above-threshold ionization of atomic targets in intense light fields is a highly nonlinear process which may lead to photoelectrons with energies exceeding the photon energy by several orders of magnitude. Theoretical approaches suitable for the wavelength regime of a typical tabletop experiment (~ 800 nm) make use of the dipole approximation, thereby neglecting the spatial dependence of the field and describing the interaction with a solely time-dependent electric field in the polarization plane. As the wavelength of the intense field increases toward the midinfrared regime, the displacement of the photoelectron along the propagation direction becomes significant and the dipole approximation breaks down. Employing the strong-field approximation with leading-order nondipole corrections, which is suitable for theoretical description of strong-field ionization in the nonrelativistic midinfrared regime, we discuss and analyze the impact of nondipole corrections on photoelectron spectra.

Maximilian Kubullek

An in-situ method for the reconstruction of ultrashort and ultrabroadband synthesized light transients

Abstract:

We present our current work on the in-situ reconstruction of the entire electromagnetic field of synthesized light transients. The transients are synthesized from two few-cycle pulses with central wavelengths at 800 nm and 1600 nm respectively giving the synthesized pulses a spectral width of nearly two octaves.
Our method relies on measuring the third-order nonlinear response of a low-pressure noble gas target to the incident field while the time delay between the two constituent pulses is scanned.
Due to the ultrabroadband spectra and the fact that the complete third-order nonlinear response and not solely the third-harmonic is recorded, our method also shows sensitivity to the relative phases of the individual pulses and the absolute carrier-envelope phase (CEP) of the complete waveform.
Simulations show that the complete fields of both constituent pulses and the absolute time-zero of the relative delay axis can be reconstructed from a spectrogram using a custom evolutionary algorithm. Thus, our method gives access to the complete set of possible synthesized waveforms achievable when varying the delay between the two pulses from a single measurement, up to the sign of the electric field.

Daniele Ronchetti

Enhancing soft x-ray diffraction by photoionization-induced manipulation of electronic populations

Abstract:

The advent of X-ray Free Electron Lasers (XFELs) opened the way for ways of exploring and controlling non-linear and collective emission phenomena. Exploiting the extreme intensity of XFEL and building upon well-established techniques - such as x-ray lasing and x-ray superfluorescence - we aim at controlling the scattering properties of individual atoms. The process starts with irradiation by an XFEL pump pulse that creates core transient resonances in a target atom via photoionization. A second probe pulse, whose energy is resonant with one of the opened inner-shell transitions, can scatter, experiencing an enhanced atomic scattering factor.
In this talk, I will present the results of a recent experiment performed at the SCS beamline of EuXFEL - in which we measured with spectral resolution the enhancement of the scattering response of copper atoms subject to XFEL pulses. We demonstrated that the enhancement strongly depends on the intensity of the pump pulse and can grow up to one order of magnitude. Our findings encourage the application of the effect in innovative crystallographic methods where 3d metals may act as heavy scatterers.

Quantum optics

Meritxell Cabrejo Ponce

Towards high-dimensional vector classification with quantum frequency combs

Abstract:

Quantum computing has received a lot of attention in the past decades since it has the potential to offer computational speedup compared to classical computing. This benefit is only hindered by the high complexity of the actual implementation in current platforms. However, some quantum computing tasks can be more efficiently addressed, as it is the case of vector classification in high-dimensional spaces. We propose a classifier based on similarity tests by using Hong-Ou-Mandel (HOM) interference. HOM is a sensitive measurement tool that has been exploited for characterizing quantum properties of photon sources, as well as for many other quantum information tasks in communication, sensing and imaging. We apply this similarity measurement between two large data strings, encoded in a biphoton quantum frequency comb. Our work shows the versatility of this simple experiment and may provide an alternative implementation for developing quantum machine learning algorithms.

Franz Roeder

Bi-photon correlation time measurements with a two-colour broadband SU(1,1) interferometer

Abstract:

SU(1,1) interferometers have lately been used for several applications such as achieving super-sensitivity for quantum metrology or enabling spectroscopy and imaging with undetected photons. So far, most of the developed interferometers are based on parametric down-conversion (PDC) from bulk crystals, limiting the brightness of the sources as well as integrability. Furthermore, only spectral or temporal interferograms have been investigated so far.Here, we demonstrate spectral and temporal interferometry using a SU(1,1) interferometer based on ultra-broadband, non-degenerate dispersion-engineered parametric down-conversion in nonlinear waveguides. These PDC sources exhibit strong frequency correlations and, simultaneously, sub-100 fs photon-photon correlation times. Measuring spectral and temporal interferograms simultaneously allows us to extract the ultra-short biphoton correlation time of our source, a task that has been challenging until now. Knowledge about this quantity is essential for further applications such as entangled two-photon absorption.

Silia Babel

Hong-Ou-Mandel Interference in LNOI

Abstract:

A quantum computer can be built solely using single photons sources, linear optics and single photon detectors. For the realisation of a photonic quantum computer, a particular interest has been devoted to the study of integrated networks since these offer many advantages such as stability, the possibility of compact devices and high efficiency, and thus provide scalability. The foundation of these integrated networks are directional couplers and interference between single photons. An interesting platform for this purpose is Lithium Niobate on Insulator (LNOI) since it combines the advantages of conventional lithium niobate, such as a wide transparency window and high nonlinear coefficients, with a high integration density. To show that this material is suited for the realisation of integrated quantum networks, we demonstrate Hong-Ou-Mandel interference (HOMI) of telecom photons on a balanced directional coupler. We designed and fabricated the coupler in-house and achieve a raw HOMI visibility of (93.5±0.7)%. Our work demonstrates a crucial building block for integrated quantum networks based on LNOI.

Majid Zahedian

Characterization of an Electron-Nuclear Spin Quantum Register

Abstract:

Color centers are promising systems for realizing quantum applications. A color center can be described as a central electron spin surrounded by nuclear spins. The electron spin can be manipulated via microwave fields and measured optically. Also, nuclear spin characterization and manipulation through the electron spin are shown for the electron spin one system via the dynamical decoupling method. However, addressing nuclear spins in an electron spin one-half system with this sequence is still challenging. In this work, we propose a method based on Electron Spin Echo Envelope Modulation to extract hyperfine couplings of nuclear spins with the central electron spin.