MAX PLANCK INSTITUTE
for the science of light

MPL News

MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT
NEWSLETTER
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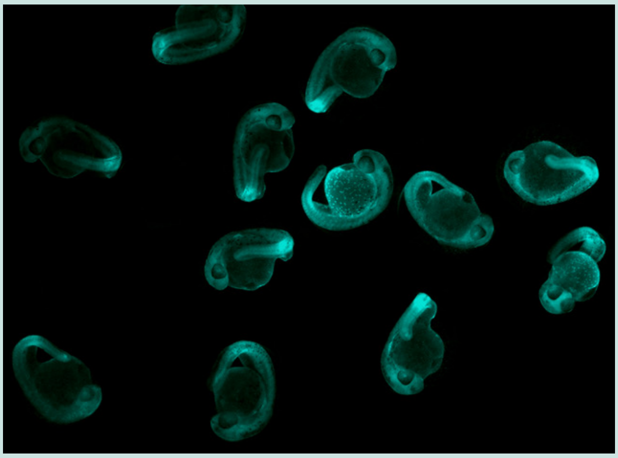
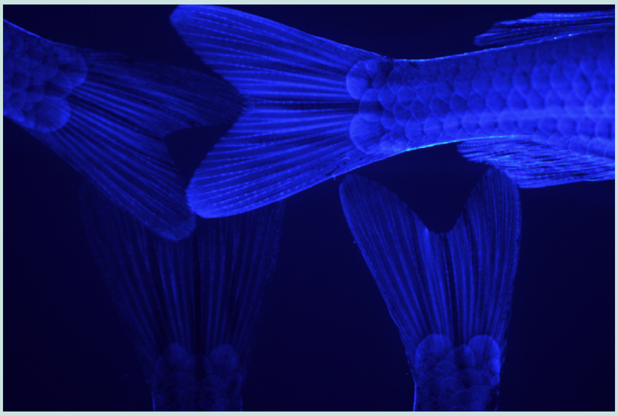
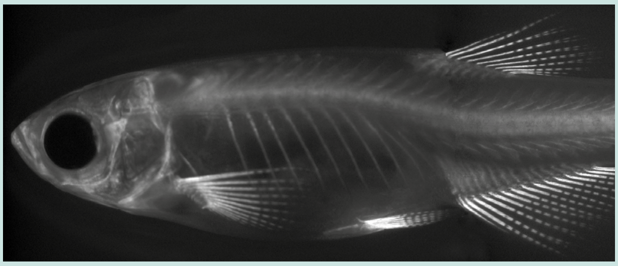
New members at MPL

In September 2019, MPL's scientific staff increased in number by about 1,700. Our new colleagues belong to the species *Brachydanio rerio*, commonly known as zebrafish. Native to the freshwater ponds of the Himalayan regions of India, Pakistan, Nepal and





Bangladesh, they are currently inhabiting a state-of-the-art aquatic system on the first floor in the Division of Biological Optomechanics. This system comprises 225 tanks with more than 1,100 liters of water, and is complemented by a robotic feeding system. Whilst zebrafish have been found to adapt to a range of elevations and water conditions in their natural habitats, reliable breeding in captivity requires careful water treatment involving water purification and reverse osmosis as well as the addition of salts and solutions to achieve distinct salinity and pH levels. The water treatment facility is tightly integrated with MPL's impressive in-house building technology and constantly monitored by MPL's technical service team and scientific staff. Zebrafish display high genetic amenability, *ex-utero* embryogenesis and remarkable regenerative capacity for their body appendages and



many internal organs, most notably the central nervous system. These characteristics, in combination with their optical transparency during embryonic and larval developmental stages, has led them to emerge as an increasingly important vertebrate model organism in various research areas. At MPL, we aim to elucidate both the biochemical and mechanical mechanisms underlying successful tissue repair and functional recovery after spinal cord injury in zebrafish.

Text: Stephanie Möllmert; pictures: Daniel Wehner (Guck Division)

Directors' foreword

In the period since last summer we have welcomed three new Max Planck Research Group leaders to MPL – the result of their success in the challenging annual competition organized by the Max Planck Society. The first to arrive was Hanieh Fattahi, from MPQ in Garching. She plans to develop a novel technique called "femtosecond fieldoscopy", where molecules are excited by ultrashort, phase-coherent pulses and the complex electric field of the transmitted light, which contains molecular information, is directly measured afterwards. Next to set up at MPL was Pascal Del'Haye, previously at the UK's National Physical Laboratory. His group plans to study nonlinear photonics in ultra-high-Q microresonators, in particular the interaction of counterpropagating light and optical frequency comb generation in whispering gallery resonators. Finally, Katja Zieske joined us in mid-February from UC San Francisco and is currently setting up her labs, which will form part of the Max-Planck-Zentrum für Physik und Medizin (MPZPM). Her research focuses on the emergent behaviour of living systems across multiple length-scales. We are looking forward to the exciting science that will undoubtedly emerge from these three groups.

In other news, at a successful event in January we informed the general public of our plans for the future development of the MPZPM. In addition, late last year we learned that our application to extend the Max-Planck-uOttawa Centre for Extreme and Quantum Photonics for a second 5-year phase was approved – a very nice result in a highly competitive process!

We hope you will find the following brief compilation of some of our most recent research highlights inspiring!

Jochen Guck   Florian Marquardt   Philip Russell   Vahid Sandoghdar

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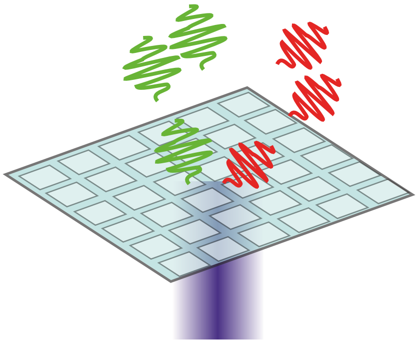
RESEARCH ARTICLE MC Chekhova Research Group

Entangled photons generated from an ultrathin layer

The recent paradigm of 'flat optics' involves linear and nonlinear optical elements implemented on a two-dimensional platform. Many papers report second-harmonic generation and other nonlinear optical effects on metasurfaces and monoatomic layers. However, spontaneous parametric down-conversion (SPDC), the inverse of second harmonic generation, has not yet been observed in a two-dimensional material. An important step in this direction is the generation of entangled photons through SPDC in a lithium niobate layer with an effective thickness of 1.4 µm. As a result of the very small sample thickness, the emitted spectrum is ultrabroad in both frequency (one octave wide) and angular spread (angular range 30°). Because the transverse size of the sample is not restricted, the photons still remain pairwise correlated in angle and frequency, leading to a very high degree of position/momentum and energy/time entanglement. We have experimentally verified broadband emission and strong entanglement using coincidence measurements and stimulated emission tomography.



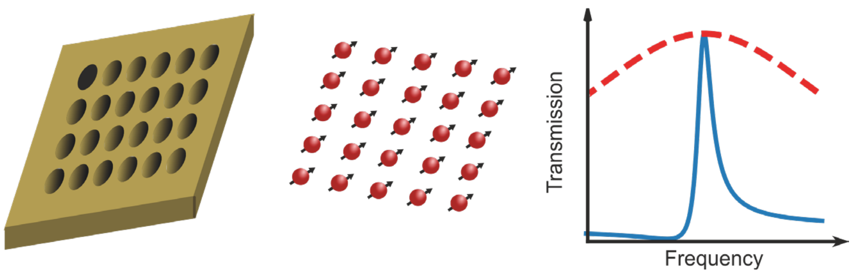
Spontaneous parametric down-conversion in a lithium niobate layer 1.4 µm thick: the first step towards generation of entangled photons from metasurfaces.

Contact: maria.chekhova@mpl.mpg.de
Group: Chekhova Research Group
Reference: C. Okoth, A. Cavanna, T. Santiago-Cruz et al., Phys. Rev. Lett. **123**, 263602 (2019); https://doi.org/10.1103/PhysRevLett.123.263602

RESEARCH ARTICLE CG Genes Research Group

Quantum electrodynamics of hybrid cavities

Two-dimensional photonic crystal structures or atomic mirrors constitute a special category of high quality reflectors that can achieve high reflectivity in an extremely reduced frequency window. Optical resonators formed from such end-mirrors are characterized by narrow, asymmetric transmission profiles and have a variety of applications in for example opto-mechanics and lasers. From a theoretical standpoint, the formulation of an input-output theory at the quantum level for such hybrid cavities is a non-trivial task. One particular difficulty comes from interference effects between the cavity-confined mode and the mirror surface modes. This interference breaks the usual assumption of frequency-insensitive tunnelling rates between the cavity and the outside continuum of modes. We have recently provided a general formalism for the derivation of a quantum theory applicable to any hybrid cavity. In particular, we have illustrated the procedure in the case of Fano cavities with photonic crystal mirrors and described an opto-mechanical application that can achieve cooling without heating.



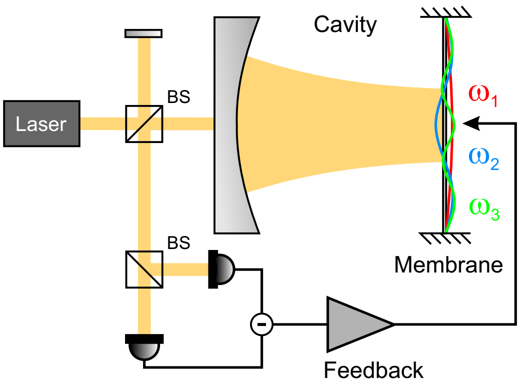
Possible realizations of frequency dependent mirrors as photonic crystal structures or two-dimensional layers of atoms.
On the right side the response of a standard cavity (red line) is compared to the asymmetric narrower response of a hybrid cavity (blue line).

Contact: claudiu.genes@mpl.mpg.de
Group: Genes Research Group
Reference: O. Cernotik, A. Dantan and C. Genes, Phys. Rev. Lett. **122**, 243601 (2019); https://doi.org/10.1103/PhysRevLett.122.243601

RESEARCH ARTICLE CG Genes Research Group

Refrigeration via multimode cold-damping feedback

In opto-mechanical systems, the goal is to control motion down to the level of the quantum ground state where only zero point fluctuations are relevant. A leading technique makes use of an optical cavity to read out the position of the mechanical resonator as a phase shift in reflection or transmission. The information thus acquired is then directed into an electronic feedback loop that dictates the correct cooling action. While this 'cold-damping' technique has proven successful in isolating and extracting the thermal motion of a single vibrational mode, it leaves the overall temperature of the object largely unaltered. We have recently demonstrated theoretically that a single feedback loop can also successfully extract thermal energy from a much larger number of vibrational modes, offering an extended bandwidth of operation for sensing, quantum state swapping etc. Our analytical results suggest that efficient refrigeration requires a specific design of the mechanical resonator vibrational modes that eliminates frequency degeneracy, thus circumventing the effect of thermal energy trapping into collective dark modes.



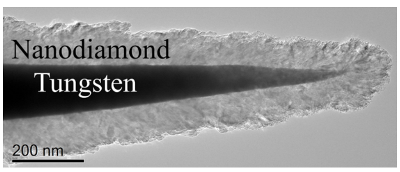
The output of a driven optomechanical cavity is homodyne detected, providing information on the collective displacement of many vibrational modes. A feedback loop is used to apply a force onto the mirror, permitting simultaneous cooling of the thermal fluctuations of many modes (cold-damping effect).

Contact: christian.sommer@mpl.mpg.de
Group: Genes Research Group
Reference: C. Sommer and C. Genes, Phys. Rev. Lett. **123**, 203605 (2019); https://doi.org/10.1103/PhysRevLett.123.203605

RESEARCH ARTICLE PH Hommelhoff Group

Tungsten needle tips coated with nano-diamond: a novel photocathode

Despite the success of ultrafast electron microscopy and other femtosecond electron techniques over the last few decades, the vast majority of electron sources were originally designed for dc operation. We have recently reported a novel photocathode, designed for femtosecond laser-triggered operation, that provides high beam quality. Being chemically inert, mechanically robust and offering a stable surface with negative electron affinity, diamond seems ideally suited as photo-electron emitter. We combined these properties with the high beam quality of nanometric tip-shaped emitters. The robustness of hydrogen-terminated diamond is manifested in superior electron emission stability for all the laser wavelengths and bunch charges investigated, with high estimated peak brightness. We also show that the complex potential landscape at the interfaces between vacuum, nanocrystalline diamond and the graphitic boundaries of the crystallites causes a surprising feature in photoelectron emission: at 512 nm driving wavelength, 3-photon emission (7.2 eV in total) dominates, whereas at 1932 nm, 5-photon emission (3.2 eV total) is sufficient for electron emission.



TEM image of a tungsten tip coated with nanocrystalline diamond in an in-house process.

Contact: alexander.tafel@fau.de
Group: Hommelhoff Max Planck Fellow Group (FAU)
Reference: A. Tafel, S. Meier, J. Ristein et al., Phys. Rev. Lett. **123**, 146802 (2019); https://doi.org/10.1103/PhysRevLett.123.146802

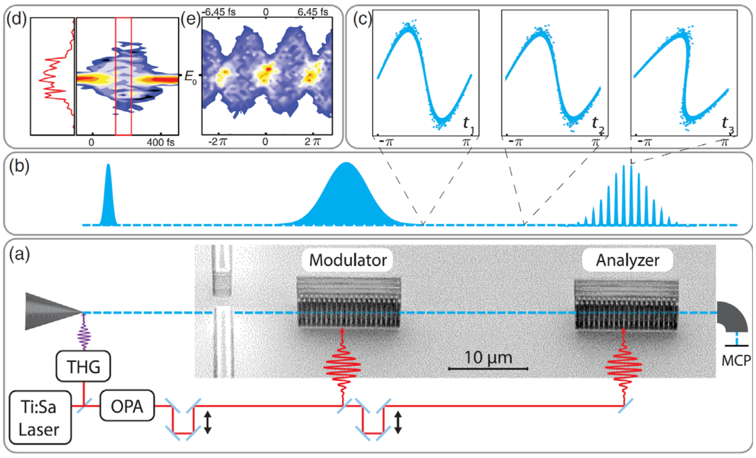
Molecular Polaritonics 2019

Together with Johannes Feist at Universidad Autonoma de Madrid in Spain, Claudiu Genes organised a successful workshop in Miraflores de la Sierra, Madrid, Spain, 8–10 July 2019. The aim was to bring together researchers with expertise in complementary aspects of molecular polaritonics, covering topics such as quantum optics & open quantum systems, quantum chemistry, condensed matter & many-body physics, and macroscopic quantum electrodynamics. Some 50 participants took part. A follow-up workshop, Molecular Polaritonics 2020, is planned for 31 Aug. to 2 Sep. 2020 in Straubing, Germany. www.molecularpolaritonics.org

RESEARCH ARTICLE PH Hommelhoff Group

Generation of attosecond electron pulse trains at photonic structures

With the development of attosecond science, it has become possible to directly observe extremely fast phenomena in nature. In contrast to probing with extreme ultraviolet pulses, when the spatial resolution is limited by diffraction, probing with high energy electrons can improve spatial resolution drastically due to the much shorter de Broglie wavelength. We employ photonics-based laser acceleration to create electron bunch trains with an individual bunch length of 280 attoseconds. Electrons interact with the optical near-field in the vicinity of nanostructures. This interaction modulates the electron energies and since the electrons are subrelativistic, their velocity changes. This velocity modulation causes the electron beam to bunch on the length of an optical cycle: the later electrons catch up with the slower, earlier electrons. At the temporal focus where the highest density is reached we placed another nanostructure to modulate the electrons phase synchronously again. The resulting phase-dependent spectra can be correlated to simulations that allow us to retrieve the temporal duration of the microbunches.



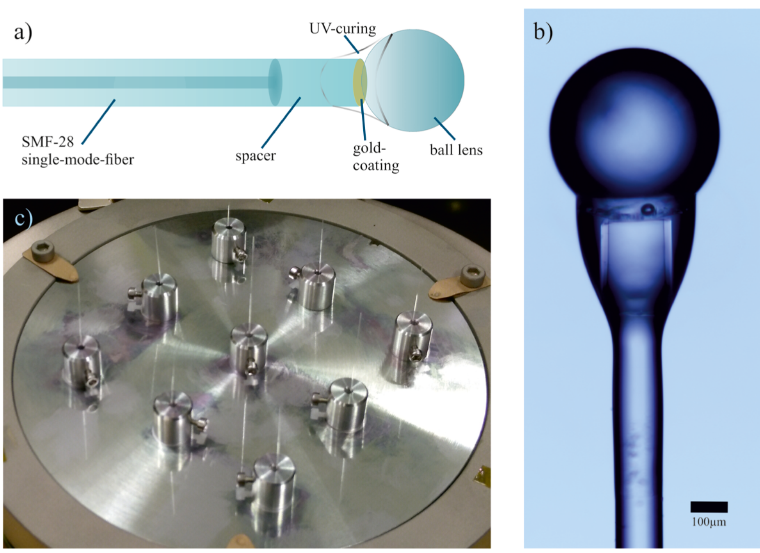
Experimental setup a) Electrons are emitted from a cathode by the photoeffect. After propagation through the electron optics, the electron energy is modulated in the first nano-structure. In a drift section, vacuum dispersion causes the electrons to bunch. In the second nanostructure, the electrons are modulated again and then spectrally analysed with a magnetic spectrometer. b) An electron pulse, initially 100 fs long, broadens to roughly 400 fs in the electron optics and bunches in the drift section. c) Phase-space during bunching. d) Energy spectrum after the modulator and e) energy spectrum after the analyser.

Contact: norbert.schoenenberger@fau.de
Group: Hommelhoff Max Planck Fellow Group (FAU)
Reference: N. Schönenberger, A. Mittelbach, P. Yousefi et al., Phys. Rev. Lett. **123**, 264803 (2019); https://doi.org/10.1103/PhysRevLett.123.264803

RESEARCH ARTICLE KS Singh Research Group

Low cost scalable endoscopic probes

Endoscopic optical coherence tomography is an interferometric imaging technique which, due to its micron-level resolution, has found several applications in medical diagnostics. However, the image quality suffers from artefacts caused by dispersion imbalance and polarisation mismatch between reference and sample arms. Such artefacts can be minimised by using special "common-path-probes" (CPPs) in which the reference surface is placed close to the sample. Previously reported CPPs suffered from a compromise between the reference power and the focal properties. In most cases, the proposed probes were not scalable for industrial applications and required sophisticated machines for fabrication, thus limiting their mass production for clinical use. We propose and demonstrate a simple fabrication procedure which would allow mass-production of CPPs. The probe design uses a thin gold layer as a reference surface, and low-cost ball lenses are used to focus the signal onto the sample. We demonstrated the application of such probes by imaging biological samples such as pig oesophagus and coronary artery.



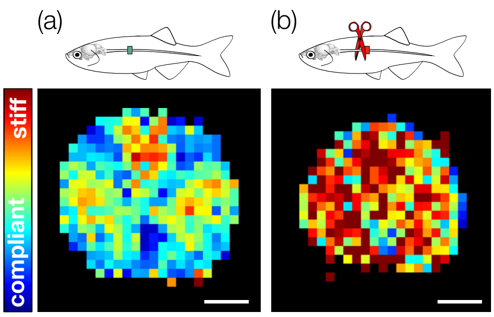
a) Schematic of the common path probe (CPP): a single-mode fibre (SMF28) is directly spliced to a 230 µm long spacer, coated with a layer of gold 7 nm thick. A ball lens is attached to the fibre with UV-curing glue. b) A 10x magnified optical micrograph of the CPP. (c) The sample holder used in the electron-beam evaporator.

Contact: kanwarpal.singh@mpl.mpg.de
Group: Singh Research Group
Reference: K. Blessing, S. Sharma, A. Gumann et al., Eng. Res. Express **1**, 025008 (2019); https://doi.org/10.1088/2631-8695/ab4783

RESEARCH ARTICLE JG Guck Division

Spinal cord tissue stiffens during successful spinal cord regeneration

In humans, traumatic spinal cord injury leads to the formation of scar tissue in and around the injury site. This scar tissue exhibits properties that inhibit nerve fibre regrowth, neuronal regeneration, and functional recovery. Patients remain therefore irreversibly paralyzed. In contrast, zebrafish display remarkable regenerative capacity. They can spontaneously and robustly repair damaged spinal cord tissue and restore lost motor function even after complete spinal cord transection. The regenerating zebrafish spinal cord displays properties that permit nerve fibre regrowth and neuronal regeneration. Contributing to these properties is a distinct mechanical phenotype that, in addition to biochemical factors, might provide equally important signals to damaged and regrowing cell populations residing in the spinal tissue. By employing AFM- based nanoindentation, we identified the spatio-temporal distribution of apparent Young's moduli of the regenerating zebrafish spinal cord and found that, in contrast to the commonly held belief that (re)growing neurons and nerve fibres rely on a particularly compliant environment, the spinal cord stiffens during successful regeneration.

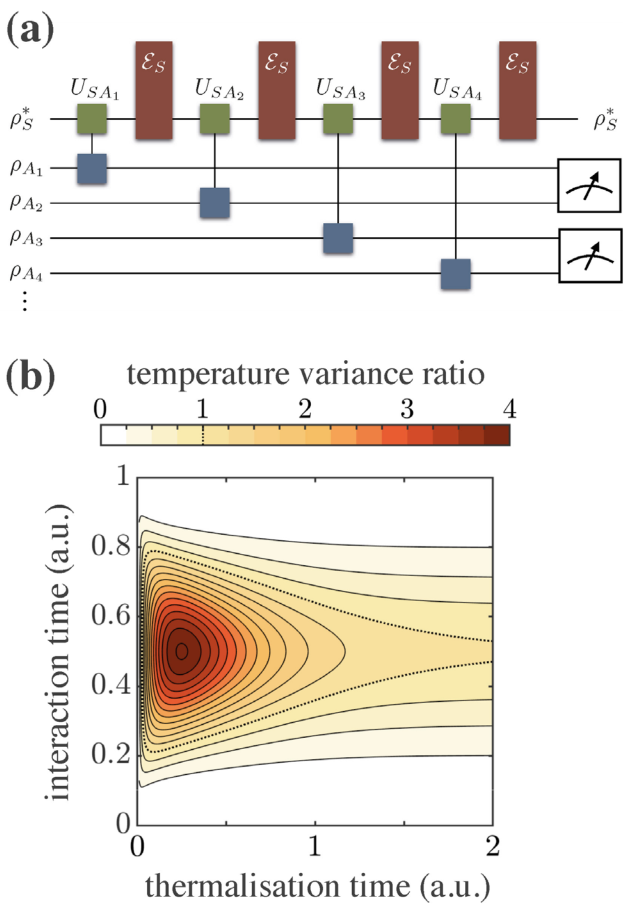


Stiffness maps of zebrafish spinal cord tissue. a) The spatial distribution of apparent elasticity values shows that grey matter (centre) is stiffer than white matter (periphery) in spinal cord tissue sections obtained from uninjured adult zebrafish. b) In the course of spinal cord regeneration, apparent elasticity values increase significantly in all areas of the spinal cord tissue. Scale-bars: 100 µm.

Contact: stephanie.moellmert@mpl.mpg.de
Group: Guck Division
Reference: S. Möllmert, M. A. Kharlamova, T. Hoche et al., Biophysical Journal **118**, 448-463 (2020);
https://doi.org/10.1016/j.bpj.2019.10.044

RESEARCH ARTICLE FM Marquardt Division

Collisional quantum thermometry



How precise can thermometers be? Typically, in the quantum regime, we measure the temperature of a thermal reservoir by sending in probes that exchange energy with it and then detecting their quantum states. In theory, one attains maximum precision (i.e. minimum error in the temperature estimate) for independent probes if each probe reaches thermal equilibrium with the reservoir before detection. In practice, however, reservoir-probe interactions might be too weak or the very presence of the probes could disrupt thermalisation. It turns out that one can circumvent the equilibrium precision limit by subjecting the reservoir to rapid repeated collisions with a stream of identical probes. This drives a local subsystem of the reservoir out of equilibrium, while thermal relaxation tries to push it back. As a result, the probes detect temperature not only through the average thermal statistics of the reservoir, but also through its relaxation rate. Ideally, the precision per probe will improve by a large temperature-dependent factor. When reservoir-probe interactions are weak, quantum correlations building up between subsequent probes result in a collective boost in measurement precision.

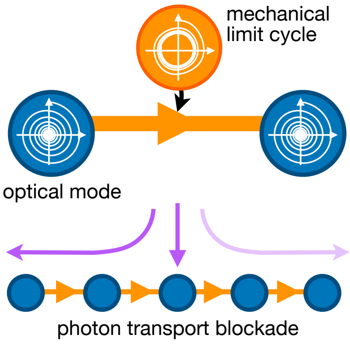
(a) Circuit diagram of a thermometry protocol with qubits. A reservoir qubit interacts, successively, with four probe qubits and partially thermalizes in between. The probes are then measured in pairs. (b) Sensitivity boost in one example, as a function of reservoir-probe interaction time and intervening thermalisation time.

Contact: stefan.nimmrichter@mpl.mpg.de **Group:** Marquardt Division
Reference: S. Seah, S. Nimmrichter, D. Grimmer et al., Phys. Rev. Lett. **123**, 180602 (2019);
https://doi.org/10.1103/PhysRevLett.123.180602

RESEARCH ARTICLE FM Marquardt Division

Dynamically generated synthetic electric fields for photons

The effects of a magnetic field on charged particles are qualitatively profound, leading from the Lorentz force to the quantum Hall effect and to topologically protected chiral edge channels. So-called artificial gauge fields try to mimic this physics even for neutral particles like photons. When the gauge field can change in response to particle motion it is called "dynamical". Recently, we introduced dynamical gauge fields for photons, brought about by optomechanical interactions with mechanical limit cycle oscillators. In our newest study, we discovered that even a 1D array can show surprising nontrivial dynamics, despite the absence of loops that permit an Aharonov-Bohm phase to be accumulated. We found that in certain regimes the system happens to undergo a spontaneous transition towards a symmetry-broken phase with a finite artificial electric field. Its emergence coincides with an asymmetric blockade of transport, where photons travelling in one direction are blocked while they can flow freely in the opposite direction. This behaviour, which sets in only above a certain light intensity, essentially produces an optical diode, enabled by mechanical vibrations.



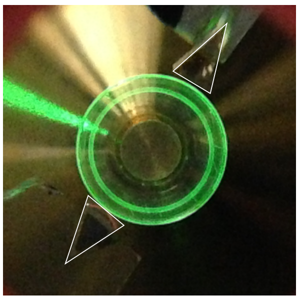
A mechanical limit cycle oscillator can produce a phonon-assisted photon transition between two optical modes. This effectively generates a mechanical dynamical gauge field for the photons. In a 1D array, our study shows this can result in the spontaneous generation of an artificial electric field, leading to a transport blockade phenomenon.

Contact: florian.marquardt@mpl.mpg.de
Group: Marquardt Division
Reference: P. Zapletal, S. Walter and F. Marquardt, Phys. Rev. A **100**, 023804 (2019);
https://doi.org/10.1103/PhysRevA.100.023804

RESEARCH ARTICLE CM C. Marquardt Research Group

Squeezed vacuum states from a whispering gallery mode resonator

Squeezed vacuum states of light are a valuable resource in various quantum applications, ranging from metrology and quantum communication to continuous variable quantum computing. But real world applications put stringent requirements on the size and power consumption of the nonclassical light source. We have recently reported the use of a crystalline whispering gallery mode resonator (WGMR) as such a source. A monolithic resonator, diamond-turned from lithium niobate, offers ultrahigh optical Q-factors, and benefits from a high second order optical nonlinearity, yielding extremely low thresholds (only a few μW) for parametric oscillation. Stringent phase-matching requirements and thermorefractive noise have, however, rendered the generation of squeezed vacuum states in such systems a challenge. For the first time with a crystalline WGMR, we have been able to verify the generation of genuinely single-mode squeezed vacuum states of light, achieving 1.4 dB of squeezing for only 300μW of pump power. The results show that a platform based on WGMRs can function as a compact and low power source of nonclassical light, ranging from tunable single photons to continuous variable quantum states of light.



Top view of the crystalline whispering gallery mode resonator with two diamond prisms used for evanescent coupling. The resonator is pumped at 532 nm, causing a green glow.

Contact: alexander.otterpohl@mpl.mpg.de
Group: C. Marquardt Research Group
Reference: A. Otterpohl, F. Sedlmeir, U. Vogl et al., Optica **6**, 1375-1380 (2019);
https://doi.org/10.1364/OPTICA.6.001375

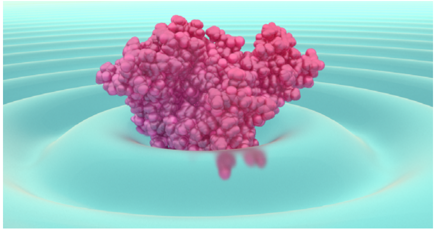
International Workshop on Interferometric Scattering Microscopy (iSCAT)

Elastic scattering is the most ubiquitous and oldest optical contrast mechanism. We are organizing an international workshop to discuss the emergence, current state and potential of iSCAT as the most sensitive method for the detection of elastic scattering from nanoparticles down to small proteins and at very high spatiotemporal resolution. A hands-on tutorial session will familiarize the participants with the experimental nuances of this powerful technique. For more information, please see http://bit.ly/iSCAT-Mpl.

RESEARCH ARTICLE VS Sandoghdar Division

iSCAT microscopy of nanoparticles & molecules via Rayleigh scattering

Fluorescence microscopy is the go-to technique for investigating optical phenomena at the nanoscale across various disciplines. However, as an optical contrast mechanism, fluorescence confronts several fundamental limitations which ultimately throttle its performance. Consequently, there has been a flurry of activities towards the development of fluorescent-free imaging methods. A decade and a half of research in the Sandoghdar group has shown that elastic scattering - the most ubiquitous and oldest optical contrast mechanism - offers excellent opportunities for sensitive detection and imaging of individual molecules and nanoparticles and that, at very high spatiotemporal resolution. In a recent review we sought to unify this technique, which we named iSCAT (for interferometric detection of scattering), with other established microscopies. The rapidly growing catalogue of iSCAT applications allowed us to present a cutting-edge showcase of recent experimental progress across the world and to discuss future challenges in a field that is having an impact in life sciences, material science, chemistry and physics.



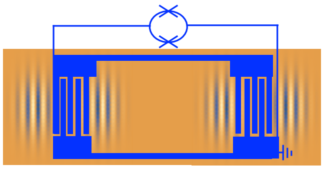
Interferometric detection of Rayleigh scattering permits sensitive detection of nanoscale objects as small as single proteins.

Group: Sandoghdar Division
Contact: richard.taylor@mpl.mpg.de
Reference: R. W. Taylor and V. Sandoghdar, Nano Letters **19**, 4827-4835 (2019); https://doi.org/10.1021/acs.nanolett.9b01822

RESEARCH ARTICLE FM Marquardt Division

Non-exponential decay of a giant artificial atom

In quantum optics, light-matter interactions are usually studied in situations where small (possibly artificial) atoms interact with light or microwaves, whose wavelengths are much larger than the atomic dimensions. Recently, however, experiments have shown that a superconducting qubit (a two-level artificial atom) can be engineered to interact with a surface acoustic wave (SAW) whose wavelength is several orders of magnitude smaller than the atom. In such a system, the atom cannot be treated as a point-like model with a local dipole coupling. Instead, the superconducting qubit couples non-locally to the SAW field and can be viewed as a giant atom, representing a new paradigm of research in quantum optics. Our recent study pushes the research of giant atoms further to the non-Markovian regime, due to the slow velocity of sound (five orders of magnitude smaller than the light speed) leading to a significant internal time-delay for the SAWs to propagate across the giant atom. In recent joint work with the experimental group at Chalmers, we demonstrate for the first time non-exponential spontaneous emission from a giant atom, perfectly confirming our theoretical predictions.



A giant atom scheme is achieved by coupling the superconducting artificial atom (blue) to a piezoelectric substrate (orange) with two distant interdigital transducers (finger-like structures). The giant atom irradiates energy via surface acoustic waves (ripples), in a non-exponential way.

Contact: lingzhen.guo@mpl.mpg.de
Group: Marquardt Division
Reference: G. Andersson, B. Suri, L. Guo et al., Nat. Phys. **15**, 1123–1127 (2019); https://doi.org/10.1038/s41567-019-0605-6

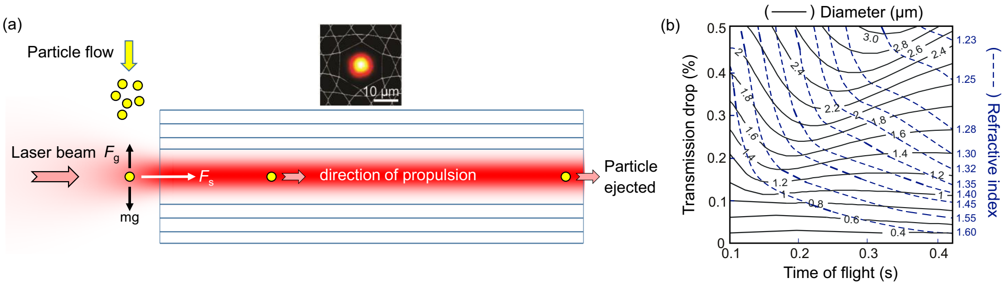
New members

Three new leaders of independent Max Planck Research Groups have joined MPL in recent months. **Hanieh Fattahi** from MPQ in Garching arrived in October 2019. She plans to focus on novel methods for detecting the complex electromagnetic field of molecular response when excited by near-infrared femtosecond pulses. **Pascal Del'Haye** joined us in January 2020 from NPL in the UK. He plans to work on integrated microphotonic devices and nonlinear optics in whispering gallery mode microresonators. And **Katja Zieske** joined us from the University of California in San Francisco in February 2020. As a member of the Max Planck Zentrum für Physik und Medizin, she plans to engineer light-activatable tissues and reconstitute mechanisms underlying tissue morphogenesis using artificial lipid membranes and synthetic biology. On the technical front, **Linda Weise, Malte Spiekermann** and **Josef Lagler** are new laboratory engineers in the fibre drawing unit (TDSU3), and **Parth Patel** has joined the Guck Division. MPL's administration has also made several new appointments: **Dr. Matthias Bär** (head of IT), **Monika Baier** (Finance), **Clarissa Grygier** (Public relations), **Mona Schneider** (Travel, Welcome Center), and **Andrea Schmelmer** (Human Resources).

RESEARCH ARTICLE PR Russell Division

On-the-fly particle metrology in hollow-core photonic crystal fibre

Efficient monitoring of airborne particulate matter is crucial for improving public health. We have recently reported a novel technique for airborne particle metrology based on hollow-core photonic crystal fibre (HC-PCF). It offers in-situ particle counting, sizing and refractive index measurement, together with an effectively unlimited device lifetime. Light from a CW laser source is launched into the LP01-like core mode of a HC-PCF, positioned inside a chamber. When an airborne particle enters the beam path, it is automatically captured by the gradient force in the transverse direction and propelled through the fibre core by the scattering force. Once in the core, the particle scatters a fraction of the guided light, resulting in a drop in transmission that is detected by a photodiode. The transmission drop and the time-of-flight can be used to unambiguously determine the particle diameter and refractive index with high accuracy. The technique can be directly applied to monitoring air pollution in the open atmosphere as well as precise particle characterization in a confined environment.



(a) Sketch illustrating the operating principle of on-the-fly particle metrology. (b) Contour plot (theory) of particle diameter and refractive index versus transmission drop and time-of-flight.

Highlighted in:

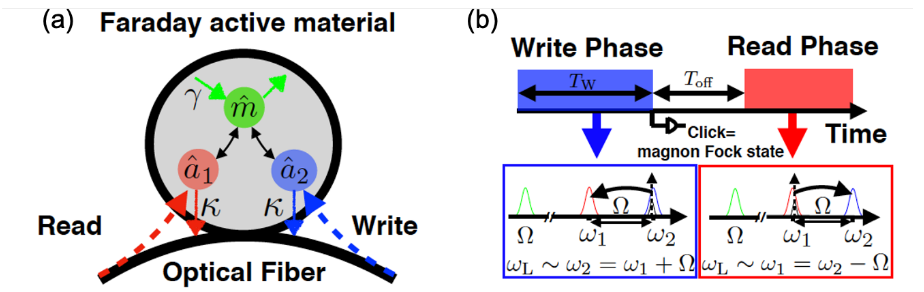
Phys.org | OSA News release | Physics World | LaserFocusWorld | ScienceDaily | Welt der Physik

Contact: shangran.xie@mpl.mpg.de
Group: Russell Division
Reference: A. Sharma et al., Opt. Exp. **27**, 34496-34504 (2019). https://doi.org/10.1364/OE.27.034496

RESEARCH ARTICLE SVK Viola Kusminskiy Research Group

Magnon heralding in cavity optomagnonics

In optomagnonics, photons couple coherently to the collective excitations of magnetic solid-state systems (magnons). The ability to write, store, and read out quantum states is essential for their successful integration with other hybrid quantum systems. In recent work we proposed an all-optical protocol for generating and reading out magnon Fock states in an optomagnonic cavity setup. A Fock state, characterized by a definite number of magnons, is the simplest purely nonclassical state (in the sense that its Wigner function in nonpositive) and can be thought as a building block for more complex quantum states. Our protocol, which is inspired by the DLCZ protocol (Duan, Lukin, Cirac, and Zoller, 2001), is akin to protocols implemented recently in atomic and optomechanical systems. We showed that its experimental feasibility in optomagnonics requires an improvement of five orders of magnitude with respect to the current state-of-the-art cooperativity. This requirement, although challenging, could be fulfilled in new-generation experiments.



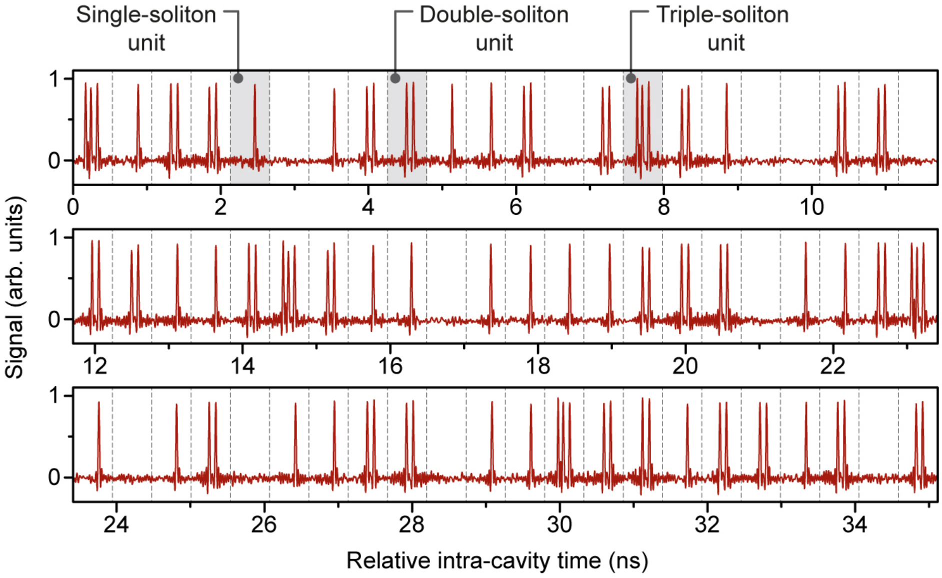
(a) Proposed setup. A dielectric Faraday active material (e.g. yttrium iron garnet) hosts two optical cavity modes which can be driven externally, and a magnon mode. (b) Heralding protocol: The write mode is tuned by pumping optical mode 2 at resonance. A single-magnon Fock state is produced by the easurement of a photon in mode 1, and can be retrieved later in mode 2 by pumping mode 1 at resonance.

Contact: victor.bittencourt@mpl.mpg.de
Group: Viola Kusminsky Research Group
Reference: V. A. S. V. Bittencourt, V. Feulner and S. Viola Kusminskiy, Phys. Rev. A **100**, 013810 (2019); https://doi.org/10.1103/PhysRevA.100.013810

RESEARCH ARTICLE PR Russell Division

Optoacoustically ordered soliton supramolecules

Optical solitons are particle-like packets of light that have been extensively studied, not least because they behave like nonlinear attractors. They can form compact "soliton molecules" - analogous with chemical molecules - when they partially overlap. In recent work, we formed "soliton supramolecules" by carefully tailoring long-range soliton interactions in a fibre laser cavity. The key element is a short length of small-core photonic crystal fibre, which greatly enhances long-range soliton interactions by its high optomechanical nonlinearity. The GHz-rate acoustic resonance in the core introduces an optomechanical lattice that divides the fibre cavity into hundreds of time-slots. Each time-slot can accommodate solitons and soliton molecules that are bound at distances much greater than the soliton duration due to balanced long-range forces exerted by optoacoustic effects and dispersive wave perturbations. Consequently, stable and highly-ordered supramolecular structures consisting of hundreds of solitons can be formed in a self-organized fashion with multiple levels of complexity and flexibility, resembling their biochemical counterparts in many ways. These structures may be useful for all-optical storage and manipulation of digital information.



Part of the stable soliton supramolecule emitted by an optoacoustically mode-locked fibre laser. The structure follows a regular time-grid (marked by the dashed lines) determined by the acoustic core resonance in the PCF. Each grid unit can accommodate null, single, or multiple solitons (sub 1 ps duration) bound at long range (~100 ps) by balanced optomechanical and optical forces.

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Reference: W. He, M. Pang, D. H. Yeh, Nat. Commun. **10**, 5756 (2019); https://doi.org/10.1038/s41467-019-13746-6;
Selected as one of the top 50 most read physics articles published by Nature Communications in 2019.

10th IMPRS-PL Annual Meeting & 6th Autumn Academy 2019

The joint Annual Meeting and Autumn Academy 2019, organized by the International Max Planck Research School: Physics of Light (IMPRS-PL), took place between October 7th and 11th. Invited lecturers and supervisors joined 45 students in Kühnhofen east of Nuremberg for a week of learning, exchanging ideas and socializing. Students presented their work in talks and posters, and attended block lectures tailored to their needs. Of particular interest were invited talks by Markus Aspelmeyer, Cornelia Denz, Thierry Grosjean and Irina Kabakova and the poster sessions, which sparked animated conversations until late into the night. Marc-Oliver Pleinert won the best poster award, and Victor Distler and Cameron Okoth received awards for the best student talks. An undisputed highlight was a discussion, organized by the student representative, in which students seized the opportunity to ask questions on a variety of topics of the invited panelists, who moved from table to table, creating a very personal and engaging atmosphere. The week ended with a presentation by IMPRS-PL alumnus Christian Schaller, followed by laboratory tours at MPL.

RESEARCH ARTICLE PR Russell Division

Chiral Bloch wave optics in twisted PCF (Review)

Work on chirally twisted photonic crystal fibre (PCF), formed either by spinning the preform during fibre drawing or by thermal post-processing, began at MPL in 2011 and led to the publication in 2012 of a paper connecting narrow spectral transmission dips to OAM-carrying cladding modes [1]. Since this early work, we have steadily built up a better and better understanding of the behaviour light in twisted PCFs, especially concerning the link between orbital angular momentum, spin and circular birefringence. The non-circularity of the modes guided in PCF means that they are forced to rotate as they propagate in twisted PCF, inducing many interesting effects including circular birefringence and permitting generation of a bright, ultra-broad-band supercontinuum that is robustly circularly polarised across its entire bandwidth [2]. This source has many potential applictions, for example in the spectroscopy of dichroic chiral biomolecules such as proteins. Another unusual result is a twisted single-ring hollow-core PCF that exhibits strong circular dichroism, even though it is made only from isotropic materials [3]. Depending on the chirality, light in one circular polarisation state couples strongly to leaky modes in the surrounding capillaries, experiencing high loss, while orthogonally polarised light is transmitted with low loss (see Fig. 1). These unique fibres may be useful in photochemistry of chiral isomeric molecules and realising polarising elements in the vacuum ultraviolet. Perhaps the most intriguing result concerns the guidance of light in twisted coreless PCF, despite the absence of any discernible core structure (Fig. 2) [4]. One of the most curious physical phenomena to have emerged in guided wave optics in recent years, this effect arises from the properties of chirally distorted 2D periodic space, within which the Bloch-wave-rays follow spiral geodesic paths, trapped by photonic bandgap effects. Interferometric measurement of the near-field phase and amplitude distributions of the fields of the resulting helical Bloch modes (HBMs) shows that twisted coreless PCF supports a family of different circularly polarised modes, each consisting of a unique lattice of phase singularities [5].

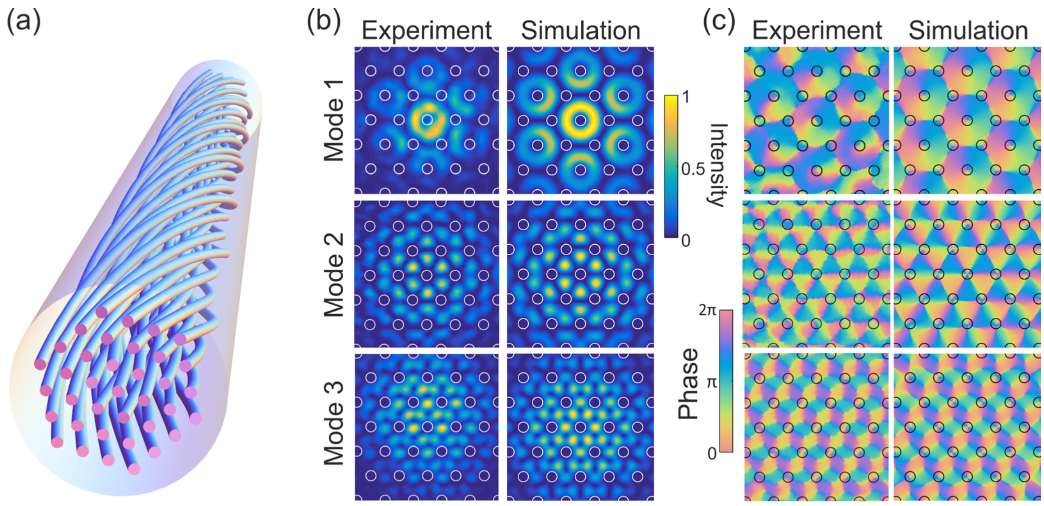

Fig. 2. (a) Sketch of a twisted coreless PCF. The axis of rotation coincides with the hollow channel in the centre. (b) Near-field intensity distributions for LCP versions of three different modes. (c) Corresponding phase distributions for (b).

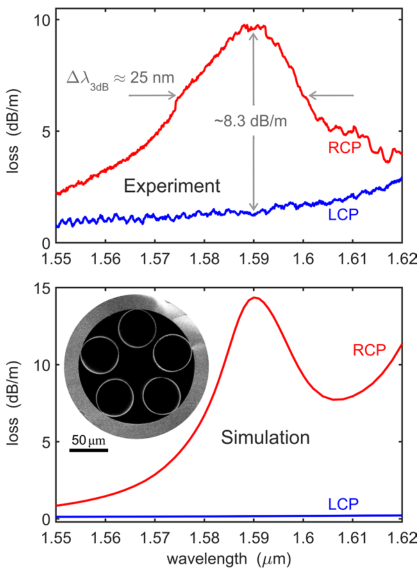

Fig. 1. Measured (upper) and numerically modelled (lower) modal loss spectrum of RCP and LCP core modes in a twisted single-ring hollow-core PCF with five thin-walled capillaries surrounding the core (inset).

1. 2. 3. 4. 5.

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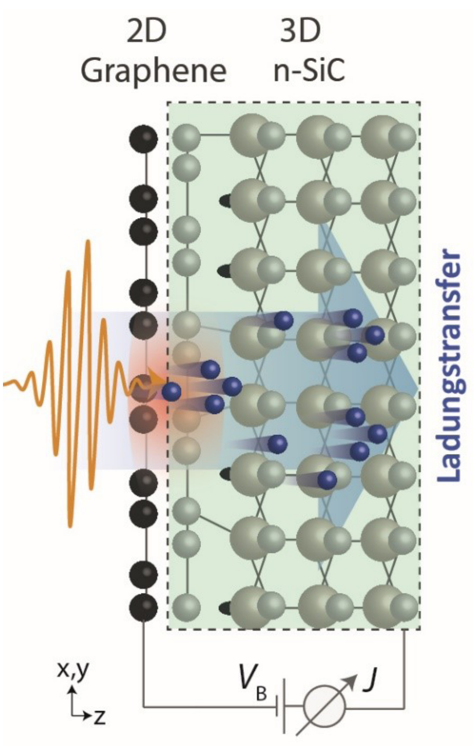
RESEARCH ARTICLE PH Peter Hommelhoff

How fast can charge be transferred from one material to another?



Charge separation at an interface between materials is a fundamental process in electronic components. It determines how fast electronic signals can be transmitted in transistors and how efficiently power is generated in solar cells. Novel combinations of stacked two-dimensional materials allow such interfaces to be tailored on the atomic scale. In order to investigate how fast charge transfer takes place at such an interface, we used the 2D semi-metal graphene attached to the semiconductor silicon carbide (SiC). We showed that charge transfer can take place within 300 attoseconds, representing the fastest charge transfer across a solid-state interface. To measure the charge transfer time, we focused femtosecond laser pulses onto the interface and use saturable absorption in graphene as an intrinsic clock to determine the lifetime of a photoexcited electron prior to charge transfer into SiC or inelastic scattering. The root cause for this extremely fast charge transfer time lies in the choice of materials: the atomically thin graphene, with photo-excited electrons right next to the interface, and the wide-bandgap 3D semiconductor, ideally suited to receive the excited electrons.

Electrons (blue) excited by femtosecond laser pulses in graphene (top layer) are transferred to SiC within a very fast 300 attoseconds, as a result of the atomically small dimensions.

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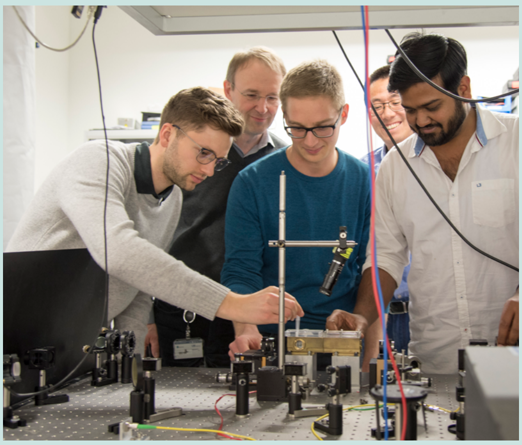
Reference: C. Heide, M. Hauck, T. Higuchi et al., Nat. Phot. **14**, 219-222 (2020); https://doi.org/10.1038/s41566-019-0580-6

DFG project by Shangran Xie & Bernhard Schmauß

A two-year DFG project, initiated by Dr. Shangran Xie (team leader in the Russell Division) and Prof. Bernhard Schmauß (Institute of Microwaves and Photonics, FAU), has been recently funded. The aim is to develop high spatial-resolution multi-parameter flying particle sensors in hollow-core photonic crystal fibre. The project combines particle trapping and guidance at MPL with a high-precision particle localization technique developed at FAU in which optical frequency domain reflectometry is used to accurately locate the axial position of optically trapped microparticles in the hollow core. These particles function as sensors, permitting multiple measurands to be probed close to the fibre with µm spatial resolution over km-long distances. Latest results show that resolutions of a few µm can be achieved for polystyrene particles 1.65 µm in diameter, which is two orders of magnitude better than in previously reported techniques.



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