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for the science of light

MPL News

MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT
NEWSLETTER
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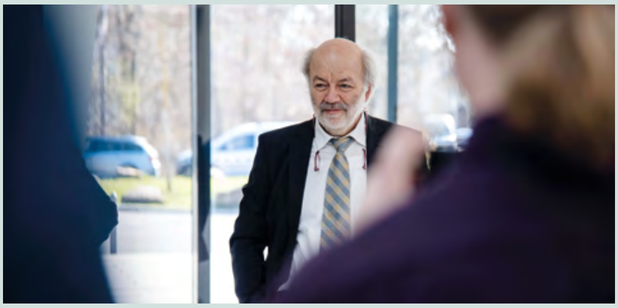
Retirement of Gerd Leuchs

The most significant item of news from MPL is that Gerd Leuchs, MPL's founding director, retired at the end of March 2019. An alumni symposium was secretly organised for him on March 29, attended by more than 80 former students, post-docs, co-workers, current division members and friends from all over the world. He said he was never so surprised in his life! The participants shared their very personal recollections of Gerd as colleague or boss, emphasising his positive influence on their lives and careers, and showing their wholehearted appreciation. This heart-warming event was followed by lab tours, a poster session and a joint dinner. A quote from Peter Banzer, "Thank you, Gerd. It has been a true honour to know you and to work with you" is echoed by all of us at MPL. We wish him a long, healthy and happy retirement, though retirement is not perhaps the best word, since he shows no sign of slowing down. Apart from the activities of his Emeritus group, he is involved in a multi-partner consortium that is planning a multi-million-Euro project on quantum communications systems, to be funded by the federal government.



Directors' foreword

It seems quite suitable to begin by mentioning the large number of new developments at MPL during the recent half year. But since such changes seem to be normal at MPL, let us pass on and take a look into the future. In March we held a Future-Leaders-Symposium with the aim of identifying possible rising stars on the international stage. It was a pleasure to learn about the remarkable work being done by the 15 selected young scientists, and get a feel for future directions in the Science of Light.

An important element in the near future of MPL is the Max-Planck-Zentrum für Physik und Medizin (MPZPM). Though not yet having its own building, MPZPM's research has already resulted in a joint publication with MPL's Sandoghdar division, and new director Jochen Guck and his team have set up a novel diagnostic tool for blood cell analysis at the Universitätsklinikum in Erlangen. In addition to MPZPM Professor Vasily Zaburdaev (FAU, Biomathematics), a second appointment in Medical Physics and Micro-Tissue Engineering is about to be announced. As mentioned in the last issue, Kanwarpal Singh and Birgit Stiller have begun setting up their independent Max Planck Research Groups (MPRGs), which leads us to yet more good news: three further MPRG leaders have chosen to base their groups at MPL. We are currently making sure these new MPRGs have the resources needed to become rapidly productive.

We are also delighted to report that MPL's founding Director Gerd Leuchs, who officially retired in March 2019, will be staying with us, leading an Emeritus Group. Together with Christoph Marquardt he is also involved in setting up a nation-wide project on quantum key distribution, which is likely to be funded by a mega-grant from the Federal Ministry of Education and Research (BMBF). Once the contracts are signed this will keep him and his team very busy over the next several years!

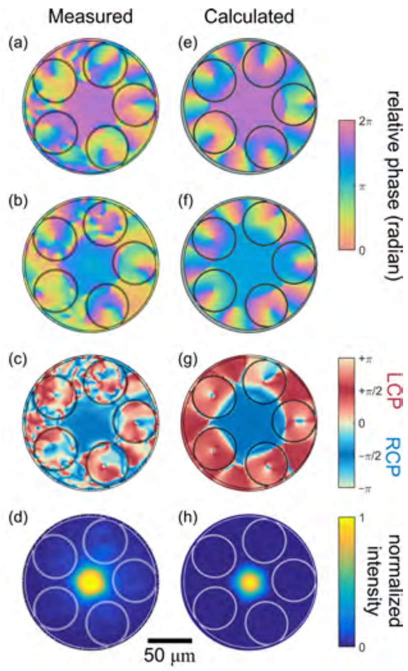
Last but not least, on May 16 we celebrated, with colleagues and guests, MPL's 10th anniversary on the occasion of the International Day of Light. The past and the future look bright here at MPL!

Jochen Guck   Florian Marquardt   Philip Russell   Vahid Sandoghdar

CONTENT

RESEARCH ARTICLE PR Russell Division

Strong circular dichroism in twisted hollow-core PCFs



Circular dichroism (CD), which occurs when the absorption rate depends on the direction of spin of the electric field, is commonly used to probe chirally active molecules such as proteins. We recently demonstrated strong CD for the fundamental core mode (the HE11 mode) in a twisted photonic crystal fiber (PCF) consisting of an "anti-resonant" ring of thin-walled capillaries surrounding a hollow core. This novel effect is purely a property of the chiral geometry of the fibre, not the materials from which it is made (glass and air). Light in a given circular polarization state couples strongly to leaky modes in the capillary ring, experiencing high loss, while orthogonally polarized light is efficiently transmitted. We also report that the complex vector fields of the helical Bloch modes are azimuthally periodic when evaluated in cylindrical coordinates. These unique chiral fibers may be useful in many contexts, including generating pure circularly polarized light in the deep and vacuum UV, photo-chemistry of chiral isomeric molecules, elimination of polarization mode dispersion and polarization instability, and realizing polarizing elements in the deep and vacuum ultraviolet.

(a)–(b) Measured near-field phase distributions at the output of a 1.2 m length of fiber when 1550 nm RCP light is launched into the core (LCP light is transmitted with low loss).
(a) Horizontal electric field component.
(b) Vertical field component.
(c) Polarization state distribution calculated from (a) and (b).
(d) Measured near-field intensity distribution.
(e)–(h) Corresponding numerically calculated distributions, based on a scanning electron micrograph of the actual fiber structure.

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REFERENCE P. Roth et al., Optica **5**, 1315-1321 (2018)
https://doi.org/10.1364/OPTICA.5.001315

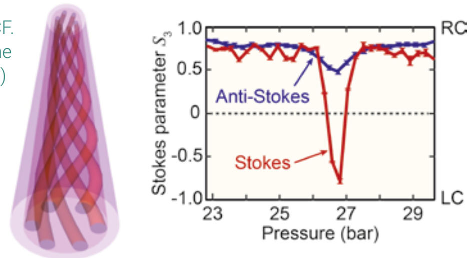
New division: Biological Optomechanics

Although Jochen Guck formally joined MPL last October as its 5th director, the relocation of his lab from TU Dresden to Erlangen is still in progress. His biological optomechanics division plans to explore the physical properties of cells and tissues using novel photonic and biophysical tools to test their biological importance, the aim being ultimately to transfer the insights gained to medical applications. This last aspect – improved diagnosis of diseases and novel approaches in regenerative medicine – fits perfectly to the new Max-Planck-Zentrum für Physik und Medizin, which he is – jointly with Vahid Sandoghdar – in the process of establishing. Jochen Guck studied physics in Würzburg (Vordiplom 1995) and obtained his Ph.D. from the University of Texas in 2001. After a 5-year stint as a junior group leader at the University of Leipzig, in 2007 he became Lecturer and then Reader at the Cavendish Laboratory in Cambridge University, UK. With his move to the TU Dresden in 2012, Jochen Guck received a prestigious Alexander von Humboldt Professorship – as did Vahid Sandoghdar and Oscar Painter before him. His work in biophotonics has been recognized by the "Young Scientists Award" of the German Cancer Research Centre (DKFZ), the "Cozarelli Award" of the National Academy of Sciences (USA) and the "Paterson Medal" of the Institute of Physics (UK).

RESEARCH ARTICLE PR Russell Division

Chiral stimulated Raman scattering

As a novel platform for chiral nonlinear interactions, twisted hollow-core photonic crystal fibre filled with gas opens up new perspectives for broadband light sources with controllable polarisation state. The circular birefringence of these chiral fibres permits robust preservation of the spin of light against external perturbations over unprecedentedly long distances. This property, along with a high damage threshold and broad transmission window, makes it possible to generate pure circularly-polarised Stokes and anti-Stokes signals by rotational Raman scattering in hydrogen. The polarisation state of the frequency-shifted Raman bands can be continuously varied by tuning the gas pressure in the vicinity of the gain-suppression point, as shown in the figure. These results pave the way towards new compact fibre-based approaches for generation, control and delivery of broadband circularly polarised light.



(Left) Artist's impression of twisted hollow-core PCF. (Right) Pressure tunability of the polarisation state of the Raman sidebands (represented by the Stokes parameter S_3) around the coherent gain suppression point.

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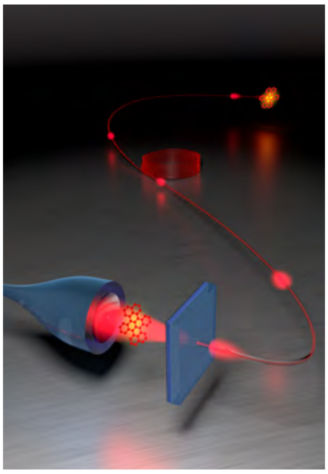
REFERENCE S. Davtyan et al., Phys. Rev. Lett. **122**, 143902 (2019)
https://doi.org/10.1103/PhysRevLett.122.143902

RESEARCH ARTICLE VS Sandoghdar Division

Turning a molecule into a two-level atom



Single photons emitted by a single molecule interact with another molecule which is coupled to a microcavity.

The complex internal structure and dynamics of molecules are governed by the laws of quantum mechanics and could lend themselves to emerging activities in quantum engineering. However, physicists usually shy away from the complexity, associating molecules with less familiar work in chemistry or biology. We have now shown that an organic molecule can be optically modified to act as a simple two-level atom. A single molecule is coupled to an ultra-small scannable Fabry-Perot cavity at the onset of strong coupling. The large enhancement of one of the many transitions in such a multilevel system renders the others negligible so that the molecule effectively behaves as a two-level quantum system. As a result, the molecule can imprint a 99% extinction dip on a laser beam and change its phase by ±66°. Photons that are resonant with the molecule-cavity-system are simply reflected! It also turns out that half a photon per lifetime is sufficient to saturate the molecule so that the molecule acts as a photon sorter: it preferentially reflects single photons, while two or more photons are more likely to pass.

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REFERENCE D. Wang et al., Nat. Phys **15**, 483–489 (2019) https://doi.org/10.1038/s41567-019-0436-5

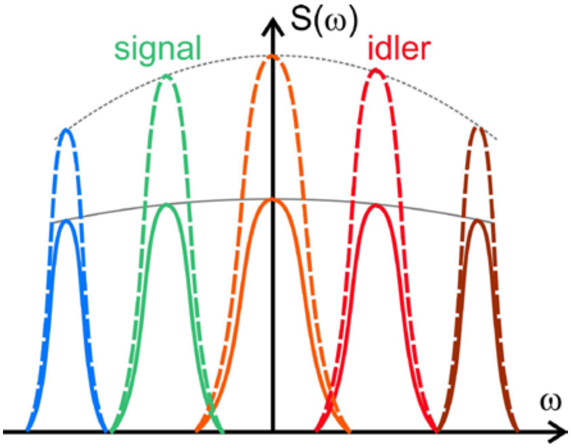
In memoriam: Roy Jay Glauber

We note with sadness the passing on December 26, 2018 of Roy Jay Glauber, Nobel Prize winner, founding father of quantum optics and much valued member of MPL's scientific advisory board (SAB). We are keenly aware of how much the successful formation of MPL depended on the support and guidance of Professor Glauber and his fellow committee members. He participated in all of MPL's biennial evaluations, the last of which took place in early 2017. We very much appreciated his advice on scientific issues as well as his dry quick-fire sense of humour, his common-sense, and his feeling for what is just in interpersonal relations. He will be greatly missed.

RESEARCH ARTICLE MC Chekhova Research Group

Electromagnetic vacuum helps calibrate a spectral device

In quantum optics, vacuum is not just "nothing", but contains fluctuations of the electromagnetic field. The brightness of these fluctuations depends only on the frequency and thus represents a natural radiometric standard. Although vacuum field fluctuations cannot be detected directly, they can be visualized through spontaneous parametric down-conversion, when they act as a seed. In recent joint work with the University of Ottawa, we used this fact to develop a method for calibrating a spectrometer. We tuned the wavelengths of signal and idler twin beams generated through high-gain parametric down-conversion and compared the registered spectrum with the one expected from the known "vacuum brightness", when the peaks lie on a parabola (solid lines in the figure). This procedure allowed us to measure the relative spectrometer sensitivity. As the parametric gain increases, the parabola becomes more pronounced (dashed lines in the figure), enabling absolute calibration of the spectrometer and measurement of the quantum efficiency of the spectrometer as a function of frequency.



The spectrum of parametric down-conversion follows a 'standard' parabolic shape (black solid line). At a higher parametric gain, the parabola becomes more pronounced (black dashed line).

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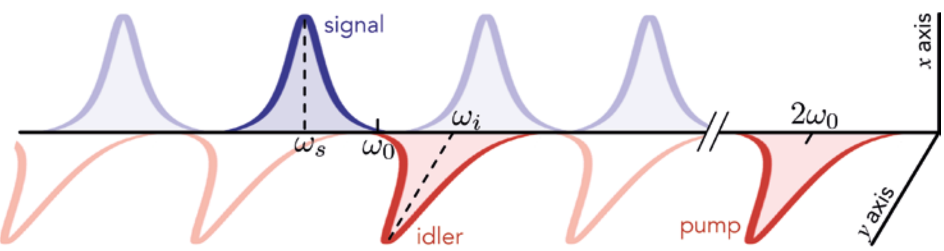
REFERENCE S. Lemieux et al., Nat. Phys. **15**, 529–532 (2019)
https://doi.org/10.1038/s41567-019-0447-2

RESEARCH ARTICLE FM Marquardt Division

Active locking and entanglement in type II optical parametric oscillators

Optical parametric oscillators (OPOs) are amongst the most tunable sources of coherent light, as well as providing highest-quality quantum-correlated light in the continuous-variable regime. They consist of an optical cavity containing a nonlinear crystal, such that when pumped with a laser at frequency $2\omega_0$, they can generate signal and idler fields at lower frequencies ω_S and ω_I satisfying $\omega_S + \omega_I = 2\omega_0$ (down-conversion). Type II conversion occurs when the down-converted fields are orthogonally polarized (see the figure). The light emerging from the cavity presents strong entanglement between these fields, making OPOs the most practical source of quantum-correlated light. However, the birefringence of the crystal means that signal and idler usually oscillate at different frequencies, limiting their use in quantum information protocols. In this paper we theoretically show that injecting a weak laser signal at the degenerate frequency ω_0 locks the frequencies of signal and idler, while keeping their entanglement levels high. Compared to previous methods, this active locking technique is minimally invasive and hence of high experimental potential.



Resonance scheme of a type II optical parametric oscillator. A pump laser at frequency $2\omega_0$ is down-converted into two orthogonally-polarized signal and idler modes oscillating at ω_s and ω_i. A weak additional laser signal at ω_0 locks the signal and idler frequencies.

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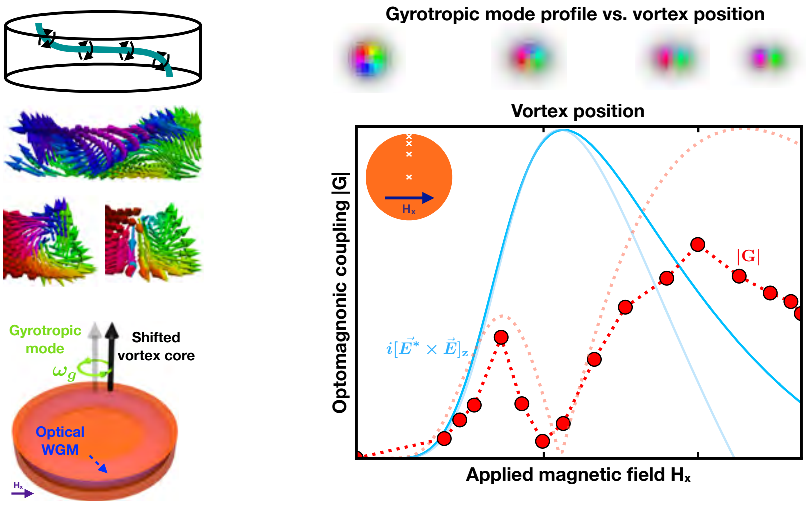
REFERENCE Ruiz-Rivas et al, New J. Phys. **20**, 023004 (2018)
https://doi.org/10.1088/1367-2630/aaa395

RESEARCH ARTICLE SVK Viola Kusminskiy Research Group

Cavity optomagnonics with magnetic textures: coupling a magnetic vortex to light

In cavity optomagnonics, light couples coherently to collective excitations in magnetically ordered solid state systems. This exciting new field is promising for quantum information platforms. A unique feature of these systems is the possibility of coherently coupling light to spin excitations on top of magnetic textures. In recent work we propose a cavity-optomagnonic system exhibiting a non-homogeneous magnetic ground state, namely, a vortex in a magnetic microdisk. Using both analytical and computational methods, we study cavity-enhanced coupling between optical whispering gallery modes and magnon modes on top of the vortex texture. The results, both in terms of value and tunability of the coupling, point to the promise of engineered optomagnonic systems for quantum information platforms at the nanoscale.



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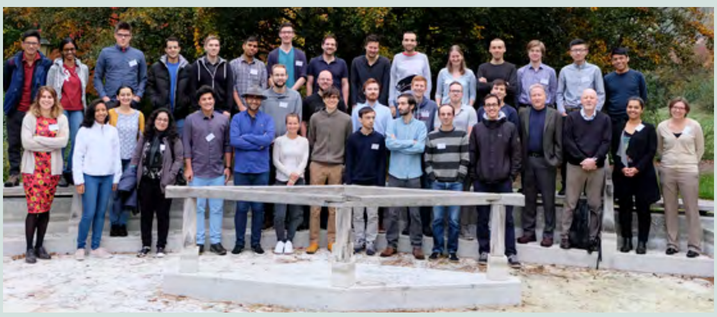
REFERENCE J. Graf et al.,
Phys. Rev. B **98**, 241406(R) (2018);
Editors' Suggestion
https://doi.org/10.1103/PhysRevB.98.241406

(Top left) Magnetic texture of a vortex in a thick disk.
(Bottom Left) Gyrotropic magnon mode of a vortex displaced by an external magnetic field, together with an optical whispering gallery mode of the disk.
(Right) Optomagnonic coupling (theory: light red line, numerics: bright red line) in a thin disk as a function of the external magnetic field.

9th IMPRS Annual Meeting and 5th MPL Autumn Academy

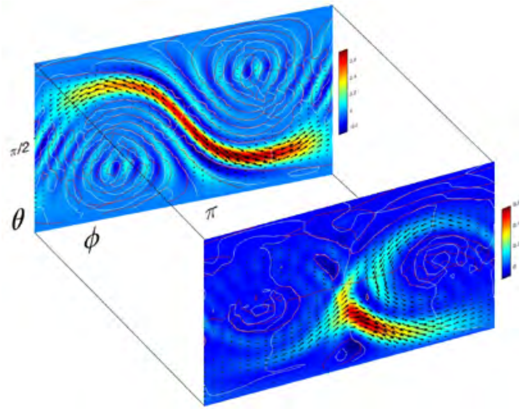
IMPRS Physics of Light held its 9th Annual Meeting jointly with the MPL Autumn Academy in Gößweinstein from October 9 to 12, 2018. Lectures were given by distinguished scientists Kerry Vahala (Caltech, USA), Lorenzo Marrucci (Università di Napoli Federico II, Italy), Dorothea Samtleben (University of Leiden, The Netherlands) and Nicolas Treps (Laboratoire Kastler Brossel, France), and Andreas Maier (FAU) and Florian Marquardt (MPL) gave block lectures. The event also included presentations from IMPRS students, poster sessions and laboratory tours at MPL. Discussions during coffee breaks and in the evenings resulted in fruitful scientific exchanges between students and lecturers. Mallika Suresh received the best poster award and Golnoush Shafiee won the award for the best student talk. Sona Davtyan was elected as IMPRS spokesperson for the upcoming year.



RESEARCH ARTICLE GL Leuchs Emeritus Group

Wigner flow on a sphere

The Wigner distribution provides a particularly convenient visual representation of the state of a single-mode quantum field as a function on the complex plane spanned by position-momentum quadratures, which is the corresponding phase space. Even though the Wigner function can take negative values and so is not a true probability distribution, it has been recently noticed that its time evolution can be recast as a continuity equation for a quasi-probability flow, which has been dubbed the Wigner flow. This is the quantum analogue of the Liouville flow in classical mechanics. Interestingly, this Wigner flow is regular and largely determined by the location and nature of its stagnation points, where the potential is force-free, i.e., $V'(x) = 0$. The Wigner function can be naturally extended to systems of symmetry group su(2), where the phase space is the Bloch sphere. We have identified the associated Wigner flow and show that the global form of this flow, and especially its behaviour in the vicinity of the stagnation points, can yield fundamental insight into the quantum evolution of these systems.



Snapshots of the Wigner flow at two times, for the case of evolution under Kerr dynamics. The pseudo-colours encode the Wigner function and the black arrows indicate the direction and strength of the flow.

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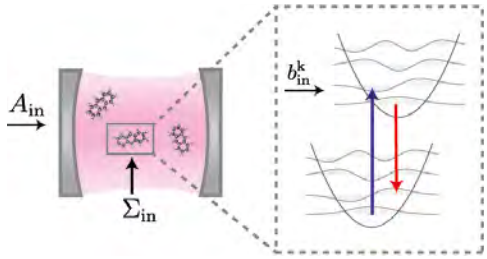
REFERENCE P. Yang et al., Physica Scripta **94**, 044001 (2019)
https://doi.org/10.1088/1402-4896/aaf91b

RESEARCH ARTICLE CG Genes Research Group

Langevin approach to quantum optics with molecules

In recent work we have developed an input-output approach to describe the interaction between light and molecular systems, modelled as quantum emitters coupled to a multitude of vibrational modes. The formalism allows the emission and absorption of molecules, either driven by classical fields or coupled to quantized optical modes, to be described. In the strong coupling regime of cavity quantum electrodynamics this provides insight into the dissipative cross-talk between hybrid light-matter states (so-called polaritons), which manifests itself in the asymmetric emission spectrum of the cavity. We also use the method to characterize uni-directional Förster resonance energy transfer between donor-acceptor molecules, such as for example occurs in photosynthesis.



Optical cavity with molecules which is driven by noise. Vibronic interactions lead Franck-Condon physics with distinct emission (red arrow) and absorption (blue arrow) lines.

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REFERENCE M. Reitz et al., Phys. Rev. Lett. **122**, 203602 (2019)
https://doi.org/10.1103/PhysRevLett.122.203602

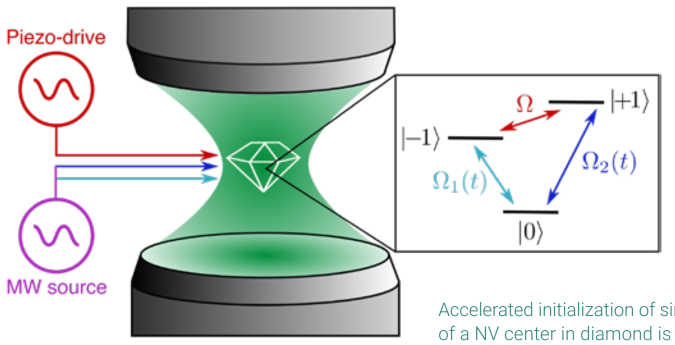
Congratulations

Congratulations to Wenbin He (Russell Division), who was recently awarded one of the 2019 Otto Hahn Medals by the Max Planck Society, for his highly original PhD work on optoacoustic mode-locking of fibre lasers, which included ground-breaking experiments on the creation of supramolecular assemblies of solitons, bound together by long-range inter-pulse optomechanical and nonlinear interactions. The award is endowed with €7,500.

RESEARCH ARTICLE FM Marquardt Division

Accelerated initialization of single spin dressed states for quantum sensing

A requisite for efficient quantum sensing protocols is the use of quantum states protected from decoherence. Such protection is primarily achieved using dynamical decoupling techniques, which suffer from drawbacks such as experimental complexity and vulnerability to pulse errors. A more promising avenue is to use dressed states generated by continuous driving. This experimentally accessible strategy offers efficient coherence protection and can be easily combined with quantum gates. However, it is experimentally challenging to achieve high-fidelity initialization into individual, well-defined dressed states. Schemes relying on adiabatic state transfer suffer from a trade-off between speed and fidelity; one needs to be sufficiently slow to fulfil the adiabatic criterion, but fast enough to avoid decoherence during state transfer. In our recent work, we report how to realize accelerated adiabatic state preparation of dressed spin states in a NV centre in diamond. As such we establish an attractive room-temperature platform for, e.g., quantum sensing of high-frequency magnetic fields on the nanoscale.



Accelerated initialization of single spin dressed states of a NV center in diamond is achieved using the general framework of shortcuts to adiabaticity. The control sequence is generated using both microwave (MW) driving fields and strain-driving (piezo drive).

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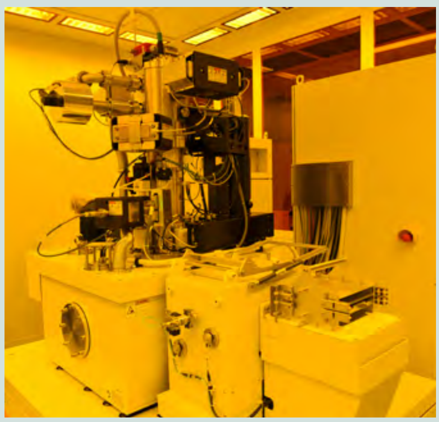
REFERENCE J. Kölbl et al., Phys. Rev. Lett. **122**, 090502 (2019); Editors' Suggestion
https://doi.org/10.1103/PhysRevLett.122.090502

New 100 kV electron beam lithography system

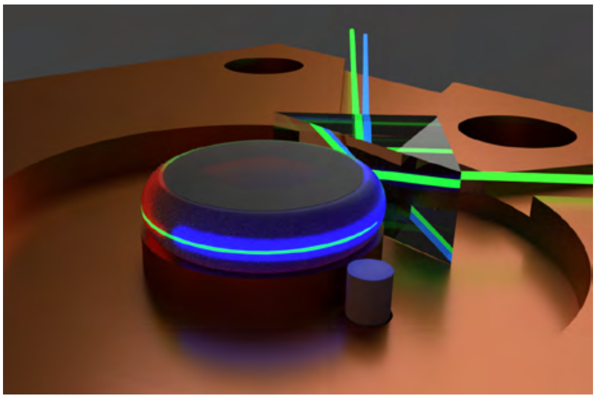
A new 100 kV electron beam lithography (EBL) system has been installed recently at MPL. Located in the cleanroom, complements the existing suite of nanofabrication equipment:
a 30 kV electron beam system (Raith 150 two), a laser-based direct-write system (DWL 66+), and a mask aligner (MA6Gen4) for contact and proximity lithography. The EBPG5200 machine offers state-of-the-art resolution, accuracy, and throughput, featuring 100 keV accelerating voltage, 100 MHz fast data path channelling, a 20-bit pattern generator, a 100 µm to 1 mm write-field, and a fast translation stage. We have fabricated nanostructures with lateral dimensions as small as 8 nm, also over large areas up to 6" wafer. The laser interferometer stage assures high stitching and overlay accuracy (to < 10 nm) and multi-level alignment of fabricated structures. The system provides very high flexibility, together with a high degree of automation. It incorporates an interactive graphical user interface (GUI) that allows ease of use in diverse, multi-user environments. Its high-current density column design minimizes exposure time for complex nanopatterning. In addition to fabricating samples according to the needs of MPL researchers and external users, the TDSU is happy to train frequent users to run the EBL system independently.



RESEARCH ARTICLE GL Leuchs Emeritus Group

Millimeter-wave photonic radiometer with electro-optic upconverter

Detection of very weak mm-wave signals is difficult because of ambient thermal radiation. This is the reason why detection of mm-wave photons traditionally involves extreme cryogenics and efficient environmental shielding. An alternative approach lies in frequency-shifting the mm-wave signal to the optical domain, where efficient room-temperature single-photon detectors are readily available. To be viable, this approach requires high spectral, directional and polarization state selectivity, as well as high conversion efficiency. All these requirements are fulfilled in a recently demonstrated electro-optic up-converter based on a lithium niobate whispering gallery resonator enclosed in a mm-wave cavity (see the figure). This room-temperature device features high-Q tunable resonances at the optical pump, mm-wave input, and optical output, allowing, in theory, for coherent conversion of every microwave signal photon to an optical photon while adding extremely little noise. The central frequency of this converter can be widely tuned, while its bandwidth can vary from one to hundreds of MHz. This device is considered for applications such as spectroscopy of the cosmic background radiation and quantum information networks.



Sketch showing the optical whispering gallery resonator with the coupling prism, all sitting inside the mm-wave resonator, the cover of which has been removed. The little post next to the optical resonator is the mm-wave coupler.

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REFERENCE G.S. Botello et al., Optica **5**, 1210-1219 (2018)
https://doi.org/10.1364/OPTICA.5.001210

RESEARCH ARTICLE FM Marquardt Division

Reinforcement learning with neural networks for quantum feedback

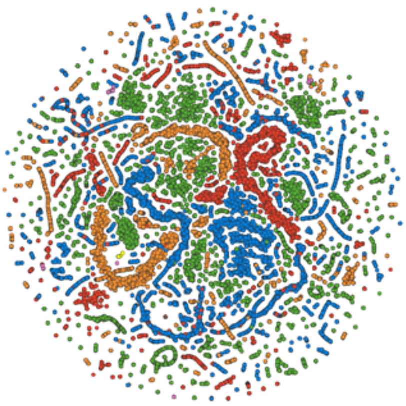

Illustration of how the neural network internally represents quantum states.

Artificial neural networks are revolutionizing science and technology, from image recognition and language processing to drug discovery and playing complex games. In recent work we have applied advanced machine learning techniques to solving formidable challenges in quantum physics. In particular, we have demonstrated that artificial neural networks can improve the performance of quantum computing devices. More generally, our work opens a new application field of machine learning: quantum feedback.Building large-scale quantum computers continues to be a challenge due to the fragility of quantum states: a quantum system inevitably interacts with the outside world, making it lose its "quantumness" over time. Suppressing this detrimental process is a critical open problem that we have addressed using reinforcement learning, a powerful machine learning technique. Without human guidance, the neural network discovers sophisticated strategies to prevent information leakage into the outside world. A key novelty of the work is the development of a measure describing how well quantum information is preserved. We expect the results to have a wide impact in the construction of quantum computers and simulators.

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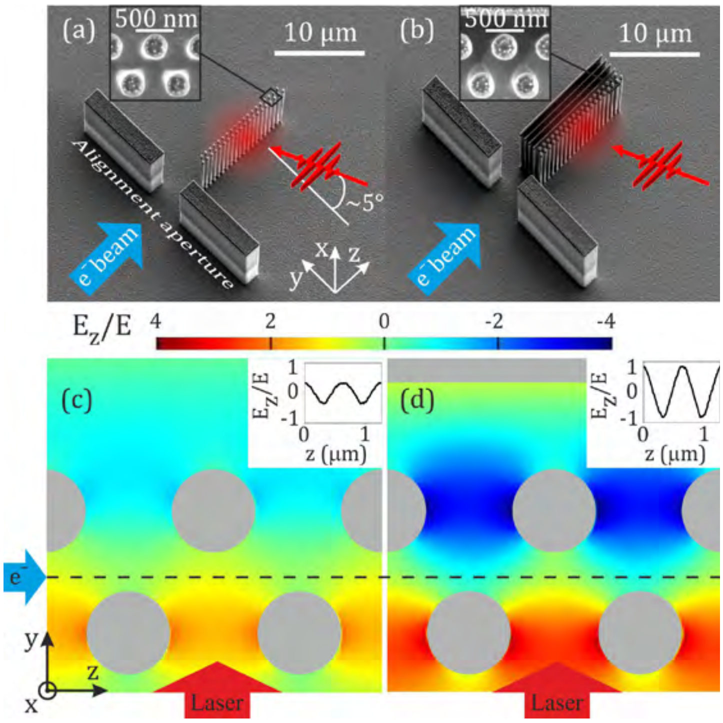
REFERENCE T. Fösel et al., Phys. Rev. X **8**, 031084 (2018)
https://doi.org/10.1103/PhysRevX.8.031084

RESEARCH ARTICLE PH Hommelhoff Max Planck Fellow Group

High efficiency dielectric laser accelerators



The colonnade structure is the nano-photonics electron acceleration structure, without (a) and with Bragg mirror (b) to enhance the field. The simulations show a snapshot of the optical field distribution without (c) and with (d) a Bragg mirror.

A particle accelerator on a chip is a revolutionary concept. It could shrink the size of the current kilometre-long accelerators to metre-long ones. With modern femtosecond lasers capable of generating high peak electric fields and well-known nano-fabrication techniques, we are now able to develop dielectric laser accelerators (DLAs) in our lab. Lithographically fabricated silicon dual-pillars are enticing candidates for DLAs as their symmetric geometries enable us to control the electron beam dynamics well. We made such structures twice more efficient by adding a Bragg reflector on its side. This approach practically leads to a constructive interference between the incident laser pulse and the reflected light from the Bragg reflector, hence doubling the electric field intensity in between the pillars where electrons gain energy. The 12 μm long structures accelerate electrons with gradients of up to 200 MeV/m in theory and 133 MeV/m in practice. DLAs could ultimately lead to a compact laser-driven particle accelerator for a variety of applications, from low energy radiation therapy devices to high energy particle colliders.

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REFERENCE P. Yousefi et al., Opt. Lett. **44**, 1520-1523 (2019)
https://doi.org/10.1364/OL.44.001520

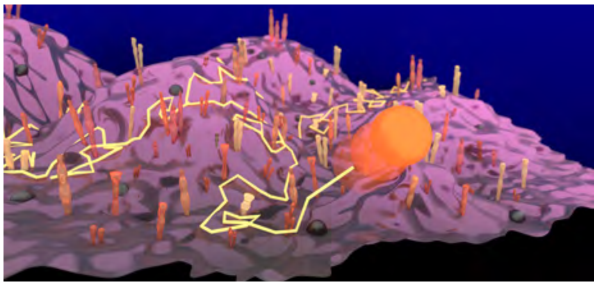
New members

Two new independent Max Planck Research Groups have been formed in recent months. In October 2018 **Kanwarpal Singh** joined the Max Planck Zentrum für Physik und Medizin (MPZPM). He plans to focus on the development of high resolution miniaturized endoscopic devices for applications ranging from gastroenterology to oncology. **Birgit Stiller** joined us in April and is planning to work on nonlinear and quantum optics with a focus on light-sound interactions and waveguide optomechanics. Two new group leaders have been appointed: **Stefan Nimmrichter** (previously at the Centre for Quantum Technologies, National University of Singapore) has joined the Marquardt Division, and **Daniel Wehner** has joined the Guck Division, having previously been at the Center for Regenerative Therapies, Technische Universität Dresden. **Axel Schulzgen**, Professor of optics & photonics at CREOL, University of Central Florida, visited the Russell Division in May and June. His interests are in imaging through random fibres. We warmly welcome new appointees to MPL's administration: **Susanne Viezens** (Public Relations), **Anna-Sophia Maranca** (Finance), **Ruth Knapheide** (personal assistant to Jochen Guck), **Adrian Thoma** (construction coordinator for the new MPZPM building), **Dennis Beck** (IT Department) and **Matthias Döllinger** (Technical Services).

RESEARCH ARTICLE VS Sandoghdar Division

Chasing a protein nano-rover on the cell membrane

The cell surface is a dense carpet of proteins and lipids rushing about in a perpetual frenzy. The physical motion of these constituents reveal a great deal about their complex, varied and nuanced biological function. However, their nanoscopic size, quick erratic motion and enduring mobility render their precise investigation a fierce challenge to even the best available microscopes. We have now demonstrated that through labelling individual membrane proteins with a tiny gold nanoparticle, and using exquisitely sensitive interferometric detection of scattering (iSCAT), the three-dimensional wandering of individual proteins can be resolved in a live cell to nanometric precision at 60 thousand frames per second. At this resolution the anomalous diffusion as well as transport of proteins can be resolved in unprecedented detail, as can the local topology explored by the protein. Our first steps in applying iSCAT to live cell investigation have already provided new insight into the molecular dynamics behind ubiquitous biological processes such as endocytosis, thus opening the door to an era of greater understanding of their biophysical role in processes that govern our health.



The sub-diffusive motion of proteins within the cell membrane reveals their function. By labelling the protein with a gold nanoparticle, and tracking with iSCAT in 3D at high-speed, the information-rich nuances of their mobility can be observed.

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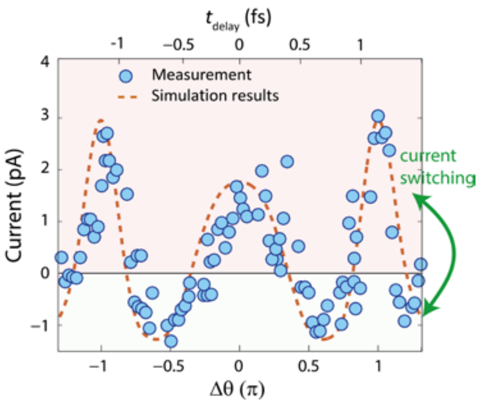
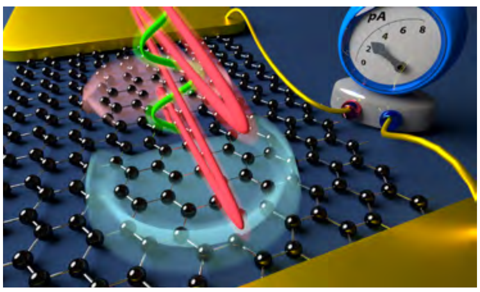
REFERENCE R. W. Taylor et al., Nat. Phot. **13**, 480–487 (2019)
https://doi.org/10.1038/s41566-019-0414-6

RESEARCH ARTICLE PH Hommelhoff Max Planck Fellow Group

Coherent electron control in graphene on attosecond timescales



We control electron trajectories in graphene at petahertz clock rates with two laser fields oriented perpendicular to each other. Depending on how exactly the green colored field is timed with respect to the red (bottom panel), the current flows in the one or other direction (top panel).



How fast can electrons be controlled in a conductor? In a recently published paper we get to the bottom of this question. We generate a laser waveform-controlled current in the atomically flat semi-metal graphene by focusing few-femtosecond laser pulses on it. At these timescales, electrons behave like quantum mechanical wave packets, coherently driven by the laser field through the material. We have previously demonstrated that the electron wave can follow different quantum paths in the material and interfere with itself, governing generation of electric current. In the current work we take electron control to a new level. When a second laser pulse is focused on to the electron wave, quantum paths can be manipulated in two dimensions. We control the quantum path interference on the attosecond timescale by delaying the pulses, and thus steer the direction of the electrons. What is remarkable is that the coherence of the electrons is pre-served in this process, i.e., the electrons retain all their wave characteristics during light-matter interaction, even at room temperature. Such control may pave the way to coherent electronics at petahertz clock rates.

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REFERENCE C. Heide et al., Phys. Rev. Lett. **121**, 207401 (2018)
https://doi.org/10.1103/PhysRevLett.121.207401

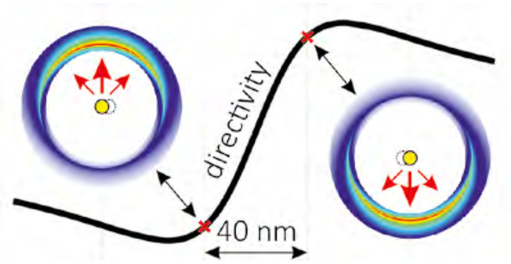
Congratulations

Congratulations to MPL group leader **Maria Chekhova**, who has been recognized as an Outstanding Referee by the American Physical Society. This highly selective program annually recognizes about 150 of the roughly 71,000 currently active referees and, like the award of an APS fellowship, is a lifetime award. Congratulations to **Carlos Navarrete-Benlloch**, former group leader in MPL's Marquardt Division, has been appointed Associate Professor in the Wilczek Quantum Centre at Shanghai Jiao Tong University. Led by Chief Scientist Prof. Frank Wilczek, this new centre focuses on theoretical quantum physics in the broadest sense. Carlos will set up a group working on open and nonequilibrium quantum optics, and plans to continue collaborating with MPL in the future.

SHORT REVIEW GL Leuchs Emeritus Group

Weak measurements in nano-optics

From a historical perspective, the concept of weak measurements first arose in the field of quantum physics more than 30 years ago. In general, it combines pre- and post-selection of the state vector for measuring a largely amplified "value" for the otherwise much smaller eigenvalue of an operator. However, weak measurements can also be utilized in classical optics, for instance, to increase the visibility of beam shift phenomena. In this context, the preparation and filtering of the polarization state of a light beam is analogous to pre- and post-selection in the original quantum-physics-related approach. A prominent application is the measurement of the spin Hall effect of light, which describes the spatial separation of right- and left-handed circular polarization upon refraction of an incoming linearly polarized beam at a dielectric interface. The weak measurement approach allows direct observation of this surprising effect, even though the spatial dimensions of the circular polarization splitting is smaller than the wavelength of the light. In recent years, optical weak measurements have also found their way into nano-optics. For example, weak measurements have been applied to realise a plasmonic version of the spin-Hall effect of light, which occurs when propagating surface plasmon polaritons are excited by elliptically polarized light impinging on a sub-wavelength metal slit. Beyond such fundamental studies, the weak measurement scheme is particularly beneficial for applications in optical nanometrology, for example in measurements of the ellipticity of highly eccentric dipole emitters by enhancing the far-field circular polarization splitting [1], an effect sometimes referred to as the giant spin-Hall effect of light. Weak measurements also allow one to improve the sensitivity, by an order of magnitude, of displacement sensing based on directional scattering of individual optical nano-antennas (see Fig.) [2]. Both these examples emphasize the relevance of weak measurements in nano-optics as a new approach for high-precision measurements.



Sub-wavelength shift of a gold nanoparticle (radius 80 nm) within a tightly focused beam results in a strong change of its polarization-filtered directional emission pattern. The scheme is inspired by quantum weak measurements [2].

[1] [2]

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REFERENCES [1] S. Nechayev et al., Phys. Rev. Lett. **121**, 243903 (2018); https://doi.org/10.1103/PhysRevLett.121.243903
[2] M. Neugebauer et al., Nano Letters **19**, 422 (2019); https://doi.org/10.1021/acs.nanolett.8b04219

IMPRINT

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