Q 40: Optomechanics and Photonics

Time: Wednesday 16:30–18:30 Location: P

Q 40.1 Wed 16:30 P

Exploring dynamics of coupled optically levitated nanoparticles — Manuel Reisenbauer[1], •Livia Egyed[1], Anton Zasedatelev[1,2], Iurie Coroli[1,2], Benjamin A. Stickler[3], Henning Rudolph[3], Markus Aspelmeyer[1,2], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]IQOQI, Austrian Academy of Sciences, A-1090 Vienna, Austria — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Arrays of coupled mechanical oscillators have been proposed for studies of collective optomechanical effects such as topological phonon transport or multipartite entanglement. However, up to date any experimental advances have typically been cavity-mediated, thus limiting the number of objects and their interaction tunability, as well as prohibiting individual detection of the oscillators.

Here, we present a novel platform in optomechanics: trap arrays for levitated nanoparticles. In our setup we can use an optically driven, programmable dipole-dipole interaction in order to realize nonreciprocal strong coupling between mechanical degrees of freedom. The directly coupled particles together with the independent readout could in the future allow us to generate steady-state entanglement in absence of a cavity, which would create the possibility to probe decoherence, something that has so far been unattainable in other optomechanical systems. Furthermore, the setup could lead to enhanced (quantum) sensing, investigations into the limits of master equations in the ultrastrong coupling limit or exploring the Casimir-Polder force between nanoscale objects.

Q 40.2 Wed 16:30 P

Dry & clean loading of nanoparticles in vacuum — •Ayub Khodaee[1,2], Kahan Dare[1], Aisling Johnson[1], Uros Delic[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna, Boltzmanngasse 5, 1090 Wien, Vienna, Austria — [2]IQOQI - Vienna, Boltzmanngasse 3, 1090 Wien, Vienna, Austria

Expanding the optomechanical experiments with nanoparticles to ultrahigh vacuum is required in order to isolate the nanoparticle from the environment sufficiently well to realize macroscopic quantum states, e.g. a superposition. One of the most commonly used loading mechanisms is spraying water/alcohol diluted particles into the chamber using a nebulizer. The drawback of this method is contaminating the whole chamber with liquid, making high and ultrahigh vacuum out of reach. On the other hand, laser-induced acoustic desorption (LIAD) has been successful in loading dry nanoparticles into a trapping potential; however, the method requires expensive components to achieve dry loading. Recently, loading of microparticles using piezoelectric shaking has been demonstrated, thus providing a simple method for launching dry particles. However, launching nanoparticles has remained a challenge due to the strong binding forces between the deposited particles and the launching pad. Here, we will present successful launching of nanoparticles with piezoelectric shaking. We report loading a silica nanoparticle with diameter as small as 143 nm directly into an optical tweezer at high pressure. Finally, we discuss the limits of the launching method and propose a way to load the particles directly into an optical trap in high vacuum.

Q 40.3 Wed 16:30 P

Force measurements with nanoparticles in microgravity — •Vincent Hock, Govindarajan Prakash, Marian Woltmann, Sven Herrmann, Claus Lämmerzahl, and Christian Vogt — Universität Bremen, ZARM (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

Optically trapped levitated nanoparticles are well suited to measure tiny and/or small range forces. Due to efficient cooling methods, they can be prepared in the motional ground state [1] allowing for precise spatial control. In addition, their position can be continuously determined with very high precision.

By observing the free evolution of a test particle in a force field one can investigate the underlying potential [2]. In a laboratory environment most measurements are dominated by gravity. Operating such a sensor in microgravity, like in the 146 m tall drop tower in Bremen, greatly increases its force sensitivity.

[1] Magrini, L. et al. Real-time optimal quantum control of mechanical motion at room temperature. Nature 595, 373-377 (2021).
[2] Hebestreit, E. et al. Sensing Static Forces with Free-Falling Nanoparticles. Phys. Rev. Lett. 121, 063602 (2018)

Q 40.4 Wed 16:30 P

Pump asymmetry compensation in a quantum hybrid system — •Christian Felix Klein[1], Jakob Butlewski[1], Klaus Sengstock[1], Roland Wiesendanger[2], Alexander Schwarz[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Hybrid Quantum Systems combine advantages of different quantum systems and are promising candidates for future quantum information and technology applications. In our experiment, we create a hybrid system through light-mediated, long-distance coupling of motional degrees of freedom of cold atoms in an optical lattice to the fundamental mode of a cryogenically cooled micromechanical trampoline oscillator inside a Fiber Fabry Pérot Cavity (FFPC).

Owing to inevitable losses between the two systems this coupling is intrinsically asymmetric which delays the backaction of the atoms on the mechanical resonator. For large atomic densities and lattice light detuned to the red side of the atomic resonance, this delay turns negative into positive feedback and drives the system resonantly into limit cycle oscillations. This effect limits the number of atoms that can contribute to the coupling strength $C_{\text{hybrid}} \propto N_{\text{atoms}}$ and diminishes i.e. feedback cooling performance.

Here we suggest a new approach to compensate this asymmetry with an additional auxiliary lattice beam and present detailed characterization measurements.

Q 40.5 Wed 16:30 P

Multi-wavelength single mode integrated optical waveguides for trapped-ion quantum computing — •Pascal Gehrmann[1,2], Anastasiia Sorokina[1,2], Steffen Sauer[1,2], Johannes Dickmann[1,2], and Stefanie Kroker[1,2,3] — [1]TU Braunschweig, Institute for Semiconductor Technology, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany — [2]LENA Laboratory for Emerging Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Trapped-ion quantum computers are based on ions as quantum systems to realize the qubits. In these systems, certain trapped ions are controlled and manipulated by laser light of multiple wavelengths ranging from the near-ultraviolet to the near-infrared spectral range. Integrated photonic elements like waveguides and couplers are required for scalable compact chip-based trapped-ion quantum computers. State-of-the-art research solutions utilize multiple waveguides and couplers to address individual wavelengths. Thus, each ion must be controlled by multiple waveguides and couplers. This sets a limit to the realization of compact systems in the long-term view. To minimize the size of a single ion trap chip, photonic devices for multi-wavelength operation are necessary. In this contribution, we show and discuss optical simulations of the broadband performance for single mode integrated optical buried channel waveguides. Furthermore, we present approaches for broadband waveguide designs to achieve the desired goal of multi-wavelength single mode operation.

Q 40.6 Wed 16:30 P

Towards net energy gain in photonic chip-based particle accelerators — •Stefanie Kraus, Roy Shiloh, Johannes Illmer, Tomas Chlouba, Peyman Yousefi, Norbert Schönenberger, and Peter Hommelhoff — Physics Department, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstraße 1, 91058 Erlangen

Particle accelerators are not only widely used in research and industry, but also in clinical practice. Nevertheless, the enormous costs and dimensions of the meter-long accelerators limit their application even for tabletop accelerators in laboratories. Taking advantage of photonic nanostructures and ultrashort laser pulses, a new scheme for high-gradient particle accelerators has been developed. Until now, the transverse forces acting on the electrons have limited the beam transport through longer structures due to significant particle loss and dephasing. The alternating phase focusing (APF) scheme here eliminates this loss by alternating focusing and defocusing the electrons in the transverse and longitudinal directions, thus confining them in a narrow channel. We have experimentally demonstrated this low-loss electron transport over a 77.7 micrometer long silicon-based nanostructure in agreement with particle tracking simulations [1,2]. In this contribution we discuss the current state of the experiment towards building the particle accelerator on a chip.

Q 40.7 Wed 16:30 P

Coupling of a nanofiber to an intracavity optical lattice — •Bernd Welker, Thorsten Österle und Sebastian slama — Center for Quantum Science and Physikalisches Institut, Universität Tübingen

Recently, nanofiber-induced losses inside optical cavities have been analyzed [1]. The subwavelength dimension of the nanofiber leads to a considerably small loss rate, described by Mie scattering at a dielectric cylinder. This makes these nanofibers potentially useful as substrates for achieving strong coupling of nanoparticles with optical cavity modes. Here, we show how the loss rate and scattering of light from the cavity mode into the guided mode of the fiber depends on the fiber position along the intracavity optical lattice. We observe a strong dependence on the fiber diameter and the polarization of light.

[1] Bernd Welker, Thorsten Österle, Sebastian Slama, Thomas Hoinkes, and Arno Rauschenbeutel. Nanofiber-Induced Losses Inside an Optical Cavity, Phys. Rev. Appl. 16, 064021 (2021)

Q 40.8 Wed 16:30 P

Adding Doublons to a Floquet-Topological Insulator — •Helena Drüeke and Dieter Bauer — University of Rostock, Germany

We characterize a Floquet-topological insulator on a finite square lattice with a linear defect in the form of an additional on-site potential along the diagonal. In addition to the usual bulk and edge states, this system also exhibits doublon states on its primary and secondary diagonals. The doublons' energies increase with the diagonal potential, which leads to a rich band structure, including crossings and avoided crossings with other states.

In real-time propagation, an edge state traveling along the boundary of the system will split when hitting the linear defect and continue propagating along the edge and the diagonal simultaneously. The strength of the diagonal potential determines the ratio between both parts. This behavior could allow for the non-destructive measurement of topological edge states. We find and explain a temporal delay between the two contributions traveling around and through the defect.

Q 40.9 Wed 16:30 P

Non-destructive 3D imaging of encapsulated monoatomic layers using XUV coherence tomography — •Florian Funke[1], Felix Wiesner[1], Johann Jakob Abel[1], Slawomir Skruszewicz[2], Julius Reinhard[3], Jan Nathanael[4], Martin Wünsche[3], Christian Rödel[5], Silvio Fuchs[1,3], and Gerhard G. Paulus[1,3] — [1]IOQ, FSU Jena, Germany — [2]DESY, Hamburg, Germany — [3]Helmholtz Institut Jena, Germany — [4]IOF, Jena, Germany — [5]TU Darmstadt, Germany

For many applications of 2D materials an encapsulation in bulk materials is required [1]. In order to further investigate them, it is crucial to have reliable methods for structural and functional characterization. While a variety of such methods exists only for uncovered 2D materials, there is a need for imaging techniques of encapsulated 2D materials as well as their surrounding matter.

We use non-destructive extreme-ultraviolet coherence tomography (XCT) [2,3] in order to generate 3D images of encapsulated monolayers of graphene and MoS2. XCT measures the broadband XUV reflectivity, which contains the depth profile information imprinted via spectral modulations. From these modulations the depth structure is reconstructed with a specialized phase retrieval algorithm for each illumination point. A 3D image is generated by lateral scanning of the sample.

[1] Z. Li, Nat. Com. 11, 1151 (2020)
[2] F. Wiesner, Optica 8, 230-238 (2021)
[3] S. Fuchs, Optica 4, 903-906 (2017)

Q 40.10 Wed 16:30 P

Modeling of non-linear and active materials in interaction with plasmonic nano structures — •Viktor Bender — Institute for Physics, Humboldt University of Berlin, Berlin, Germany

A framework to investigate the interaction of 2D materials with electromagnetic radiation has been developed in the joint group between the Humboldt University of Berlin and the Max Born Institute on Theoretical Optics & Photonics on the example of graphene flakes. Here, using a tight binding approach to model the electronic structure, the material is additionally treated as a conductive current sheet to calculate the electromagnetic feedback. Introducing a minimal coupling between the time-dependant Schrödinger equation and Maxwell's equations allows then for a numerical treatment of the respective fields in time-domain. A crucial role to perform numerical simulations is here played by the group's implementation of the Discontinuous Galerkin Time-Domain (DGTD) finite element method. In my work I extend the mentioned framework for graphene to MoS2, using the DGTD software tool to study respective optical properties and effects, collaborating with and providing predictions for the experiment. Adjustments to respective tight-binding approaches for MoS2 have already been reported and an extension of the model for the treatment of excitons seems also feasible.

Q 40.11 Wed 16:30 P

Waveguide-Intergrated Superconducting Nanowire Avalanche Single-Photon Detectors — •Connor A. Graham-Scott[1,2], Erik M. Baldauf[1,2], Matthias Häussler[1,2], Mikhail Yu. Mikhailov[3], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, 61103 Kharkiv, Ukraine

Superconducting nanowire single-photon detectors (SNSPDs) are of great interest for applications in quantum sciences and technologies. SNSPDs fabricated from amorphous superconducting thin films adapt to a wide range of substrate-materials and show high sensitivities over broad spectral range. A drawback of these however is a low signal-to-noise ratio of the electrical output resulting from a lower critical current when operated close to the superconductor*s critical temperature in user-friendly cost-efficient cryogenic systems.

This challenge can be overcome by parallelizing SNSPDs in an avalanche system to create a superconducting nanowire avalanche single photon detector (SNAP).

Here we show how SNAPs can be integrated with nanophotonic circuitry to allow for on-chip single-photon counting with ultra-high signal-to-noise ratio. We furthermore present simulation results on how the SNAP architecture can benefit both internal and absorption efficiencies of waveguide-integrated SNSPDs.

Q 40.12 Wed 16:30 P

Efficient and broadband in-plane interfacing to nanophotonic circuitry — •Hendrik Hüging[1], Daniel Wendland[1], Wladick Hartman[2], Helge Gehring[1], and Wolfram Pernice[1] — [1]Institute of Physics, University of Münster, Germany — [2]Pixel Photonics GmbH

Efficient coupling over a wide wavelength regime between nanophotonic circuits and fiber optic components is crucial for optical communication, computing and sensing. It requires overcoming the size mismatch between the mode of the fiber core and that of the planar waveguide. This is currently archieved by edge coupling with inverse taper or by out-of-plane coupling via 3D laser written structures.

Here we present our work on 3D nanostructures for in-plane interfacing to reach high efficiency and broadband coupling. Finite difference time domain simulations are performed to find a suitable geometry for a coupling structure consisting of a linear taper and a focusing lens. Our experimental realization shows a coupling efficiency of -1.5dB/coupler at a wavelength of 1550nm. We plan to further optimize the geometry and test the adaptability of this approach for different wavelength regimes and fiber mode-field diameters. The structures are manufactured via Direct Laser Writing of IP-n162 at tapered Si3N4 photonic waveguides on a SiO2 on Si substrate.

Q 40.13 Wed 16:30 P

Estimating the point spread function of a THz imaging system based on real image data — •Florian Lemke[1,2], Konstantin Wenzel[1], Clemens Seibold[1], Martin Schell[1,2], Peter Eisert[1], Björn Globisch[1,2], and Lars Liebermeister[1] — [1]Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany

Time-Domain-Spectroscopy (TDS) based on pulsed Terahertz (THz) radiation has steadily improved in recent years, leading to diverse applications in science and industry. Since THz radiation is reflected by conductors and transmitted by dielectric materials, THz TDS is well suited for non-destructive inspection of complex devices through raster scan imaging. In practice, however, the image quality of THz scans is not only limited by wavelength (0.03 mm to 3 mm) but also by the THz optical setup. In conventional image restoration, a sharpened image can be reconstructed by deconvolution of the recorded image with the optical system's characteristic point spread function (PSF). For THz imaging, this has only been done with a theory-based modeled PSF that does not account for aberrations caused by the setup itself. In our work, we estimate the PSF of a THz TDS imaging system using real image data through deconvolution of THz scans of specifically designed samples with their corresponding sharp models. This opens the possibility for image restoration with the obtained PSF and provides a method to evaluate the imaging quality of THz optical setups and components.