Nanomaterial Transport to Cells

Bioengineers can design smart drugs for antibody and nanomaterial-based therapies to optimize drug efficiency for increasingly efficient, early-stage preclinical trials. [41]

Many of these products use nanomaterials, but little is known about how these modern materials and their tiny particles interact with the environment and living things. [40]

When chemists from the Institute of Physical Chemistry of the Polish Academy of Sciences in Warsaw were starting work on a new material designed for the efficient production of nanocrystalline zinc oxide, they didn't expect any surprises. [39]

Now writing in Light Science & Applications, Hamidreza Siampour and co-workers have taken a step forward in the field of integrated quantum plasmonics by demonstrating on-chip coupling between a single photon source and plasmonic waveguide. [38]

Researchers at University of Utah Health developed a proof-of-concept technology using nanoparticles that could offer a new approach for oral medications. [37]

Using scanning tunneling microscopy (STM), extremely high resolution imaging of the molecule-covered surface structures of silver nanoparticles is possible, even down to the recognition of individual parts of the molecules protecting the surface. [36]

A fiber optic sensing system developed by researchers in China and Canada can peer inside supercapacitors and batteries to observe their state of charge. [35]

The idea of using a sound wave in optical fibers initially came from the team's partner researchers at Bar-Ilan University in Israel. Joint research projects should follow. [34]

Researchers at the Technion-Israel Institute of Technology have constructed a first-of-its-kind optic isolator based on resonance of light waves on a rapidly rotating glass sphere. [33]

The micro-resonator is a two-mirror trap for the light, with the mirrors facing each other within several hundred nanometers. [32]

"The realization of such all-optical single-photon devices will be a large step towards deterministic multi-mode entanglement generation as well as high-fidelity photonic

quantum gates that are crucial for all-optical quantum information processing," says Tanji-Suzuki. [31]

Researchers at ETH have now used attosecond laser pulses to measure the time evolution of this effect in molecules. [30]

A new benchmark quantum chemical calculation of C_2, Si_2, and their hydrides reveals a qualitative difference in the topologies of core electron orbitals of organic molecules and their silicon analogues. [29]

A University of Central Florida team has designed a nanostructured optical sensor that for the first time can efficiently detect molecular chirality—a property of molecular spatial twist that defines its biochemical properties. [28]

UCLA scientists and engineers have developed a new process for assembling semiconductor devices. [27]

A new experiment that tests the limit of how large an object can be before it ceases to behave quantum mechanically has been proposed by physicists in the UK and India. [26]

Phonons are discrete units of vibrational energy predicted by quantum mechanics that correspond to collective oscillations of atoms inside a molecule or a crystal. [25]

This achievement is considered as an important landmark for the realization of practical application of photon upconversion technology. [24]
Considerable interest in new single-photon detector technologies has been scaling in this past decade. [23]

Engineers develop key mathematical formula for driving quantum experiments. [22]

Physicists are developing quantum simulators, to help solve problems that are beyond the reach of conventional computers. [21]

Engineers at Australia's University of New South Wales have invented a radical new architecture for quantum computing, based on novel 'flip-flop qubits', that promises to make the large-scale manufacture of quantum chips dramatically cheaper - and easier - than thought possible. [20]

A team of researchers from the U.S. and Italy has built a quantum memory device that is approximately 1000 times smaller than similar devices— small enough to install on a chip. [19]

The cutting edge of data storage research is working at the level of individual atoms and molecules, representing the ultimate limit of technological miniaturisation. [18]

This is an important clue for our theoretical understanding of optically controlled magnetic data storage media. [17]

A crystalline material that changes shape in response to light could form the heart of novel light-activated devices. [16]

Now a team of Penn State electrical engineers have a way to simultaneously control diverse optical properties of dielectric waveguides by using a two-layer coating, each layer with a near zero thickness and weight. [15]

Just like in normal road traffic, crossings are indispensable in optical signal processing. In order to avoid collisions, a clear traffic rule is required. A new method has now been developed at TU Wien to provide such a rule for light signals. [14]

Researchers have developed a way to use commercial inkjet printers and readily available ink to print hidden images that are only visible when illuminated with appropriately polarized waves in the terahertz region of the electromagnetic spectrum. [13]

That is, until now, thanks to the new solution devised at TU Wien: for the first time ever, permanent magnets can be produced using a 3D printer. This allows magnets to be produced in complex forms and precisely customised magnetic fields, required, for example, in magnetic sensors. [12]

For physicists, loss of magnetisation in permanent magnets can be a real concern. In response, the Japanese company Sumitomo created the strongest available magnet—one offering ten times more magnetic energy than previous versions—in 1983. [11]

New method of superstrong magnetic fields' generation proposed by Russian scientists in collaboration with foreign colleagues. [10]

By showing that a phenomenon dubbed the "inverse spin Hall effect" works in several organic semiconductors - including carbon-60 buckyballs - University of Utah physicists changed magnetic "spin current" into electric current. The efficiency of this new power conversion method isn't yet known, but it might find use in future electronic devices including batteries, solar cells and computers. [9]

Researchers from the Norwegian University of Science and Technology (NTNU) and the University of Cambridge in the UK have demonstrated that it is possible to directly generate an electric current in a magnetic material by rotating its magnetization. [8]

This paper explains the magnetic effect of the electric current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories.

The changing acceleration of the electrons explains the created negative electric field of the magnetic induction, the changing relativistic mass and the Gravitational Force, giving a Unified Theory of the physical forces. Taking into account the Planck Distribution Law of the electromagnetic oscillators also, we can explain the electron/proton mass rate and the Weak and Strong Interactions.

Contents

Preface

Surprisingly nobody found strange that by theory the electrons are moving with a constant velocity in the stationary electric current, although there is an accelerating force **F** = **q** **E**, imposed by the **E** electric field along the wire as a result of the **U** potential difference. The accelerated electrons are creating a charge density distribution and maintaining the potential change along the wire. This charge distribution also creates a radial electrostatic field around the wire decreasing along the wire. The moving external electrons in this electrostatic field are experiencing a changing electrostatic field causing exactly the magnetic effect, repelling when moving against the direction of the current and attracting when moving in the direction of the current. This way the **A** magnetic potential is based on the real charge distribution of the electrons caused by their acceleration, maintaining the **E** electric field and the **A** magnetic potential at the same time.

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the electromagnetic matter. If the charge could move faster than the electromagnetic field, this self maintaining electromagnetic property of the electric current would be failed.

More importantly the accelerating electrons can explain the magnetic induction also. The changing acceleration of the electrons will create a –**E** electric field by changing the charge distribution, increasing acceleration lowering the charge density and decreasing acceleration causing an increasing charge density.

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as a relativistic changing electromagnetic mass. If the mass is electromagnetic, then the gravitation is also electromagnetic effect. The same charges would attract each other if they are moving parallel by the magnetic effect.

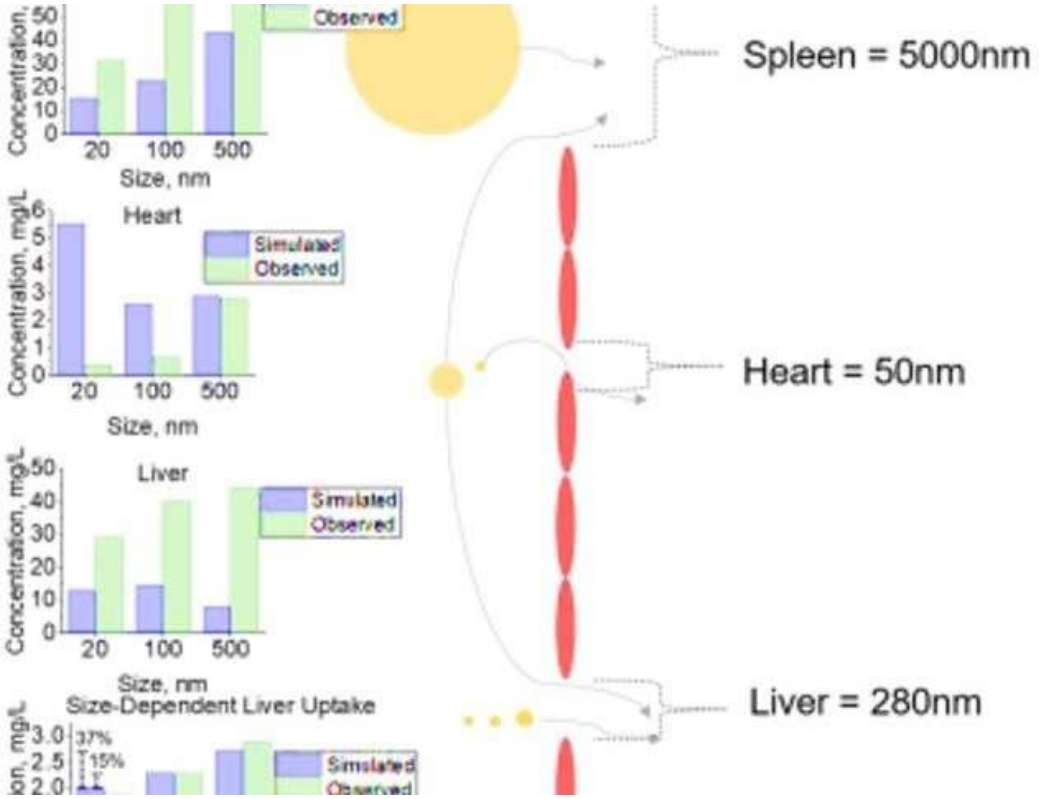
Animal simulations and smart drug design: Nanomaterial transport to individual cells

Bioengineers can design smart drugs for antibody and nanomaterial-based therapies to optimize drug efficiency for increasingly efficient, early-stage preclinical trials. The ideal drug will have maximum efficiency at target tissue sites for transport from the tissue vasculature to the cellular environment. Researchers can use biological simulations coupled to in vitro approaches to predict their exposure rapidly and efficiently to predict drug biodistribution within single cells of live animal tissue without relying on animal studies. In a new study now published on *Science Advances*, Edward Price and Andre J. Gesquiere successfully used an in vitro assay and computational fluid dynamic (CFD) model to translate in vitro cell kinetics to whole-body simulations across multiple species and nanomaterial types. The work allowed them

to predict drug distributions inside individual tissue cells and the team expect this work to refine, reduce and replace animal testing while providing scientists a fresh perspective on drug development.

Nanomedicines (NMs) in the form of antibodies and synthetic nanomaterials can complement conventional small-molecule medicine through active tissue targeting, variable circulation timeframes and stability, coupled to adjustable biodistribution. Research teams heavily rely on animal models to quantify delivered doses, raising questions on ethics and surges in time and cost. From a scientific viewpoint, tissue architecture destruction conducted during tissue homogenization for quantification can eliminate critical knowledge of nanomedicine transport inside tissue cells and vasculature. A drug can reach cells by exhibiting optimal plasma pharmacokinetics to reach the tissue vasculature. The architecture and nanoparticle diameter allow critical transport of the drug across microvessel walls into an infected or normal tissue cell environment.

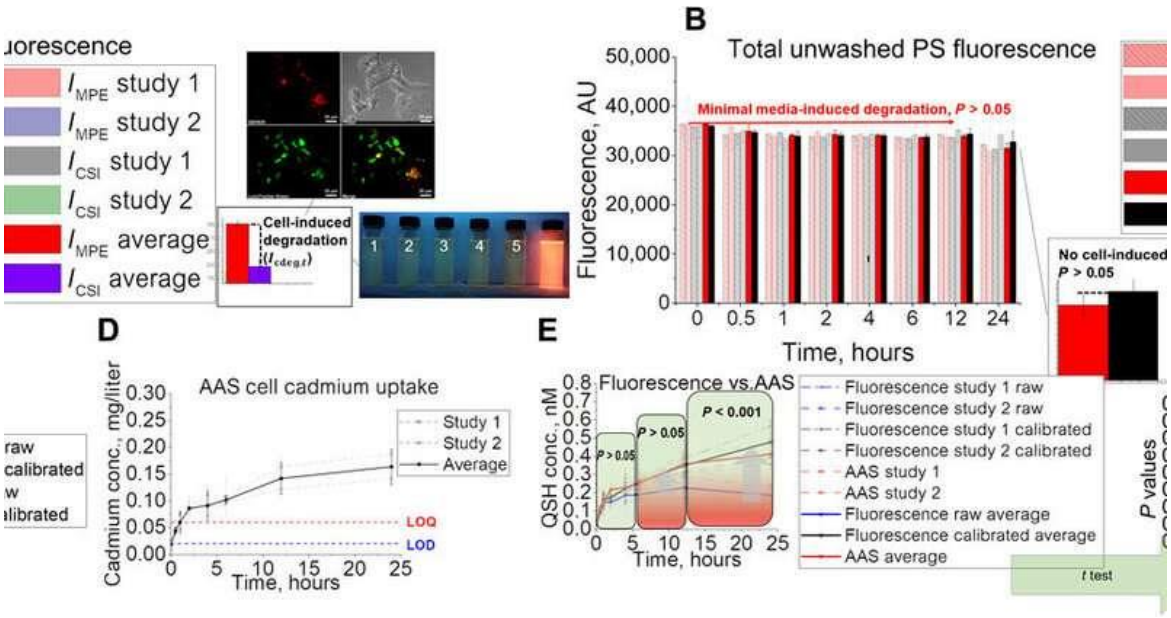
In the present work, Price and Gesquiere coupled an in vitro/in silico simulation approach to predict NM biodistribution within preclinical species (animal and cell models) at the level of the single cell. They accounted differences in nanoparticle size, animal species and vasculature pore size diameters using a fluid dynamic model. The team quantified cellular NM content in situations where results were difficult to translate to animal studies due to a lack of systematic perspectives. They also addressed existing experimental issues where cells induced degradation of nanoparticle fluorescence to produce false negatives.



Cellular analysis of NM uptake in varying tissues for NM with different diameters. Cellular uptake of NMs with diameters of 20, 100, and 500nm for spleen, heart, and liver with fenestrae diameters of 5000, 50, and 280nm respectively. Sensitivity analysis of incremental changes in NM diameter (24, 32, and 44nm) with subsequent liver cell uptake were performed. All simulated (predicted) outputs are compared to observed data from literature cellular datasets.
Credit: *Science Advances*, doi: 10.1126/sciadv.aax2642

To validate their work in vitro, the team simulated lysosomal analysis coupled to atomic absorption spectroscopy (AAS), and substantiated in vivo simulations by comparing results to the published literature of whole-body animal data for rats, mice and nonhuman primates. The scientists used quantum dots (QDs) as a model system due to their potential in nanoparticle detection, while also considering their limits. Price et al. accounted the complexities in an NM platform to extend the capabilities to antibody- and metal/polymer-based nanoparticles.

When a nanoparticle circulates through animal blood supply to enter the tissue environment, it will interact with tissue cells via adsorption, desorption, internalization or active uptake processes. The scientists exposed nanoparticles to non-toxic QDs (quantum dots) to fluorescently detect their interactions with cells commonly encountered by NMs such as macrophages, endothelial cells and epithelial cells, after intravenous injection. The research team quantified the concentration of nanoparticles interacting with cells in vitro and built cell kinetics simulations to assess the rate kinetics and NM-cell interactions.

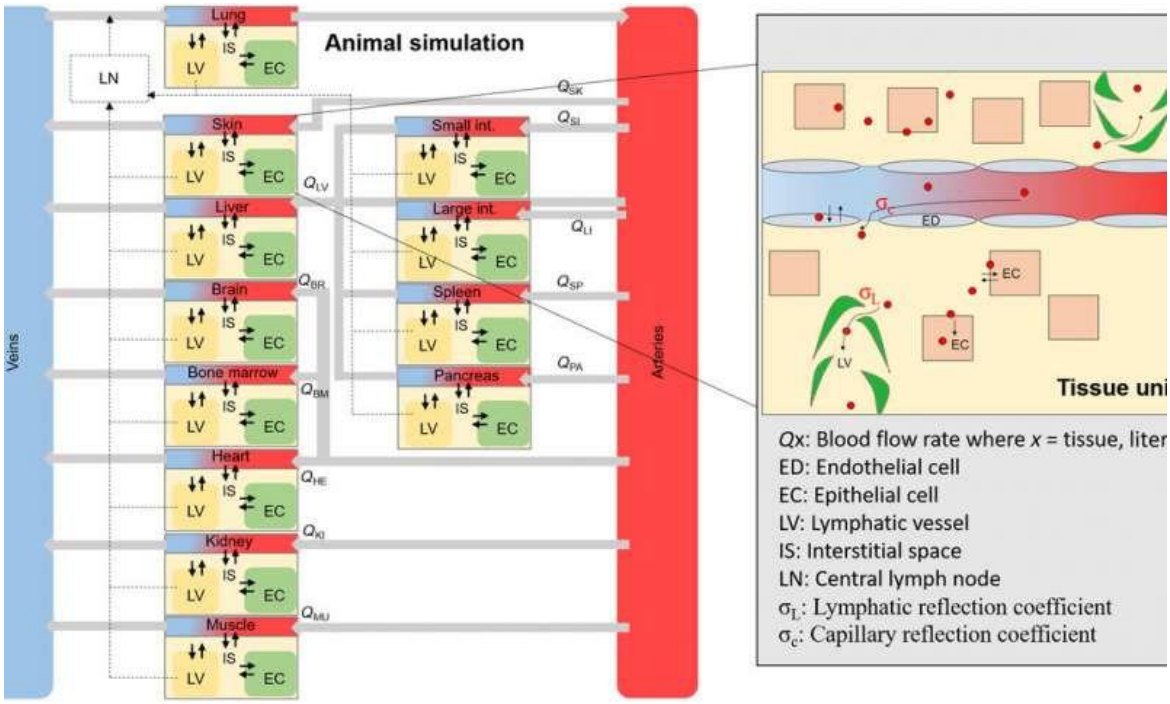


In vitro assay development and validation to AAS. (A and B) In vitro assay setup with its coupled unwashed fluorescence signal for (A) QD and (B) PS. Images show Hepa1-6 colocalization of QD in lysosomal compartments as well as snapshots of fluorescence under ultraviolet illumination under simulated lysosomal exposure conditions with pH 2.5, 3.0, 3.5, 4.0, 4.5, and 7.4 (1 to 6, respectively). (C to E) QD uptake studies using the in vitro technique with (C) fluorescence, (D) AAS, (E) combined, and the (F) statistical results using two-tailed t test when comparing raw and calibrated fluorescence uptake to AAS data. The asterisks in figure represent significance at the * ($P < 0.05$), ** ($P < 0.01$), and *** ($P < 0.001$) levels. Credit: *Science Advances*, doi: 10.1126/sciadv.aax2642

The simulation contained a (i) medium, (ii) cell membrane and (iii) cell space compartments interconnected via basic mass transfer equations and first-order rate constants. They optimized the system using a genetic algorithm in MATLAB and noted the membrane adsorption rate constant to be highest for macrophages and lowest for endothelial and liver cells. Of the cell types, the internalization process was also relatively highest for liver tissue cells and lowest for endothelial cells. Confocal imaging visually supported these data with rapid uptake and saturation of macrophages within an hour of exposure, while epithelial and endothelial tissue cells were further delayed.

The team demonstrated the presence of cell degradation factors within in vitro assays using cell kinetics simulations to help efficiently translate the in vitro data to animal studies. Atomic adsorption spectroscopy (AAS) validated the results of QD uptake via fluorescence assays and highlighted the importance of calculating cell- and medium-induced degradation. Since nanomedicines (NMs) located inside tissues can accumulate in the interstitia, vasculature or inside a variety of cell types, the team translated in vitro cellular kinetics to in silico animal simulations to account for this. They conducted two pilot studies and assessed trends in whole-tissue uptake as a function of size and quantified NM uptake at the level of the single cell.

Architecturally, each tissue compartment simulation contained four sub-compartments to represent the epithelial, endothelial and macrophage cells.

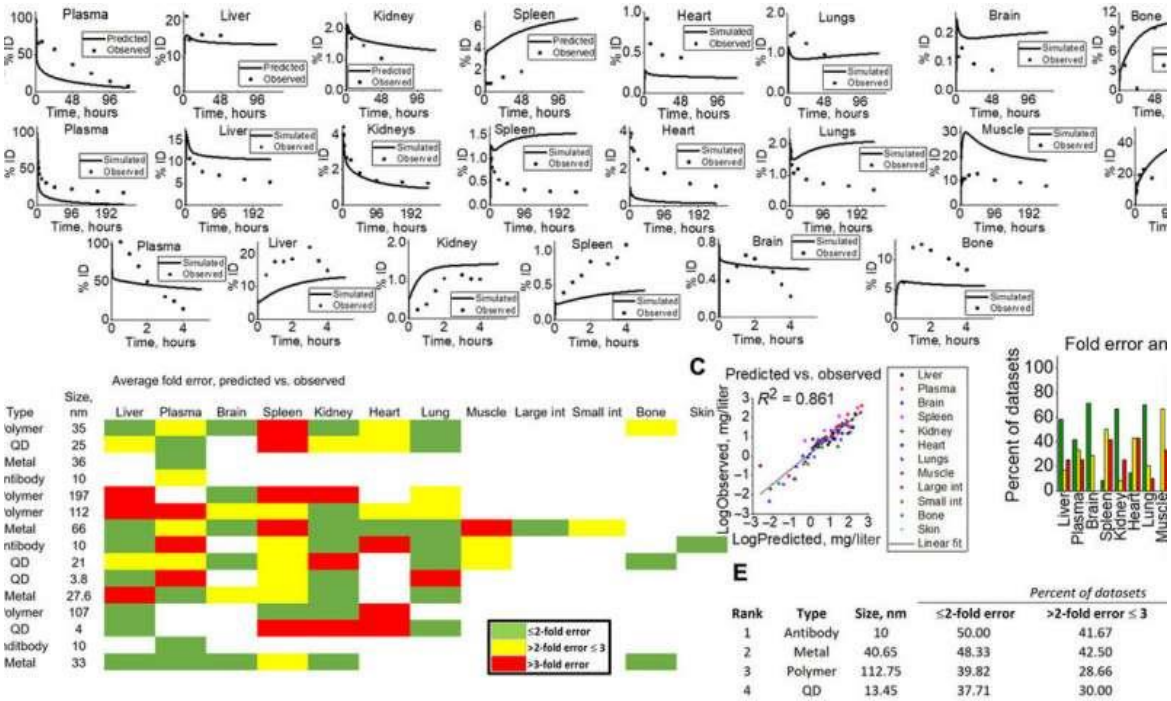


An overall schematic of the animal NM simulation. Scheme of the overall tissue and blood compartments that make up the full animal. Each tissue compartment is interconnected through blood flow rates and contains sub-compartments (zoomed-in area), where an NM will distribute upon internalization through endothelial fenestrae. Credit: *Science Advances*, doi: 10.1126/sciadv.aax2642

Since the liver and spleen are common targets for NM accumulation, they used these tissues as case studies to understand and capture, the sensitivity and accuracy of the simulation. For example, the simulation showed that increased NM sizes exceeded the tissue pore sizes of most tissue types to funnel toward tissues with larger pore sizes such as the liver. At this point, the liver endothelial cells interacted with the NMs for rapid membrane binding and saturation within 24 hours. When the NM entered the interstitia of the tissue it quickly interacted with epithelial (for liver) and macrophage (for spleen) tissue cells. The results built confidence in the predictive power of the simulation and its capacity to predict variable-sized drug content at the single-cell level for animals for the first time—strictly based on in vitro data alone.

The scientists then indicated the predictive power and translational capacity of the simulation by comparing against measured tissue-level content for multiple NM types and species, including rats, mice and cellular content (epithelial, endothelial and macrophage). They tested the predictive performance across multiple variables based on the World

Health Organization guidelines and standards of academic and pharmaceutical consortium for drug development and safety. The model-predicted averages and the observed averages correlated linearly to indicate reasonable model predictions across all species and NM types.



Simulation outputs for validation to various animal studies. (A) Tissue-level predicted (line) versus observed (points) examples for all species types (rats, mice, and NHP) for visual evidence of model capabilities. (B) Heat map of fold error analysis calculated for all tissue, NM, and species types in simulation. Green, yellow, and red represent <2-fold, <3-fold, and >3-fold errors. Fold error was calculated according to equations given in Materials and Methods, where simulated dataset averages were compared to observed. (C) All data point averages specific to tissue types for simulations and observed were plotted against each other to yield a linear fit (R2 = 0.861). (D) Tissue-specific fold errors are shown to visualize model accuracy for each tissue in this study. (E) NM-simulated outputs were ranked (1 to 4) according to fold error analysis. Credit: *Science Advances*, doi: 10.1126/sciadv.aax2642

In this way, Edward Price and Andre J. Gesquiere developed a viable platform to reduce and refine animal testing during nanomedicine (NM) development. The in vitro concentrated data coupled to cell kinetics simulations delivered cell-NM interactions to show excellent translational potential. The results did not require fitting to animal biodistribution datasets, since all parameters were optimized to in vitro data or calculated using a fluid dynamic model. The process also worked under conditions of NM degradation in the biological environment. The combined in vitro and in silico techniques will assist future smart drug design to help scientists form better and informed discussions while reducing live animal testing. Price and Gesquiere

expect this work to serve a new approach for predictive simulations of nanomedicine transport. [41]

Study provides insight into how nanoparticles interact with biological systems

Personal electronic devices—smartphones, computers, TVs, tablets, screens of all kinds—are a significant and growing source of the world's electronic waste. Many of these products use nanomaterials, but little is known about how these modern materials and their tiny particles interact with the environment and living things.

Now a research team of Northwestern University chemists and colleagues from the national Center for Sustainable Nanotechnology has discovered that when certain coated nanoparticles interact with living organisms it results in new properties that cause the nanoparticles to become sticky. Fragmented lipid coronas form on the particles, causing them to stick together and grow into long kelp-like strands. Nanoparticles with 5-nanometer diameters form long structures that are microns in size in solution. The impact on cells is not known.

"Why not make a particle that is benign from the beginning?" said Franz M. Geiger, professor of chemistry in Northwestern's Weinberg College of Arts and Sciences. He led the Northwestern portion of the research.

"This study provides insight into the molecular mechanisms by which nanoparticles interact with biological systems," Geiger said. "This may help us understand and predict why some nanomaterial/ligand coating combinations are detrimental to cellular organisms while others are not. We can use this to engineer nanoparticles that are benign by design."

Using experiments and computer simulations, the research team studied polycation-wrapped gold nanoparticles and their interactions with a variety of bilayer membrane models, including bacteria. The researchers found that a nearly circular layer of lipids forms spontaneously around the particles. These "fragmented lipid coronas" have never been seen before.

The study points to solving problems with chemistry. Scientists can use the findings to design a better ligand coating for nanoparticles that avoids the ammonium-phosphate interaction, which causes the aggregation. (Ligands are used in nanomaterials for layering.)

The results will be published Oct. 18 in the journal *Chem*.

Geiger is the study's corresponding author. Other authors include scientists from the Center for Sustainable Nanotechnology's other institutional partners. Based at the University of Wisconsin-Madison, the center studies engineered nanomaterials and their interaction with the environment, including biological systems—both the negative and positive aspects.

"The nanoparticles pick up parts of the lipid cellular membrane like a snowball rolling in a snowfield, and they become sticky," Geiger said. "This unintended effect happens because of the presence of the nanoparticle. It can bring lipids to places in cells where lipids are not meant to be."

The experiments were conducted in idealized laboratory settings that nevertheless are relevant to environments found during the late summer in a landfill—at 21-22 degrees Celsius and a couple feet below ground, where soil and groundwater mix and the food chain begins.

By pairing spectroscopic and imaging experiments with atomistic and coarse-grain simulations, the researchers identified that ion pairing between the lipid head groups of biological membranes and the polycations' ammonium groups in the nanoparticle wrapping leads to the formation of fragmented lipid coronas. These coronas engender new properties, including composition and stickiness, to the particles with diameters below 10 nanometers.

The study's insights help predict the impact that the increasingly widespread use of engineered nanomaterials has on the nanoparticles' fate once they enter the food chain, which many of them may eventually do.

"New technologies and mass consumer products are emerging that feature nanomaterials as critical operational components," Geiger said. "We can upend the existing paradigm in nanomaterial production towards one in which companies design nanomaterials to be sustainable from the beginning, as opposed to risking expensive product recalls—or worse—down the road." [40]

Hidden gapless states on the path to semiconductor nanocrystals

When chemists from the Institute of Physical Chemistry of the Polish Academy of Sciences in Warsaw were starting work on a new material designed for the efficient production of nanocrystalline zinc oxide, they didn't expect any surprises. They were thus greatly astonished when the electrical properties of the changing material turned out to be extremely exotic.

The single source precursor (SSP) approach is widely regarded as a promising strategy for the preparation of semiconductor nanocrystalline materials. However, one obstacle to the rational design of SSPs and their controlled transformation to the desired nanomaterials with highly controlled physicochemical properties is the scarcity of mechanistic insights during the transformation process. Scientists from the Institute of Physical Chemistry of the Polish Academy of Sciences (IPC PAS) and the Faculty of Chemistry of Warsaw University of Technology (WUT) now report that in the thermal decomposition process of a pre-organized zinc alkoxide precursor, the nucleation and growth of the semiconducting zinc oxide (ZnO) phase is preceded by cascade transformations involving the formation of previously unreported intermediate radical zinc oxo-alkoxide clusters with gapless electronic states. Up to now, these types of clusters have not been considered either as intermediate structures on the path to the

semiconductor ZnO phase or as a potential species accounting for the various defect states of ZnO nanocrystals.

"We discovered that one of the groups of ZnO precursors that have been studied for decades, zinc alkoxide compounds, undergo previously unobserved physicochemical transformations upon thermal decomposition. Originally, the starting compound is an insulator. When heated, it rapidly transforms into a material with conductor-like properties, and a further increase in temperature equally rapidly leads to its conversion into a semiconductor," says Dr. Kamil Sokołowski (IPC PAS).

The design and preparation of well-defined nanomaterials in a controlled manner remains a tremendous challenge, and is acknowledged to be the biggest obstacle for the exploitation of many nanoscale phenomena. Professor Lewiński's (IPC PAS, PW) group has for many years been engaged in the development of effective methods of producing nanocrystalline forms of zinc oxide, a semiconductor with wide applications in electronics, industrial catalysis, photovoltaics and photocatalysis. One of the approaches is based on the single source precursors. The precursor molecules contain all components of the target material in their structure and only temperature is required to trigger the chemical transformation.

"We dealt with a group of chemical compounds with the general formula RZnOR, as single source pre-designed ZnO precursors. A common feature of their structure is the presence of the cubic [Zn_4O_4] core with alternating zinc and oxygen atoms terminated by organic groups R. When the precursor is heated, the organic parts are degraded, and the inorganic cores self-assemble, forming the final form of the nanomaterial," explains Dr. Sokołowski.

The tested precursor had the properties of an insulator, with an energy gap of about five electronvolts. When heated, it eventually transformed into a semiconductor with an energy gap of approximately 3 eV.

"An exceptional result of our research was the discovery that at a temperature close to 300 degrees Celsius, the compound suddenly transforms into almost gapless electronic state, showing electrical properties rather more typical of metals. When the temperature rises to approximately 400 degrees, the energy gap suddenly expands to a width characteristic of semiconductor materials. Ultimately, thanks to the combination of advanced synchrotron experiments with quantum-chemical calculations, we have established all the details of these unique transformations," says Dr. Adam Kubas (IPC PAS), who carried out the quantum-chemical calculations.

The spectroscopic measurements were carried out using methods developed by Dr. Jakub Szlachetko (Institute of Nuclear Physics PAS, Cracow) and Dr. Jacinto Sa (IPC PAS and Uppsala University) at the Swiss Light Source synchrotron facility at the Paul Scherrer Institute in Villigen, Switzerland. The material was heated in a reaction chamber, and its electron structure was sampled using an X-ray synchrotron beam. The setup allowed for real-time monitoring of the transformations.

This detailed in situ study of the decomposition process of the zinc alkoxide precursor, supported by computer simulations, revealed that any nucleation or growth of a semiconducting ZnO phase is preceded by cascade transformations involving the formation of previously unreported intermediate radical zinc oxo-alkoxide clusters with gapless electronic states.

"In this process, homolytic cleavage of the R-Zn bond is responsible for the initial thermal decomposition process. Computer simulations revealed that the intermediate radical clusters tend to dimerise through an uncommon bimetallic Zn-Zn-bond formation. The following homolytic O-R bond cleavage then leads to sub-nano ZnO clusters which further self-organise to the ZnO nanocrystalline phase," says Dr. Kubas.

Until now, the radical zinc oxo clusters formed have not been considered either as intermediate structures on the way to the semiconductor ZnO phase or as potential species accounting for various defect states of ZnO nanocrystals. In a broader context, a deeper understanding of the origin and character of the defects is crucial for structure-property relationships in semiconducting materials.

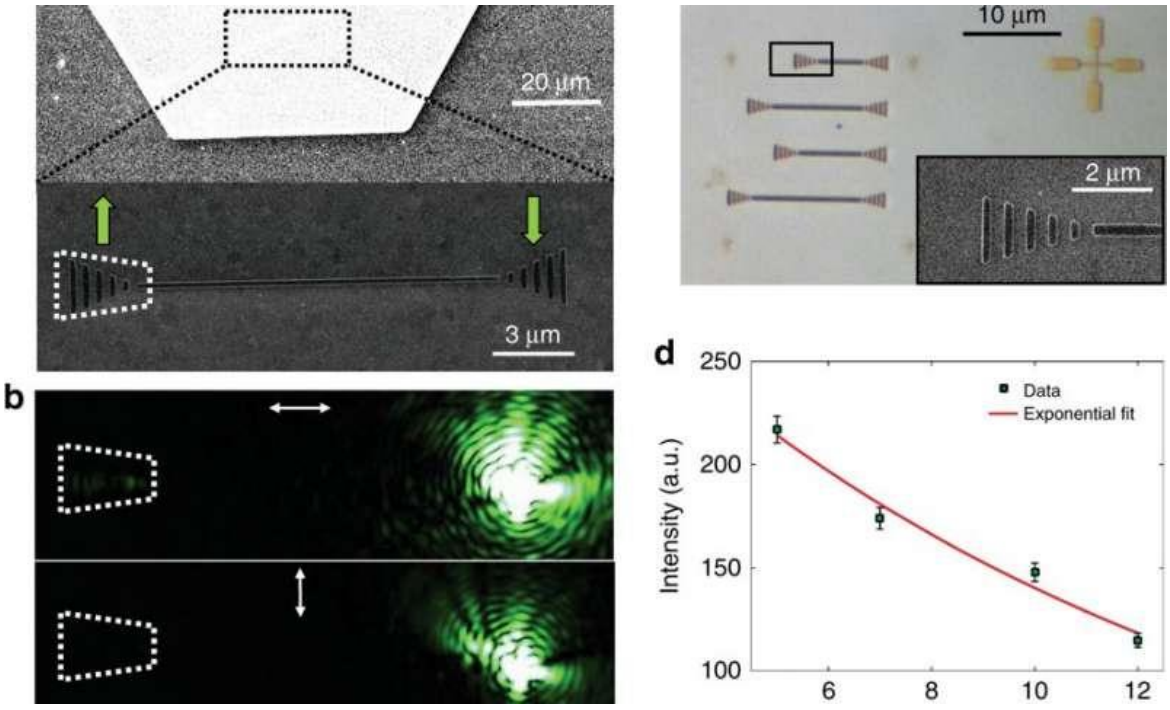
The research, funded by the National Science Centre and the TEAM grant of the Foundation for Polish Science co-financed by the European Union, will contribute to the development of more precise methods of controlling the properties of nanocrystalline zinc oxide. So far, with greater or lesser success, these properties have been explained with the help of various types of material defects. For obvious reasons, however, the analyses have not taken into account the possibility of forming the specific radical zinc-oxo clusters discovered by the Warsaw-based scientists in the material. [39]

On-chip excitation of nanodiamonds embedded in plasmonic waveguides

Quantum emitters can be integrated in monolithic nanoscale plasmonic circuitry via low-loss plasmonic configurations to confine light well below the diffraction limit. In integrated quantum plasmonics, waveguides based on surface plasmon polariton (SPP) modes that propagate electromagnetic waves along metal-dielectric or metal-air interfaces are superior to dielectric-based (and therefore diffraction-limited) photonic waveguides. The observation is in respect to the available Purcell enhancement from embedded quantum emitters and the ongoing trend toward on-chip integration and miniaturization to realize optical signal processing and integrated circuits. Different metal-dielectric configurations have been developed for strong light-matter interactions at the scale of the single photon to support the propagation of plasmonic modes confined beyond the diffraction limit. The property can enable unique prospects to design highly integrated photonic-signal processing systems, sensors and optical imaging techniques with nanoscale resolution.

A variety of SPP-based structures created in the past include metal nanowires (NW), parallel NWs, V-grooves (VGs) and wedge waveguides that have demonstrated single plasmon guidance for potential quantum applications. The practical realization of such integrated quantum photonics has remained elusive due to several challenges, including high propagation losses of SPP modes and the limited control on single quantum emitters. More recently, studies have nanofabricated low-loss, dielectric-loaded SPP waveguides (DLSPPWs) structured on a silver film for simple quantum plasmonic circuits composed of embedded nanodiamonds with nitrogen-vacancy centers.

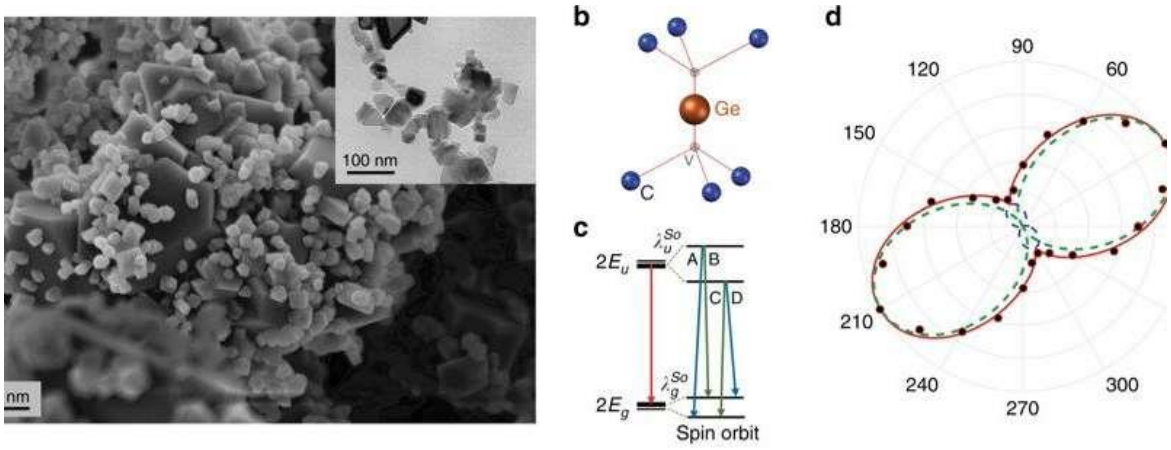
Now writing in *Light Science & Applications*, Hamidreza Siampour and co-workers have taken a step forward in the field of integrated quantum plasmonics by demonstrating on-chip coupling between a single photon source and plasmonic waveguide. In the approach, the physicists engineered a nanodiamond featuring a germanium vacancy (GeV) center that emits single photons, embedded inside a plasmonic waveguide composed of dielectric hydrogen silsesquioxane (HSQ) atop a layer of silver fabricated using electron-beam lithography. When a green laser light (532 nm) was coupled to one end of the waveguide via grating couplers to propagate to the nanodiamond, it excited the GeV center, which emitted a single photon that coupled into the plasmon mode of the waveguide. In the work, the researchers achieved long waveguide transmission lengths (33 µm) and efficient coupling (56 percent) to open new avenues in the development of chip-based quantum circuitry.



Transmission of green laser light (532 nm) along the low-loss plasmonic waveguide, a) SEM image of a single crystalline flake (top) and fabricated DLSPP waveguide atop of the Ag plate (bottom), b) optical characterization of the waveguide …more

The study was the first to detail the synthesis and characterization of the GeV nanodiamonds. The nanodiamonds were produced using the high-pressure, high-temperature (HPHT) method; Ge was introduced during the growth process to incorporate single GeV centers. The scientists proposed and demonstrated a hybrid approach for nanofabrication using DLSPPW structured on single silver (Ag) crystals that considerably lowered SPP dampening rates, compared to Ag films fabricated by other techniques. The method facilitated sufficiently long SPP propagation at the excitation and emission wavelengths of GeV centers in nanodiamonds incorporated within a plasmonic chip.

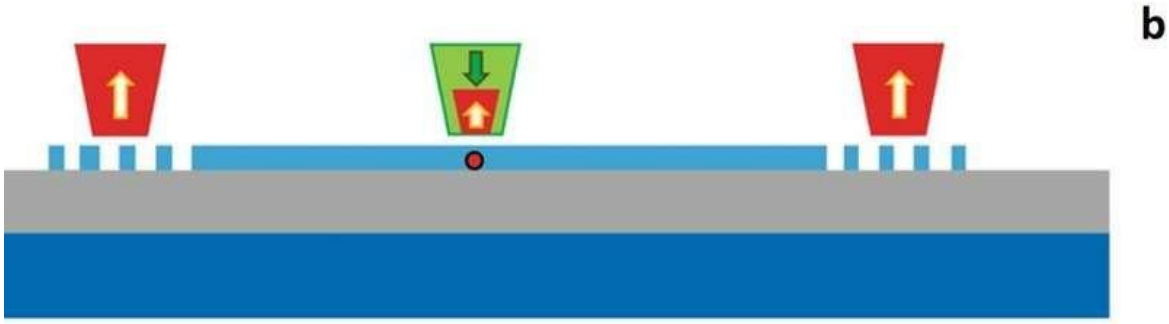
The structure of the synthetic GeV nano and microdiamonds were observed in the raw sample using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Synthetic nanodiamonds were spin coated onto Ag-coated silicon wafers and scanned with confocal fluorescence microscopy. Measured data indicated ultrabright, spectrally narrow and stable single photon sources based on single GeV centers in the nanodiamonds, suitable for highly integrated circuits. The polarization characteristics of the GeV nanodiamonds were measured using an analyzer in the detection pathway to determine the projection of single photons emitted on the surface plane. The data measured for a single GeV nanodiamond fit the model polarization characteristics of diamond color centers based on group-IV elements in the periodic table (e.g. silicon-vacancy SiV, germanium-vacancy GeV, and tin-vacancy SnV).



Characterization of the nanodiamonds: a) SEM images of the GeV nano and microdiamonds of the raw sample after HPHT synthesis, the TEM image is seen inset. b) the Ge atom is located in the middle of two empty lattice sites, which includes …more

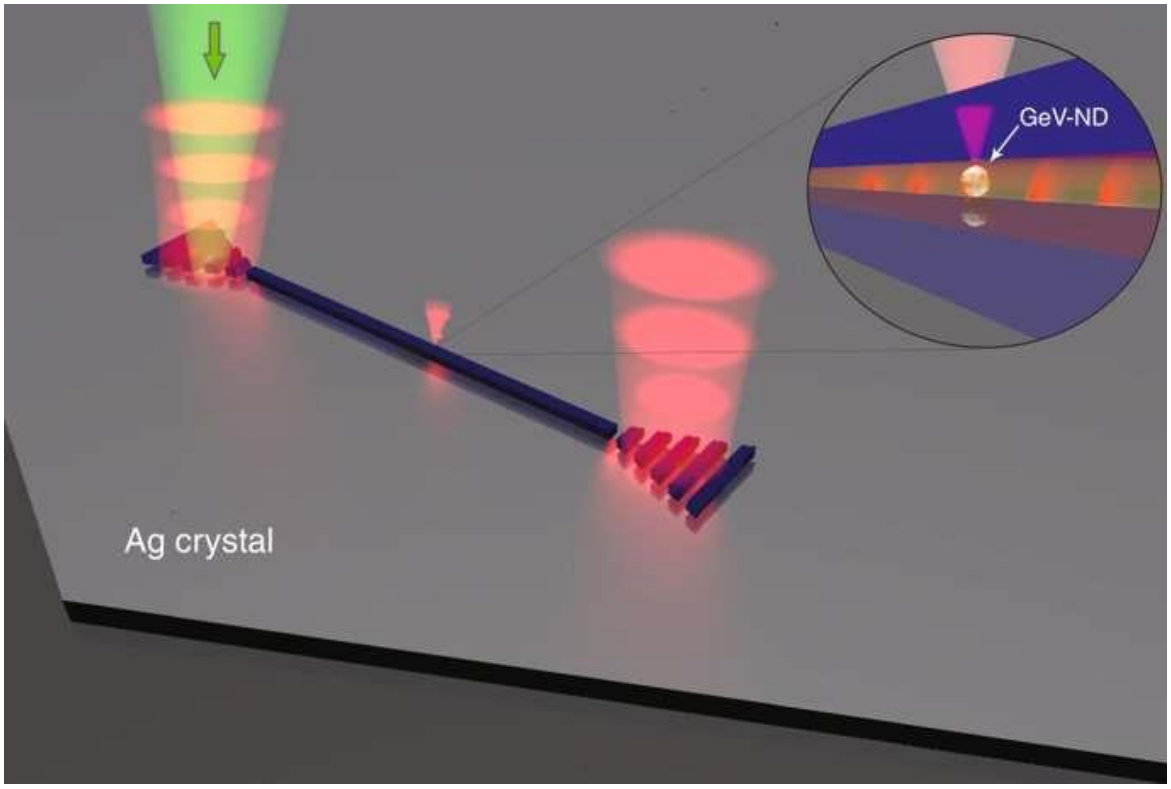
The observed capacity for single-photon emission in diamond nanocrystals can enable hybrid quantum-plasmonic systems that can facilitate remote excitation of the GeV centers incorporated in a plasmonic chip. Siampour et al. elegantly demonstrated the efficient long-range delivery of the GeV-DLSPPW system compared with other hybrid quantum plasmonic systems. An exceptional figure of merit (FOM) of 180 was revealed in the study due to a ~six-fold Purcell enhancement, 56 percent coupling efficiency and ~33 µm transmission length at a wavelength (λ) of 602 nm.

Electron beam lithography was used to fabricate the waveguides with HSQ resist on Ag-coated substrates to contain the nanodiamonds featuring single GeV centers - added via controlled placement into the device. The technology provided ~30 nm precision in placement, enhanced via observations with SEM imaging, limited by the size of nanodiamonds, which could be fabricated down to 1 nm using existing diamond synthetic technology. The fabricated waveguide was visualized with atomic force microscopy (AFM) and with a charge coupled device (CCD) camera after nanodiamond excitation via a green pump laser.



On-chip excitation of a single GeV nanodiamond (ND) assigned via controlled placement in a device fabricated with hydrogen silsesquioxane (HSQ) atop Ag film a) the sample layout and working principle of direct excitation of a GeV …more

Additionally, the authors used a single crystalline Ag flake instead of Ag film to significantly enhance the DLSPPW propagation length. Green laser light transmitting through the DLSPPW mode was optically characterized as polarization along the waveguide axis. Transmission was measured for several waveguides of varying lengths to show extraordinary propagation lengths (~11.8 μm) for the green laser light through the low-loss DLSPPW.



Schematic illustration of the device layout and working principle for on-chip excitation of a nanodiamond. The nanodiamond carries spectrally narrow single GeV quantum emitters embedded in a DLSPP waveguide. Credit: Light Science & Applications, doi: 10.1038/s41377-018-0062-5.

Using a similar set-up, the scientists proceeded to demonstrate and confirm remote excitation of the GeV center coupled to the DLSPPW mode. Subsequently, the GeV decay rate was simulated using the finite element modeling (FEM) method and a decay rate of up to four-fold was predicted for a GeV center in the waveguide compared to its emission in vacuum. The system demonstrated superior performance when compared with previously demonstrated systems, the observed Purcell factor can be further enhanced in future studies by using a larger refractive index dielectric such as titanium dioxide (TiO_2).

The study opens the way to integrate an excitation laser, quantum emitter and plasmonic circuit onto the same chip. Previous strategies have demonstrated the detection of single plasmons and two-plasmon interference on a chip. By combining all three technologies on a single chip, the authors envision that it will be possible to integrate all elements of a quantum plasmonic circuit on a chip in the near future. [38]

Proof-of-concept technique makes nanoparticles attractive for new medications

Since the development of insulin to manage diabetes, pharmacists have longed to create an insulin pill. Past attempts have failed because insulin does not survive the harsh conditions of the gastro-intestinal (GI) system and cannot easily cross the GI wall. Researchers at University of Utah Health developed a proof-of-concept technology using nanoparticles that could offer a new approach for oral medications. The results will be published online in the August 8 issue of the journal *ACS Nano*.

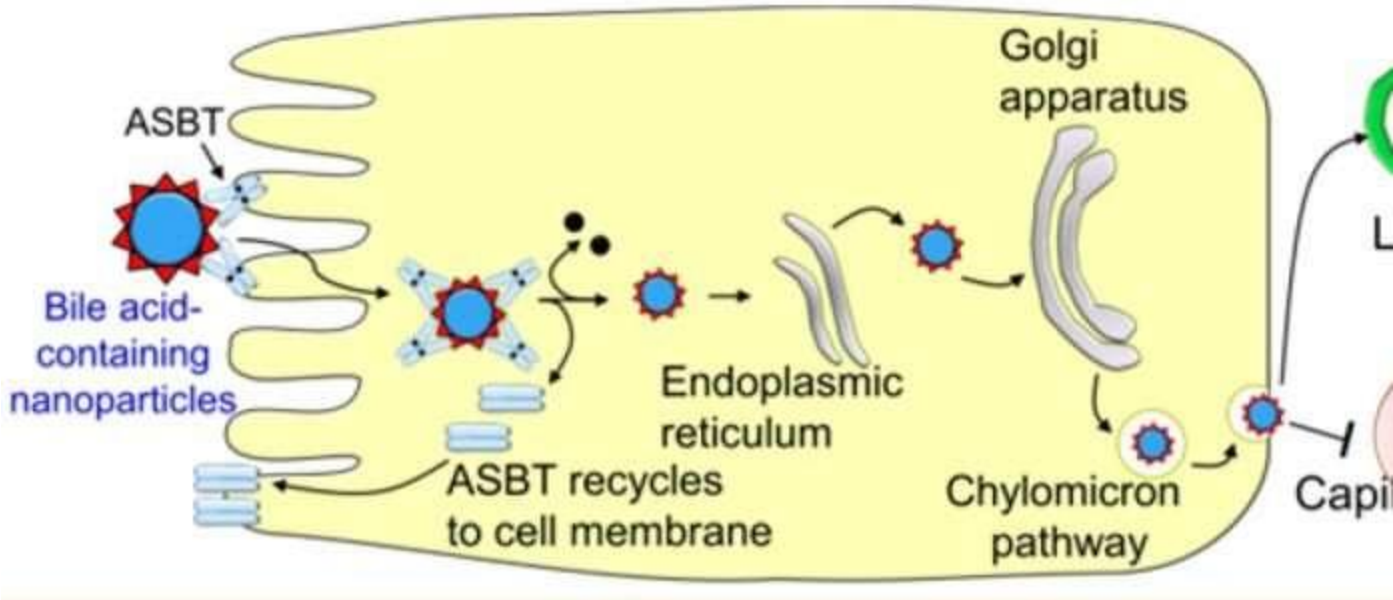
"In the pharmaceutical world, this has been regarded as the holy grail," said You Han Bae, Ph.D., professor Pharmaceutics and Pharmaceutical Chemistry at U of U Health and senior author on the paper.

Nanomedicine is a burgeoning field of medicine that delivers tiny particles (nanoparticles) to carry drugs to treat a variety of conditions, including cancer. These treatments are commonly given intravenously, because solid nanoparticles have a poor absorption rate in the body.

Bae and his team modified the surface of the nanoparticles with glycocholic acid, a bile acid that helps the body absorb fat in the small intestine.

The glycocholic acid acts like a cloak, allowing the nanoparticle to slip incognito through the lining of the small intestine. Preliminary evidence suggests that the coating helps the nanoparticles bind to proteins that let them move into the gut lymphatic system where it can access the bloodstream.

"Nanoparticles were not expected to be absorbed through the lymphatic system," said Kyoung Sub Kim, Ph.D., a post-doctoral research assistant in Bae's lab and first author on the paper. "Lymphocyte delivery of nanoparticles allows a wide range of medicines to be applied through this method."



Credit: ACS

Without this chemical cloak, only seven percent of nanoparticles are absorbed and enter the blood stream. With this new technique, bioavailability increased seven-fold. Bae notes that it takes about one to ten hours for the nanoparticles to appear in the bloodstream.

Bae and his colleagues found nanoparticle size matters. They fed rodents oral nanoparticles in two sizes (100 or 250 nm) at doses ranging from 1 to 20 mg/kg. Surprisingly, larger nanoparticles were not less well absorbed. Dose, however, did not affect the uptake of nanoparticles into the body.

To monitor the nanoparticle movement, the researchers affixed a red fluorescence tag on the treated particles and watched the particles circulate through the body.

Nanoparticles are tiny—ten thousand times smaller than the head of a pin. In medicine, researchers design these particles to seek out diseased cells for direct treatment, reducing the damage to risk of damage to healthy cells. Researchers have long sought a way to deliver an oral dose of nanoparticles to make these treatments more accessible to patients.

Bae notes that this work is still at the preliminary stages and more work is needed to move the results from animal studies to clinical trials. As a proof of concept, the researchers used polystyrene nanoparticles that are not appropriate for clinical use because the particles are not dissipated or excreted from the body.

"This is basic research with broad future applications," Bae said. "Our work is a stepping stone." [37]

High-resolution imaging of nanoparticle surface structures is now possible

Using scanning tunnelling microscopy (STM), extremely high resolution imaging of the molecule-covered surface structures of silver nanoparticles is possible, even down to the recognition of individual parts of the molecules protecting the surface. This was the finding of joint research between China and Finland, led in Finland by Academy Professor Hannu Häkkinen of the University of Jyväskylä. The research was recently published in the prestigious *Nature Communications* series and the publication was selected by the journal editors to the journal's monthly collection of highlighted papers.

Studying the surface structures of nanoparticles at atomic resolution is vital to understanding the chemical properties of their structures, molecular interactions and the functioning of particles in their environments. Experimental research on surface structures has long involved imaging techniques suitable for nanometer-level resolution, the most common of which are based on electron tunnelling, the abovementioned scanning tunnelling microscopy (STM), and atomic force microscopy (AFM) based on the measurement of small, atomic-scale forces.

However, achieving molecular resolution in imaging has proven highly challenging, for example because the curvature of the object to be imaged i.e. the nanoparticle's surface, is of the same order as the curvature of the scanning tip. Measurements are also sensitive to environmental disturbances, which may affect the thermal movement of molecules, for example.

The researchers used previously characterised silver nanoparticles, with a known atomic structure. The metal core of the particles has 374 silver atoms and the surface is protected by a set of 113 TBTT molecules. TBBT (tert-butyl-benzene thiol) is a molecule with three separate carbon groups on its end. The particle's outer surface has a total of 339 such groups. When this type of nano-particle sample was imaged at low temperatures in the STM experiment, clear sequential modulations were observed in the tunnelling current formed by the image (see left part of the image). Similar modulations were noted when individual TBBT molecules were imaged on a flat surface.

Based on density functional theory (DFT), the simulations performed by Häkkinen's research team showed that each of the three carbon groups of the TBBT molecule provides its own current maximum in the STM image (see the right part of the image) and that the distances between the maxima corresponded to the STM measurement results. This confirmed that measurement was successful at sub-molecular level. The simulations also predicted that accurate STM measurement can no longer be successful at room temperature, as the thermal movement of the molecules is so high that the current maxima of individual carbon groups blend into the background.

"This is the first time that STM imaging of nanoparticle surface structures has been able to 'see' the individual parts of molecules. Our computational work was important to verifying the experimental results. However, we wanted to go one step further. As the atomic structure of particles is well known, we had grounds for asking whether the precise orientation of the imaged particle could be identified using simulations," says Häkkinen, describing the research.

To this end, Häkkinen's group computed a simulated STM image of the silver particle from 1,665 different orientations and developed a pattern recognition algorithm to determine which simulated images best matched the experimental data.

"We believe that our work demonstrates a new useful strategy for the imaging of nanostructures. In the future, pattern recognition algorithms and artificial intelligence based on machine learning will become indispensable to the interpretation of images of nanostructures. Our work represents the first step in that direction. That's why we have also decided to openly distribute the pattern recognition software we had developed to other researchers," says Häkkinen.

The nanoparticle synthesis was performed in Xiamen University by Professor Nanfeng Zheng's research group and the STM measurements were carried out at Dalian Institute of Chemical Physics under the direction of Professor Zhibo Man. Ph.D. student Sami Kaappa and senior researcher Sami Malola from Professor Häkkinen's group performed the calculations for the project. The research of Professor Häkkinen's group is in receipt of funding from the AIPSE programme of the Academy of Finland. The CSC – IT Center for Science in Finland and the Barcelona Supercomputing Center provided the resources for all simulations requiring high-power computing. The Barcelona simulations were part of the NANOMETALS project supported by the PRACE organisation. [36]

A breakthrough of monitoring energy storage at work using optical fibers

A fiber optic sensing system developed by researchers in China and Canada can peer inside supercapacitors and batteries to observe their state of charge.

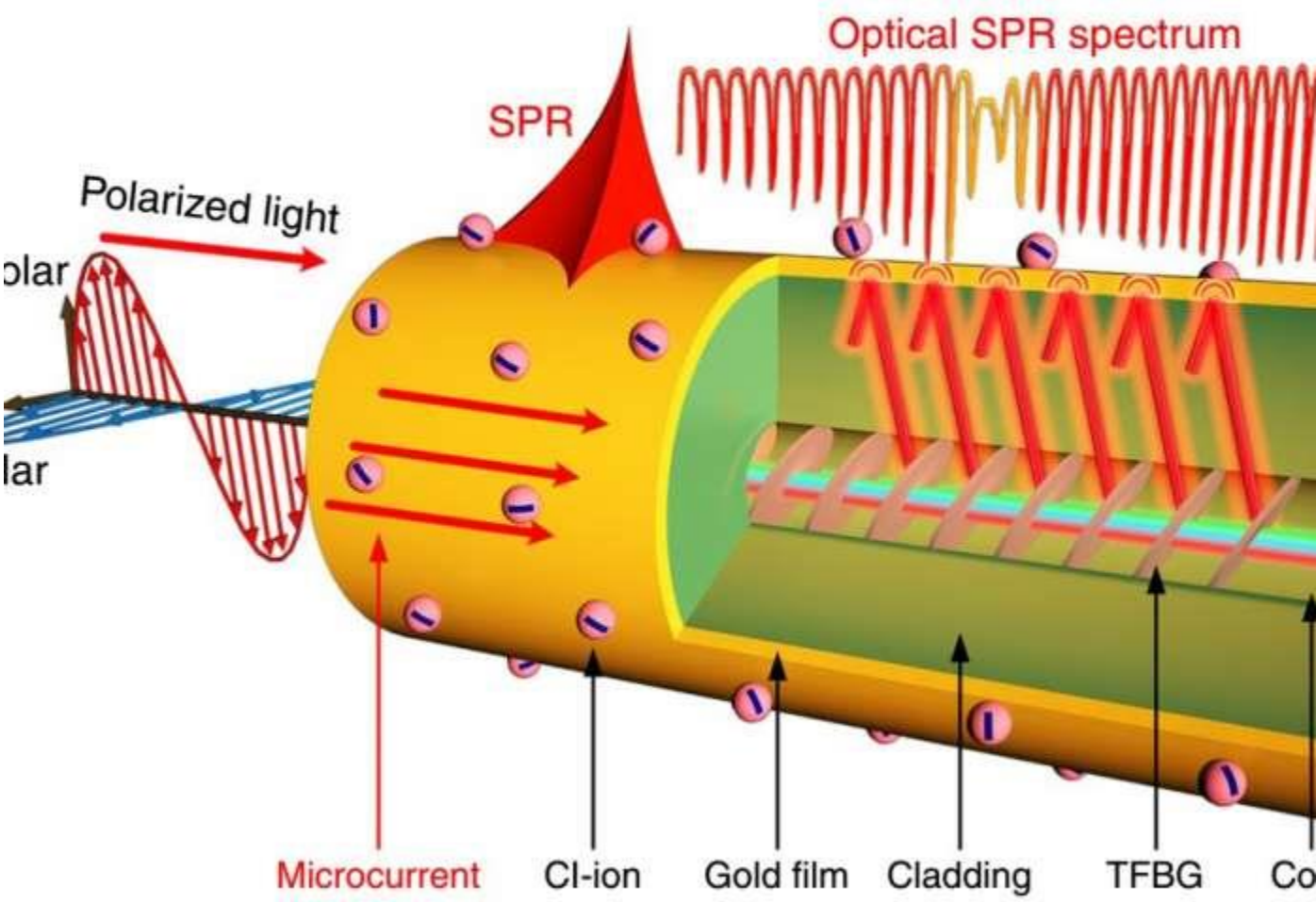
Renewable energy sources are naturally inconsistent, and thus require new energy storage technologies. Supercapacitors offer rapid charging and long-term storage, but it is important to be able to monitor their working state. To tackle this issue, a team including Tuan Guo and Wenjie Mai at Jinan University adapted an approach based on an optical fiber-based plasmonic sensor. The sensor is embedded inside the capacitor and is able to measure the state of charge of the electrodes and electrolytes in real time, while operating, and over its lifetime. The sensor demonstrates a clear and repeatable high correlation between measurements of the optical transmission of the fiber device and simultaneous supercapacitor's state of charge,

offering a unique, low-cost method for real-time monitoring of energy storage devices in operation.

This result has been published in *Light: Science & Applications* (July 11, 2018), with a manuscript title of "In Situ Plasmonic Optical Fiber Detection of the State of Charge of Supercapacitors for Renewable Energy Storage. "

Electrochemical energy storage devices (such as supercapacitors) are considered to be the next generation of energy storage devices with the highest energy storage efficiency and very promising prospects. They are widely used in clean electric power, electric vehicles, mobile medical, portable electronic devices and other fields. In situ and continuous monitoring is a key method for understanding and evaluation of their performance and operation quality. However, the present methods cannot offer the real-time charge state information when the energy storage devices are in operation. They are required to take the supercapacitors offline (thus interrupting their function) and carry out electrical measurements, and in some cases, opening up the supercapacitors to examine their components by electron microscopy.

To address this fundamental challenge, Prof. Guo and Prof. Mai and their colleague developed optical fiber devices small enough to be inserted near the surface of the capacitor electrodes. Based on telecommunication-grade fibers, they can be left there and monitored remotely at any time and from any distance. Another important aspect of their approach is that in contrast to current techniques that rely on an indirect estimate of the state of charge from current/voltage tests, the optical fiber devices detect the amount of charge accumulated in a sub-micrometer-sized layer on the electrodes and the adjacent electrolyte directly through its impact on the plasmonic properties of a nanometer-scale gold coating applied to the fiber surface.



Electrochemical surface-plasmon-resonance sensing principle and experimental demonstration with a gold-coated TFBG optical fiber sensor. Sketch of the configuration of a plasmonic optical fiber sensor for in situ monitoring of …more

It demonstrated a clear and repeatable high correlation between measurements of the optical transmission of the fiber device and simultaneous electrical validation measurements. This new technology will have important implications for energy suppliers who rely on renewable energy sources from sun, wind and hydro-electricity for at least part of their power grid requirements. The main implication is that faulty or deteriorating capacitors will be identified before catastrophic failures can occur, and that no interruption of power systems will be required for testing them. [35]

Optical fibers that can sense the materials around them

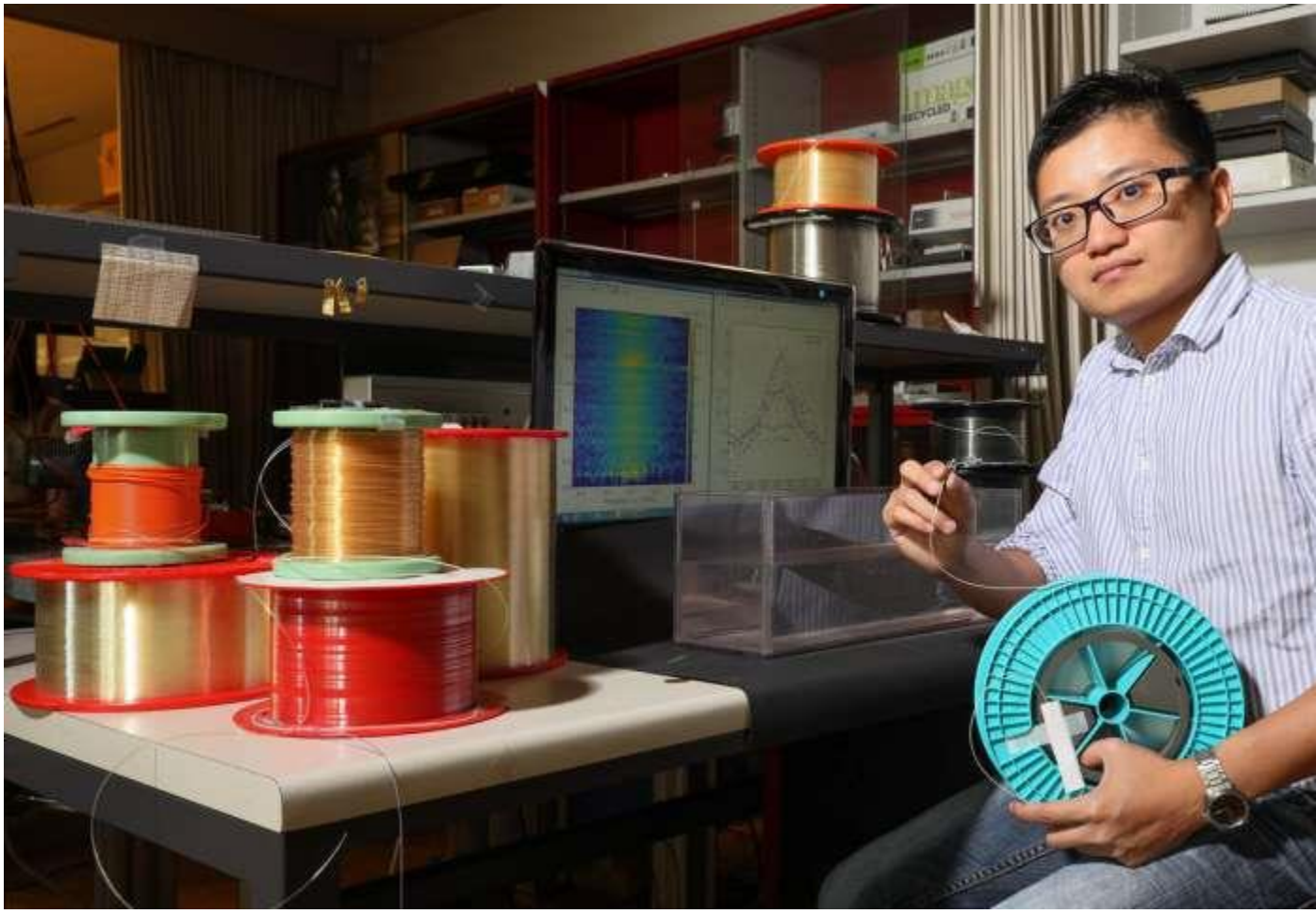
In recent years optical fibers have served as sensors to detect changes in temperature, like a thermometer, and pressure, like an artificial nerve. This technique is particularly useful in structures such as bridges and gas pipelines.

EPFL researchers have now come up with a new method that enables optical fibers to identify whether they are in contact with a liquid or a solid. This is achieved by simply generating a sound wave with the help from a light beam within the fiber. The study was conducted by the Group for Fibre Optics (GFO) run by Luc Thévenaz within the School of Engineering and has been published in *Nature Communications*.

A sensor that doesn't disturb the light

No wider than a strand of hair, an optical fiber made of glass transmits light that varies according to four parameters: intensity, phase, polarization and wavelength. These parameters are altered when the fiber is stretched or the temperature changes, enabling the fiber to act like a sensor by detecting cracks in structures or abnormal temperatures. But up to now it was not possible to determine what was happening around the fiber without having light escape the fibre, which disrupts its path.

The method developed at EPFL uses a sound wave generated inside the fiber. It is a hyper-frequency wave that regularly bounces off the fiber's walls. This echo varies at different locations depending on the material the wave comes into contact with. The echoes leave an imprint on the light that can be read when the beam exits the fiber, making it possible to map out the fiber's surroundings. This imprint is so faint that it hardly disturbs the light propagating within the fiber. The method could be used to sense what is going on around a fiber and send light-based information at the same time.



Desmond Chow in the lab. Credit: Alain Herzog / EPFL

The researchers have already immersed their fibers in water and then in alcohol, before leaving them out in the open air. Each time, their system was capable of correctly identifying the change in the surroundings. "Our technique will make it possible to detect water leakages, as well as the density and salinity of fluids that come into contact with the fiber. There are many potential applications," says Thévenaz.

Spatial and temporal detection

These changes in the surroundings are located thanks to a simple time-based method. "Each wave impulse is generated with a slight time lag. And this delay is reflected upon the beam's arrival. If there were any disturbances along the way, we can both see what they were and determine their location," explains Thévenaz. "For the moment, we can locate disturbances to within around ten meters, but we have the technical means to increase our accuracy to one meter."

The idea of using a sound wave in optical fibers initially came from the team's partner researchers at Bar-Ilan University in Israel. Joint research projects should follow. [34]

Researchers develop first-of-its-kind optic isolator

Researchers at the Technion-Israel Institute of Technology have constructed a first-of-its-kind optic isolator based on resonance of light waves on a rapidly rotating glass sphere. This is the first photonic device in which light advancing in opposite directions moves at different speeds.

"Essentially, we developed a very efficient photonic isolator, which can isolate 99.6% of the light," said research team leader Professor Tal Carmon. "Namely, if we sent 1,000 light particles, the device will effectively isolate 996 photons and will miss only 4. Such isolation efficiency is necessary for applications that include quantum optics communication devices and building high-powered lasers. The isolator we developed here fulfills several additional requirements: it also works well when light from both opposing directions is simultaneously perceived, it is compatible with standard optical-fiber technology, it can be scaled down and it does not change the color of the light."

Just as swimming downstream is faster than swimming upstream and riding a bicycle with the wind behind you is faster than riding against the wind, light also changes its speed with "tailwinds" or "counter-flow," in response to the medium in which it is moving. The speed of light in glass, for instance, is slower than its speed in air. Also, two beams of light advancing in opposite directions in glass, or any other material, will advance at the same speed.

"At the Technion, I also learned that the speed of light depends on the speed of the medium in which it is moving," said Professor Carmon. "Precisely like a swimmer in a river – the speed of light against the movement of the medium is slower than its speed with the movement of the medium."

This effect was already described in 1849 by the French scientist Armond Fizeau, who showed, that like a swimmer in a river, the speed of light down a current is faster than light going up a current. Fizeau's discovery had a significant impact on the development of Einstein's theory of Special Relativity.

The Fizeau drag may lead to significant applications in optics and computers, as its unique ability to differentiate between the speeds of light for counter-propagating beams can generate an optic isolator – a device into which light entering on one side is blocked, while the light entering from another side is transmitted. Until now, a device in which opposing light beams advance at different speeds, had not be constructed.

But now, for the first time, Technion researchers have succeeded in constructing such a device. The spherical optic device rotates at a high speed. Light beams are delivered into it from opposite directions via a nearby tapered fiber. The light approaching from the right moves along the circumference of the ball, in the direction of the rotation of the sphere, while the light

approaching from the left turns opposite the direction of the rotation and therefore moves at a slower speed.

The novel device constitutes an optic isolator – it transmits light approaching from the left and turns off light coming from the right. Another effect that is relevant here is resonance. Just like a musical instrument that resonates at a specific frequency, light circumferentially circulating in the sphere resonantly echoes. Yet, the different speeds for counter-circulating light forces these counter-circulating light to have different colors. This way, light entering from one side

echoes inside the sphere while circulating thousands of times in the sphere, until it is absorbed. In contrast, light entering from the opposing side of the isolator is nonresonating and hence passes through the device practically undisturbed. In other words, the light moving with the device, resonates and is shut off, while the light moving against the device is transmitted and continues on."

Professor Carmon noted that the device was constructed at the Technion glass blowing workshop. It was constructed from a glass rod whose tip was melted to a 1 millimeter-radius ball. The light enters the isolator from both sides of a standard optical fiber, tapered at the vicinity of the sphere to a diameter 100-time smaller than that of a hair, and positioned several nanometers away from the sphere. The sphere, which serves as the resonator, rotates at an ultra-fast speed – the tip of the ball moves at a speed of 300 kph – and the light coming from the fiber rotates within it thousands of times.

One of the engineering challenges the research group faced was maintaining the ultra-short distance between the fiber – via which light is provided – and the spherical resonator constant.

"Maintaining an accurate distance is a true challenge, even when the device is not moving, and is an enormous challenge when the sphere is rotating at such a high speed," said Prof. Carmon. "Therefore, we sought a means of forcing the fiber to move together with the sphere, despite the fact that the fiber and sphere are not connected. We finally achieved this by designing the fiber to float on the wind generated by the rotation of the sphere. In this way, if the device wobbles – which it does due to the rapid rotation – the fiber will wobble with it and the distance between them will be preserved. In fact, the fiber is actually flying above the rotating sphere at a constant and self-alighted nano-elevation"

The photo shows the fiber (the empty circle), the tip of the rotating sphere (at the bottom, in grey), and the flow of wind between them, upon which the fiber floats. The fiber floats above the sphere while maintaining a distance of several tens of nanometers.

Professor Carmon hopes this nano-seperated paves a path toward a novel type of mechanical device based on relatively unexplored forces that dominates at nano-scale separation.

"The forces acting at such distances include Casimir and Van der Waals forces – very strong forces originating from quantum effects, which, to date, have barely been exploited in

mechanical devices, in general, and in mechanical oscillators, in particular," he said. "We recently demonstrated, for the first time, lasers in which water waves mediate laser emission; and also, for the first time, micro-lasers where sound mediates laser emission."

In the future, the researchers may be able to generate such lasers that are based on vibrations where the restoring force is Casimir or Van der Waals. Using their self-aligned nano separation method might also allow micro electro mechanical devices [MEMS] where Casimir and Van der Waals forces will be used. [33]

Scientists develop unique trap for light

Based at the National Research Nuclear University MEPhI (Russia), a research team led by Prof. Yuri Rakovich has developed a tunable micro-resonator for hybrid energy states between light and matter using light to control the chemical and biological properties of molecules. The results have been published in the *Review of Scientific Instruments*.

The micro-resonator is a two-mirror trap for the light, with the mirrors facing each other within several hundred nanometers. A photon caught in the trap would form a localized state of an electromagnetic wave. By modifying the resonator's form and size, operators can control the spatial distribution of the wave, as well as the duration of the photon's life in the resonator.

The new invention makes it possible to control chemical and biological properties of molecules with the help of light. The micro-resonator can serve as the basis for new-generation instruments that can be used in biological and chemical sensing as well as to control the speed of chemical reactions and energy transfer efficacy.

The resonance interaction between quantum emitters and a localized electromagnetic field is of interest primarily because it provides an opportunity to control the properties of light-matter hybrid states. The light and matter in these systems form an intermediate state with changed properties which are controllable with the help of optical emission (light). One of the ways to induce these states is to place emitting or absorbing molecules in a resonator.

According to the scientists, their tunable micro-resonator will substantially simplify and extend relevant research by making it possible to analyze light-matter interactions in both strong and weak communication modes for samples of practically any matter in the UV-IR spectrum.

The instrument is a Fabry-Perot micro-resonator (λ2) consisting of mirrors, one flat and one convex, that secure plane-parallelism at least in one point on the surface of the latter, thus minimizing the mode volume. This is a light trap of two mirrors placed in front of each other within less than a light wave length, according to Prof. Yuri Rakovich, a leading researcher at the MEPhI Laboratory of Hybrid Photon Nano-Materials.

As a light quantum falls into the trap or is emitted by a light source inside the resonator, it is repeatedly reflected by the mirrors, which links photons with the microresonator's own energy states.

"We can control the properties of light and effectiveness of the trap by modifying the form and size of the resonator," Rakovich said.

The micro-resonator is easy to use and its design is simple enough to launch its industrial production. It can be used not only in instruments intended to control the speed of chemical reactions but also as a basis for developing highly effective light sources and new lasers with a low control generation threshold.

The instrument will provide new opportunities for studying the effects of strong and weak connections on combinational scattering, the speed of chemical reactions, electric conductivity, laser generation, non-radiative energy transfer, and other physical, chemical and biological functions. This will also mean an important step forward in developing various practical applications of the light-matter connection effect, primarily in order to modify physical, chemical and biological processes. [32]

Controlling photons with a photon

Photons are considered to be ideal information carriers and expected to play important roles in quantum communication and information processing, where quantum mechanics allows for absolutely secure cryptographic key distribution as well as computation much faster than conventional computers. In order to take full advantage of quantum information carried by photons, it is important to make them directly interact with each other for information processing.

However, photons generally do not interact with one another. So it is necessary to mediate such interactions with matter to realize effective photon-photon interaction, but light-matter interaction is usually extremely weak in normal media.

Haruka Tanji-Suzuki and colleagues at the Institute for Laser Science, the University of Electro-Communications, Tokyo, are currently working to develop all-optical quantum devices that are sensitive to a single photon input, such as a single photon switch in which an incoming photon switches the state of another photon.

In order to realize the strong light-matter interaction that is necessary for such devices, Tanji-Suzuki uses a laser-cooled ensemble of 87Rb atoms (~10 uK) trapped within a high-finesse optical resonator (finesse ~50000) in an ultrahigh-vacuum chamber. Notably, in order to switch a photon with a photon in such a system, the researchers use an effect known as 'vacuum-induced

transparency' observed recently by Tanji-Suzuki et al., in which an electromagnetic field as weak as a vacuum field (light with no photons) is shown to alter the optical properties of atoms.

"The realization of such all-optical single-photon devices will be a large step towards deterministic multi-mode entanglement generation as well as high-fidelity photonic quantum gates that are crucial for all-optical quantum information processing," says Tanji-Suzuki. [31]

The photoelectric effect in stereo

In the photoelectric effect, a photon ejects an electron from a material. Researchers at ETH have now used attosecond laser pulses to measure the time evolution of this effect in molecules. From their results they can deduce the exact location of a photoionization event.

When a photon hits a material, it can eject an electron from it provided it has enough energy. Albert Einstein found the theoretical explanation of this phenomenon, which is known as the photoelectric effect, in Bern during his "year of wonders" 1905. That explanation was a crucial contribution to the development of quantum mechanics, which was under way at the time, and it earned him the Nobel Prize in Physics in 1921. An international team of physicists led by Ursula Keller at the Institute for Quantum Electronics of the ETH Zurich has now added a new dimension to the experimental investigation of this important effect. Using attosecond laser pulses they were able to measure a tiny time difference in the ejection of the electron from a molecule depending on the position of the electron inside the molecule.

"For quite some time, people have studied the time evolution of the photoelectric effect in atoms", says Ph.D. student Jannie Vos, "but very little has so far been published on molecules." That is mainly due to the fact that molecules are considerably more complex than single atoms. In an atom, the outermost electron moving around the atomic nucleus is essentially catapulted out of its orbit. In a molecule, by contrast, two or more nuclei share the same electron. Where it is located depends on the interplay between the different attractive potentials. Exactly how the photoelectric effect happens under such conditions could only now be studied in detail.

To do so, Keller and her co-workers used carbon monoxide molecules, which consist of two atoms – one carbon and one oxygen atom. Those molecules were exposed to an extreme ultraviolet laser pulse that only lasted for a few attoseconds. (An attosecond is the billionth part of a billionth of a second). The energy of the ultraviolet photons ripped an electron out of the molecules, which subsequently broke up into their constituent atoms. One of those atoms turned into a positively charged ion in the process. Using a special instrument, the researchers then measured the directions in which the electrons and ions flew away. A second laser pulse, which acted as a kind of measuring stick, also allowed them to determine the precise instant at which the electron left the molecule.

"In this way we were able, for the first time, to measure the so-called Stereo Wigner time delay," explains Laura Cattaneo, who works as a postdoctoral researcher in Keller's group. The stereo Wigner time delay measures how much earlier or later an electron leaves the molecule if it is located close to the oxygen atom or to the carbon atom when photoionization occurs. The extremely short laser pulses make it possible to measure that instant to within a few attoseconds. From that information, in turn, it is possible to determine the location of the ionization event inside the molecule to within a tenth of a nanometre. The experimental results agree well with theoretical predictions that describe the most likely position of an electron at the time of photoionization.

Next, the ETH researchers want to take a closer look at larger molecules, starting with the laughing gas N2O. The extra atom in that molecule already makes the theoretical description quite a bit more difficult, but at the same time the physicists hope to obtain new insights, for example into the so-called charge migration inside molecules, which plays an important role in chemical process.

In principle it should even be possible to use attosecond laser pulses not just to study those processes, but also to deliberately steer them and thus to control chemical reactions in detail. Right now, however, such atto-chemistry is still a long way off, as Jannie Vos points out: "In theory that's all very exciting, but a lot remains to be done before we get there." [30]

Core electron topologies in chemical bonding

YNU researchers have solved the age-old mystery of why silicon cannot replace carbon in organic compounds. A new benchmark quantum chemical calculation of C_2, Si_2, and their hydrides reveals a qualitative difference in the topologies of core electron orbitals of organic molecules and their silicon analogues. The researchers propose other elements with carbon's propensity to reshape their core electron nodal structures upon chemical bonding.

Since the discovery of silicon and Wöhler's success in the mid-19th century with synthesizing organic compounds, Wöhler himself was among the first to suggest replacing carbon by silicon in organic compounds. It became clear in the early 20th century that silicon does not have a chemistry similar to carbon, and dreams of silicon-based life only survive in science fiction. We know empirically that carbon has the capability to form a variety of unsaturated compounds, which silicon does not. However, the root cause of why only carbon has this capability has remained a mystery.

Quantum chemical calculations of unprecedented accuracy carried out at YNU reveal that core electrons (which were not supposed to participate in chemical bonding) have a very different role in the unsaturated compounds of carbon and silicon. Carbon has the propensity to alter the topology (nodal structure) of its core electrons, which, for C_2, results in the formation of a torus-

like ring in the 1σg orbital formed of C1s electrons (see Figure). Si_2, however, maintains the spherical like core orbitals centered at each atomic site in all its molecules. This flexibility of carbon's core orbitals allows carbon to form a cornucopia of different valence bond structures, whereas silicon is restricted to bond structures orthogonal to the atomic like spherical core orbitals.

The impact of this discovery is far-reaching. Core electrons have thus far been assumed more or less inert, but perhaps it becomes necessary to reassess their contribution to chemical bonding—at least in the case of unsaturated bonds. Finally, the study suggests that other elements, such as nitrogen, phosphorous, and fluorine, exhibit similar flexibility to modify their core electron topologies, and thus, exhibit similarly rich chemistries.

The paper, "Core Electron Topologies in Chemical Compounds: Case Study of Carbon versus Silicon," is published in *Angewandte Chemie International Edition* vol 57(24) on June 6th, 2018. [29]

New optical sensor can determine if molecules are left or right 'handed'

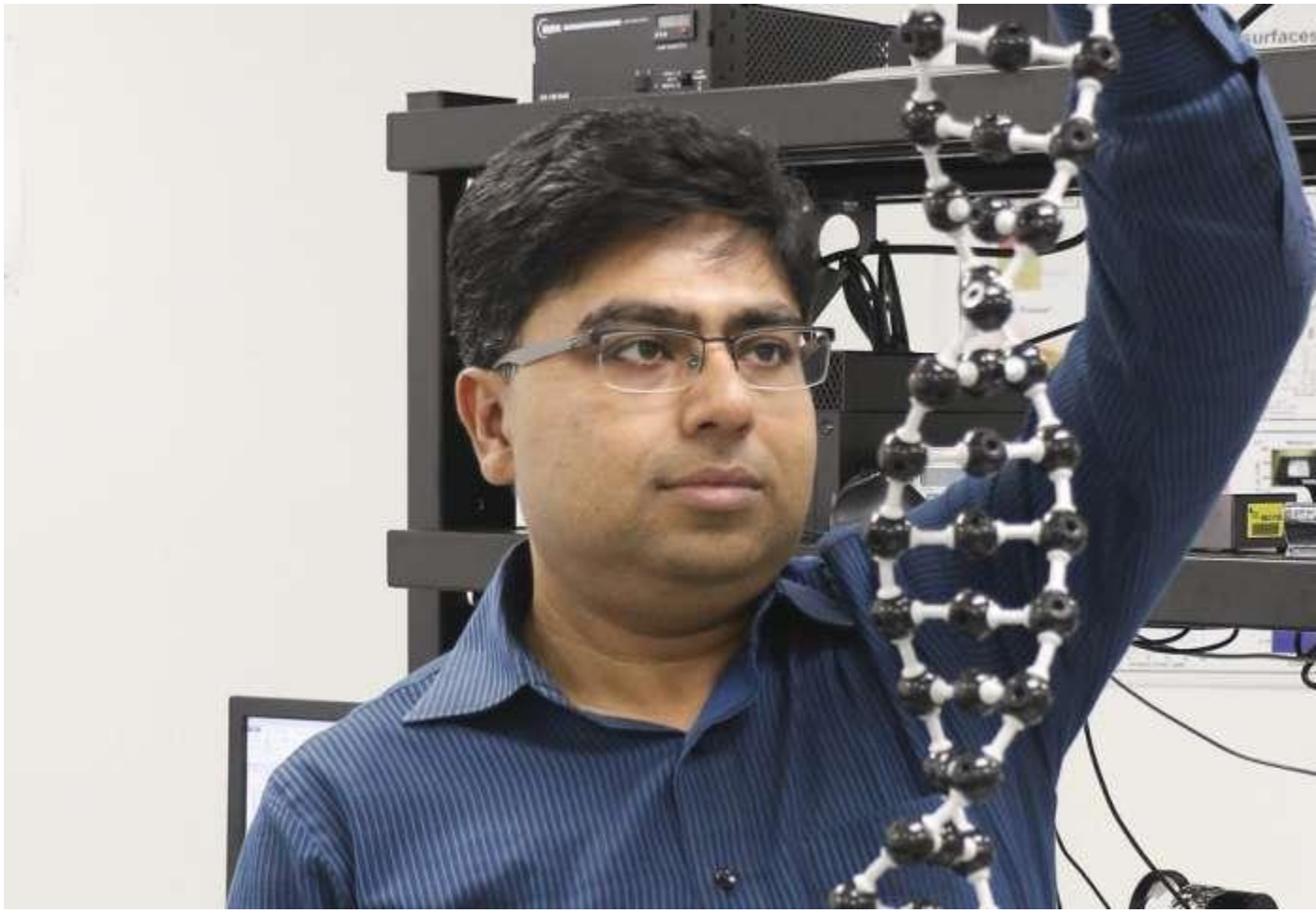
A University of Central Florida team has designed a nanostructured optical sensor that for the first time can efficiently detect molecular chirality—a property of molecular spatial twist that defines its biochemical properties.

Determining chirality is critical for new drug development.

Think of molecules as having little hands. They are not identical, but they serve almost undistinguishable functions. You can grip, pinch, punch and open your hands, regardless of whether you use your left or right hand. But when you get to some functions, such as writing, it matters if you are right-handed or left-handed.

Scientists have struggled to determine if molecules have unique left- or right-hand functions because their physical attributes such as length, weight, density, elasticity, etc. appear to be identical.

UCF's NanoScience Technology Center Associate Professor Debashis Chanda and Ph.D. student Abraham Vazquez-Guardado have figured out a unique way to do it. The interaction between light and the specially designed nanostructure they built creates a strong chiral light field—called superchiral light. Such a nanostructure does not have geometrical chirality yet it creates two opposite light chirality (left or right) on demand. When light and matter's chirality match, just as hand-shaking with our right hand, successful identification happens. Therefore, this rotating light field has the ability to probe and identify any chiral molecule like drugs, proteins or DNAs. The light field lets scientist see the tiny hands, so to speak.



UCF's NanoScience Technology Center Associate Professor Debashis Chanda. Credit: University of Central Florida: Karen Norum

Their findings were recently published in the *Physical Review Letters* journal.

"Chirality detection is vital in the drug-development industry, where newly synthesized chiral drugs also have two-handed strands and always form with the same likeliness during the synthesis process," Chanda said. "But while one chiral strand constitutes the active element in the drug, its opposite can turn out to be toxic or render detrimental side effects. Consequently, pharmacological and toxicological characterization of chirality plays a crucial role in the pharmaceutical drug industry and FDA approval process."

By being able to detect chirality at this level, scientists will have a better way to identify what may be causing bad side effects or perhaps finding places to upload life-saving drugs.

In this preliminary study, the UCF team demonstrated chiral molecule-detection sensitivity that is four times higher compared to the conventional technique, but without the extensive and tedious sample preparation and at much lower sample volume.

The single optical element thin-film chirality sensor, when fabricated based on low cost and large-area nanoimprinting technique, will immensely benefit drug design and protein-conformation identification, both of paramount importance in treating and understanding several diseases, Chanda added. [28]

Tiny defects in semiconductors created 'speed bumps' for electrons—researchers cleared the path

UCLA scientists and engineers have developed a new process for assembling semiconductor devices. The advance could lead to much more energy-efficient transistors for electronics and computer chips, diodes for solar cells and light-emitting diodes, and other semiconductor-based devices.

A paper about the research was published in *Nature*. The study was led by Xiangfeng Duan, professor of chemistry and biochemistry in the UCLA College, and Yu Huang, professor of materials science and engineering at the UCLA Samueli School of Engineering. The lead author is Yuan Liu, a UCLA postdoctoral fellow.

Their method joins a semiconductor layer and a metal electrode layer without the atomic-level defects that typically occur when other processes are used to build semiconductor-based devices. Even though those defects are minuscule, they can trap electrons traveling between the semiconductor and the adjacent metal electrodes, which makes the devices less efficient than they could be. The electrodes in semiconductor-based devices are what enable electrons to travel to and from the semiconductor; the electrons can carry computing information or energy to power a device.

Generally, metal electrodes in semiconductor devices are built using a process called physical vapor deposition. In this process, metallic materials are vaporized into atoms or atomic clusters that then condense onto the semiconductor, which can be silicon or another similar material. The metal atoms stick to the semiconductor through strong chemical bonds, eventually forming a thin film of electrodes atop the semiconductor.

One issue with that process is that the metal atoms are usually different sizes or shapes from the atoms in the semiconductor materials that they're bonding to. As a result, the layers cannot form perfect one-to-one atomic connections, which is why small gaps or defects occur.

"It is like trying to fit one layer of Lego brand blocks onto those of a competitor brand," Huang said. "You can force the two different blocks together, but the fit will not be perfect. With semiconductors, those imperfect chemical bonds lead to gaps where the two layers join, and those gaps could extend as defects beyond the interface and into the materials."

Those defects trap electrons traveling across them, and the electrons need extra energy to get through those spots.

The UCLA method prevents the defects from forming, by joining a thin sheet of metal atop the semiconductor layer through a simple lamination process. And instead of using chemical bonds to hold the two components together, the new procedure uses van der Waals forces—weak electrostatic connections that are activated when atoms are very close to each other—to keep the molecules "attached" to each other. Van der Waals forces are weaker than chemical bonds, but they're strong enough to hold the materials together because of how thin they are—each layer is around 10 nanometers thick or less.

"Even though they are different in their geometry, the two layers join without defects and stay in place due to the van der Waals forces," Huang said.

The research is also the first work to validate a scientific theory that originated in the 1930s. The Schottky-Mott rule proposed the minimum amount of energy electrons need to travel between metal and a semiconductor under ideal conditions.

Using the theory, engineers should be able to select the metal that allows electrons to move across the junction between metal and semiconductor with the smallest amount of energy. But because of those tiny defects that have always occurred during manufacturing, semiconductor devices have always needed electrons with more energy than the theoretical minimum.

The UCLA team is the first to verify the theory in experiments with different combinations of metals and semiconductors. Because the electrons didn't have to overcome the usual defects, they were able to travel with the minimum amount of energy predicted by the Schottky-Mott rule.

"Our study for the first time validates these fundamental limits of metal–semiconductor interfaces," Duan said. "It shows a new way to integrate metals onto other surfaces without introducing defects. Broadly, this can be applied to the fabrication of any delicate material with interfaces that were previously plagued by defects."

For example, besides electrode contacts on semiconductors, it could be used to assemble ultra–energy-efficient nanoscale electronic components, or optoelectronic devices such as solar cells.

The paper's other UCLA authors are graduate students Jian Guo, Enbo Zhu and Sung-Joon Lee, and postdoctoral scholar Mengning Ding. Researchers from Hunan University, China; King Saud University, Saudia Arabia; and Northrop Grumman Corporation also contributed to the study.

The study builds off of nearly a decade of work by Duan and Huang on using van der Waals forces to integrate materials. A study they led, published in *Nature* in March 2018, described their use of van der Waals forces to create a new class of 2-D materials called monolayer atomic crystal molecular superlattices. In an earlier study, which was published in *Nature* in 2010, they described their use of van der Waals forces to build high-speed transistors using graphene. [27]

How to measure quantum behaviour in nanocrystals

A new experiment that tests the limit of how large an object can be before it ceases to behave quantum mechanically has been proposed by physicists in the UK and India. The measurement involves trapping a nanocrystal with light and then measuring its position to see if its behaviour violates the Leggett-Garg inequality – which is a test of the quantum nature of a system. While the team is keen to have their proposal tested in the lab, not all physicists believe that it could be implemented.

A crucial important feature of quantum mechanics is Heisenberg's uncertainty principle. Whereas in classical mechanics, both the position and momentum of an object can be determined at arbitrarily high precision at the same time, the principle states that it is impossible to measure both position and momentum in quantum mechanics beyond a certain degree of accuracy. Furthermore, the more you know about one measurement, the more uncertain the other becomes.

The proposed experiment tests how large an object can be before the rules of quantum measurement do not apply. Sougato Bose of University College London and colleagues at the Bose Institute and the SN Bose National Centre for Basic Sciences in Kolkata studied the behaviour of a quantum linear harmonic oscillator, which bears a strong resemblance to its classical counterpart. "The uncertainties in position and momentum are both as low as they can get," explains Bose.

Caught in a trap

Bose and colleagues have done an analysis of a hypothetical experiment involving a cooled nanocrystal oscillating in a trap that is created by an optical harmonic potential. The experiment can detect which side of the trap is occupied by the nanocrystal at any instant by focusing a beam of light on one side of the trap. The light causes fluorescence in the nanocrystal, and if fluorescent light is not detected it can be concluded that the nanocrystal is in the other side of the trap – a procedure called negative result measurement.

The experiment begins with a position measurement and then the system evolves for about a microsecond before the position is measured again. If the nanocrystal is a purely classical object, the researchers reasoned, a negative result in the first measurement would not affect the nanocrystal's position in the second measurement. This is because the nanocrystal would have been in the other half of the trap, and therefore would not have interacted with the beam. If there were quantum uncertainty in the position and momentum of the nanocrystal, however, the null result at the start of the experimental run could still affect its measured position at the second measurement. This is because the nanocrystal's position would not be well defined until it was actually measured. Therefore, the nanocrystal could have interacted with the light beam in one half of the trap despite not being detected there.

The team calculated the Leggett-Garg inequality for the systems. This is analogous to Bell's inequality, which is famously used to rule out hidden variable explanations of quantum mechanics. Bell's inequality quantifies the maximum statistical correlation that is possible between properties of independent particles separated by distances so great that information could not pass between them without travelling faster than light.

The Leggett-Garg inequality uses similar reasoning to calculate the maximum statistical correlation between two results that had not influenced each other. Violation of the inequality, therefore, would show that the nanocrystal's state could be influenced by the earlier negative result, and therefore that the nanocrystal is a quantum, rather than a classical, object. Crunching the numbers, the researchers calculated that it should be feasible to detect non-classical behaviour in objects with masses up to around 10^{10} amu or about 10^{-14} g. Bose says experimentalists are planning to test this.

"That's pretty tricky"

Bose and colleagues report their results in *Physical Review Letters*. Theoretical physicist Clive Emary of Newcastle University in the UK says "if someone goes on to do these experiments, we'll all look back and say it was a significant paper". He cautions, however, that: "it looks like it needs very high time resolution to do the proposed measurements and in my experience that looks like the kind of thing you propose to experimentalists and they come back and say 'that's pretty tricky'." Quantum information theorist Renato Renner of ETH Zurich is more optimistic: "We can now do experiments in quantum technologies that, five or ten years ago, people would have said were not possible," he says, "I'm optimistic that most quantum experiments we can think of will at some point be feasible."

Emary and Renner agree, however, that, whereas in Bell's inequality, the two measurements are isolated classically by the fact that nothing that can travel faster than the speed of light, the Leggett-Garg inequality relies on proving there can be no classical explanation for the earlier measurement disturbing the later one. "That's just not possible," says Emary, "There's always a loophole: you could disturb the air molecules in the lab next door and they could come back and disturb your system, for example." [26]

Detecting the birth and death of a phonon

Phonons are discrete units of vibrational energy predicted by quantum mechanics that correspond to collective oscillations of atoms inside a molecule or a crystal. When such vibrations are produced by light interacting with a material, the vibrational energy can be transferred back and forth between individual phonons and individual packets of light energy, the photons. This process is called the Raman effect.

In a new study, the lab of Christophe Galland at EPFL's Institute of Physics has developed a technique for measuring, in real time and at room-temperature, the creation and destruction of individual phonons, opening up exciting possibilities in various fields such as spectroscopy and quantum technologies.

The technique uses ultra-short laser pulses, which are bursts of light that last less than 10^{-13} seconds (a fraction of a trillionth of a second). First, one such pulse is shot onto a diamond crystal to excite a single phonon inside it. When this happens, a partner photon is created at a new wavelength through the Raman effect and is observed with a specialized detector, heralding the success of the preparation step.

Second, to interrogate the crystal and probe the newly created phonon, the scientists fire another laser pulse into the diamond. Thanks to another detector, they now record photons that have reabsorbed the energy of the vibration. These photons are witnesses that the phonon was still alive, meaning that the crystal was still vibrating with exactly the same energy.

This is in strong contradiction with our intuition: we are used to seeing vibrating objects progressively lose their energy over time, like a guitar string whose sound fades away. But in quantum mechanics this is "all or nothing": the crystal either vibrates with a specific energy or it is in its resting state; there is no state allowed in between. The decay of the phonon over time is therefore observed as a decrease of the probability of finding it in the excited state instead of having jumped down to the rest state.

Through this approach, the scientists could reconstruct the birth and death of a single phonon by analyzing the output of the two photon detectors. "In the language of quantum mechanics, the act of measuring the system after the first pulse creates a well-defined quantum state of the phonon, which is probed by the second pulse," says Christophe Galland. "We can therefore map the phonon decay with very fine time resolution by changing the time delay between the pulses from zero to a few trillionths of a second (10^{-12} seconds or picoseconds)."

The new technique can be applied to many different types of materials, from bulk crystals down to single molecules. It can also be refined to create more exotic vibrational quantum states, such as entangled states where energy is "delocalized" over two vibrational modes. And all this can be performed in ambient conditions, highlighting that exotic quantum phenomena may occur in our daily life—we just need to watch very fast. [25]

Sustainable solvent platform for photon upconversion increases solar utilization efficiency

The conversion of solar energy into electricity is currently restricted by a concept known as the Shockley-Quesser limit. This limitation allows only photons that have higher energies than those of the bandgap to be used, while those with lower energies are wasted. In an effort to obtain a solution to this problem and make solar energy conversion more efficient, researchers have developed a process of converting photons with lower energies into ones with higher energies, called photon upconversion.

In the past decade, a method of photon upconversion that uses triplet-triplet annihilation (TTA) of organic molecules has drawn attention because it is presently the only method applicable to weak light such as sunlight. This method combines two kinds of organic molecules or chromophores, a sensitizer and an emitter. The sensitizer will absorb a photon and convert it to its excited triplet state. The excitation energy is then transferred to the emitter. When two emitters with excitation energy collide, one will convert to its lowest excited singlet state and release an upconverted photon that can be harvested for energy conversion.

While many studies into photon upconversion have been carried out in organic solvents, their practical use is limited due to the high vapor pressures, vapor toxicity, flammability, and lack of thermal stability of the solvent mixtures. Multiple approaches have been proposed to overcome these limitations, including the use of viscous fluidic media like ionic liquids that have low vapor pressures and high thermal stability. Ionic liquids are also limited in practicality, however, due to the relatively high costs of starting materials and synthetic processes, as well as their poor biodegradability.

To fundamentally resolve these previous problems, scientists at Tokyo Tech developed a TTA photon upconversion using a new class of liquids known as deep eutectic solvents (DESs). DESs are a potential alternative to ionic fluids, because they possess desirable properties similar to those of ionic fluids and can be created through a simple mixing of two substances, a hydrogen bond donor and a hydrogen bond acceptor, without the need for synthetic processes. The starting substances for the generation of DESs are also generally much cheaper, safer and more biodegradable than those needed for the creation of ionic liquids, making them an ideal alternative.

Photographs of the DESs and photon upconverters are shown in Fig. 1. The prepared DES was optically transparent and colorless and used as the solvent for the sensitizer and emitter chromophores. The sample converts weak incident green light (wavelength: 532 nm; power: 2-3 mW) into blue emission (wavelength: ~440 nm). The expected high thermal stability was confirmed by the absence of ignition and fuming during exposure to a burner flame for 1 min.

Notably, the photon upconversion quantum yield of the samples reached 0.21 (where the maximum quantum yield is defined as 0.5; one higher-energy photon is created by using two lower-energy photons at maximum in photon upconversion). This corresponds to the upconversion quantum efficiency of 42 percent (whose maximum is defined as 100 percent). This is a relatively high efficiency.

The scientists developed a novel material platform for TTA photon upconversion using cheaper, less toxic, and thermally stable DESs. This achievement is considered as an important landmark for the realization of practical application of photon upconversion technology. [24]

Graphene single photon detectors

Considerable interest in new single-photon detector technologies has been scaling in this past decade. Nowadays, quantum optics and quantum information applications are, among others, one of the main precursors for the accelerated development of single-photon detectors. Capable of sensing an increase in temperature of an individual absorbed photon, they can be used to help us study and understand, for example, galaxy formation through the cosmic infrared background, observe entanglement of superconducting qubits or improve quantum key distribution methods for ultra-secure communications.

Current detectors are efficient at detecting incoming photons that have relatively high energies, but their sensitivity drastically decreases for low frequency, low energy photons. In recent years, graphene has shown to be an exceptionally efficient photo-detector for a wide range of the electromagnetic spectrum, enabling new types of applications for this field.

Thus, in a recent paper published in the journal Physical Review Applied, and highlighted in APS Physics, ICFO researcher and group leader Prof. Dmitri Efetov, in collaboration with researchers from Harvard University, MIT, Raytheon BBN Technologies and Pohang University of Science and Technology, have proposed the use of graphene-based Josephson junctions (GJJs) to detect single photons in a wide electromagnetic spectrum, ranging from the visible down to the low end of radio frequencies, in the gigahertz range.

In their study, the scientists envisioned a sheet of graphene that is placed in between two superconducting layers. The so created Josephson junction allows a supercurrent to flow across the graphene when it is cooled down to 25 mK. Under these conditions, the heat capacity of the graphene is so low, that when a single photon hits the graphene layer, it is capable of heating up the electron bath so significantly, that the supercurrent becomes resistive – overall giving rise to an easily detectable voltage spike across the device. In addition, they also found that this effect would occur almost instantaneously, thus enabling the ultrafast conversion of absorbed light into electrical signals, allowing for a rapid reset and readout.

The results of the study confirm that we can expect a rapid progress in integrating graphene and other 2-D materials with conventional electronics platforms, such as in CMOS-chips, and shows a promising path towards single-photon-resolving imaging arrays, quantum information processing applications of optical and microwave photons, and other applications that would benefit from the quantum-limited detection of low-energy photons. [23]

Engineers develop key mathematical formula for driving quantum experiments

Since he was a graduate student, Washington University in St. Louis systems engineer Jr-Shin Li has provided specific mathematical information to experimentalists and clinicians who need it to perform high-resolution magnetic resonance applications, such as body MRIs for medical diagnosis or spectroscopy for uncovering protein structures. Now, after more than a decade of

work, he has developed a formula that researchers can use to generate that information themselves.

Li, the Das Family Career Development Distinguished Associate Professor in the School of Engineering & Applied Science, and his collaborators have derived a mathematical formula to design broadband pulse sequences to excite a population of nuclear spins over a wide band of frequencies. Such a broadband excitation leads to enhanced signal or sensitivity in diverse quantum experiments across fields from protein spectroscopy to quantum optics.

The research, the first to find that designing the pulse can be done analytically, was published in Nature Communications Sept. 5.

"This design problem is traditionally done by purely numerical optimization," Li said. "Because one has to design a common input—a magnetic field to excite many, many particles—the problem is challenging. In many cases in numerical optimization, the algorithms fail to converge or take enormous amounts of time to get a feasible solution."

For more than a decade, Li has sought a better way for pulse design using the similarity between spins and springs by applying numerical experiments. Spin is a form of angular momentum carried by elementary particles. Spin systems are nonlinear and difficult to work with, Li said, while spring systems, or harmonic oscillators, are linear and easier to work with. While a doctoral student at Harvard University, Li found a solution by projecting the nonlinear spin system onto the linear spring system, but was unable to prove it mathematically until recently.

"We have very rigorous proof that such a projection from nonlinear to linear is valid, and we also have done a lot of numerical simulations to demonstrate the discovery," Li said. "My collaborator, Steffan Glaser (of the Technische Universität Munich), has been in this field of NMR spectroscopy for more than 20 years, and he is confident that if the quantum pulses perform well in computer simulations, they may perform the same in experimental systems."

The team plans to conduct various experiments in magnetic resonance to verify the analytical invention.

The theoretical work opens up new avenues for pulse sequence design in quantum control. Li plans to create a website where collaborators can enter their parameter values to generate the pulse formula they will need in their quantum experiments. [22]

New tool for characterizing quantum simulators

Physicists are developing quantum simulators, to help solve problems that are beyond the reach of conventional computers. However, they first need new tools to ensure that the simulators work properly. Innsbruck researchers around Rainer Blatt and Christian Roos, together with researchers from the Universities of Ulm and Strathclyde, have now implemented a new technique in the laboratory that can be used to efficiently characterize the complex states of

quantum simulators. The technique, called matrix product state tomography, could become a new standard tool for characterizing quantum simulators.

Many phenomena in the quantum world cannot be investigated directly in the laboratory, and even supercomputers fail when trying to simulate them. However, scientists are now able to control various quantum systems in the laboratory very precisely and these systems can be used to simulate other quantum systems. Such Quantum Simulators are therefore considered to be one of the first concrete applications of the second quantum revolution.

However, the characterization of large quantum states, which is necessary to guide the development of large-scale quantum simulators, proves to be difficult. The current gold standard for quantum-state characterization in the laboratory - quantum-state tomography - is only suitable for small quantum systems composed of a handful of quantum particles. Researchers from the Institute of Experimental Physics at the University of Innsbruck and the Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences have now established a new method in the laboratory that can be used to efficiently characterize large quantum states.

A collaborative effort

In ion traps, charged atoms (ions) are cooled to temperatures close to absolute zero and manipulated with the aid of lasers. Such systems represent a promising approach to performing quantum simulations that can go beyond the capabilities of modern supercomputers. The Innsbruck quantum physicists are amongst the world leaders in this field and can currently entangle 20 or more ions in their traps. In order to fully characterize such large quantum systems, they need new methods. For this, theorists around Martin Plenio from the University of Ulm, Germany, came to their aid. In 2010, the Plenio team proposed a new method for the characterization of complex quantum states called matrix-product-state tomography. Using this method, the state of a group of entangled quantum particles can be estimated precisely without the effort increasing dramatically as the number of particles in the group is increased. In collaboration with the teams around Martin Plenio from Ulm and Andrew Daley from the University of Strathclyde in Scotland, the Innsbruck experimental physicists around Christian Roos, Ben Lanyon and Christine Maier have now implemented this procedure in the laboratory.

More efficient measurements

As a test case, the physicists built a quantum simulator with up to 14 quantum bits (atoms), that was first prepared in a simple initial state without quantum correlations. Next, the researchers entangled the atoms with laser light and observed the dynamical propagation of entanglement in the system. "With the new method, we can determine the quantum state of the whole system by measuring only a small fraction of the system properties," says START prize winner Ben Lanyon. The theorists around Martin Plenio took the characterization of the global quantum state from the measured data: "The method is based on the fact that we can theoretically describe locally-distributed entanglement well and can now also measure it in the laboratory."

When the work group of Rainer Blatt realized the first quantum byte in 2005, more than 6,000 measurements were required for the characterization of the quantum state, taken over a period of ten hours. The new method requires only 27 measurements to characterise the same size system, taken over around 10 minutes. "We were able to show that this method can be used to identify large and complex quantum states efficiently," says Christine Maier, a team member from Innsbruck. Now the scientists want to further develop the algorithms so that they can also be used flexibly by other research groups.

New gold standard

The new method allows the complete characterization of systems containing large numbers of correlated quantum particles and thus provides a comparison option for quantum simulations. "We can use the new technique to calibrate quantum simulators, by comparing the states that we find in the lab with the ones expected from analytical calculations," explains Christian Roos. "Then we know if the simulator does what we want." The new method offers physicians a tool for many applications and could become a new standard for quantum simulations. [21]

Flip-flop qubits: Radical new quantum computing design invented

Engineers at Australia's University of New South Wales have invented a radical new architecture for quantum computing, based on novel 'flip-flop qubits', that promises to make the large-scale manufacture of quantum chips dramatically cheaper - and easier - than thought possible.

The new chip design, detailed in the journal Nature Communications, allows for a silicon quantum processor that can be scaled up without the precise placement of atoms required in other approaches. Importantly, it allows quantum bits (or 'qubits') - the basic unit of information in a quantum computer - to be placed hundreds of nanometres apart and still remain coupled.

The design was conceived by a team led by Andrea Morello, Program Manager in UNSW-based ARC Centre of Excellence for Quantum Computation and Communication Technology (CQC2T) in Sydney, who said fabrication of the new design should be easily within reach of today's technology.

Lead author Guilherme Tosi, a Research Fellow at CQC2T, developed the pioneering concept along with Morello and co-authors Fahd Mohiyaddin, Vivien Schmitt and Stefanie Tenberg of CQC2T, with collaborators Rajib Rahman and Gerhard Klimeck of Purdue University in the USA.

"It's a brilliant design, and like many such conceptual leaps, it's amazing no-one had thought of it before," said Morello.

"What Guilherme and the team have invented is a new way to define a 'spin qubit' that uses both the electron and the nucleus of the atom. Crucially, this new qubit can be controlled using electric signals, instead of magnetic ones. Electric signals are significantly easier to distribute and localise within an electronic chip."

Tosi said the design sidesteps a challenge that all spin-based silicon qubits were expected to face as teams begin building larger and larger arrays of qubits: the need to space them at a distance of only 10-20 nanometres, or just 50 atoms apart.

"If they're too close, or too far apart, the 'entanglement' between quantum bits - which is what makes quantum computers so special - doesn't occur," Tosi said.

Researchers at UNSW already lead the world in making spin qubits at this scale, said Morello. "But if we want to make an array of thousands or millions of qubits so close together, it means that all the control lines, the control electronics and the readout devices must also be fabricated at that nanometric scale, and with that pitch and that density of electrodes. This new concept suggests another pathway."

At the other end of the spectrum are superconducting circuits - pursued for instance by IBM and Google - and ion traps. These systems are large and easier to fabricate, and are currently leading the way in the number of qubits that can be operated. However, due to their larger dimensions, in the long run they may face challenges when trying to assemble and operate millions of qubits, as required by the most useful quantum algorithms.

"Our new silicon-based approach sits right at the sweet spot," said Morello, a professor of quantum engineering at UNSW. "It's easier to fabricate than atomic-scale devices, but still allows us to place a million qubits on a square millimetre."

In the single-atom qubit used by Morello's team, and which Tosi's new design applies, a silicon chip is covered with a layer of insulating silicon oxide, on top of which rests a pattern of metallic electrodes that operate at temperatures near absolute zero and in the presence of a very strong magnetic field.

At the core is a phosphorus atom, from which Morello's team has previously built two functional qubits using an electron and the nucleus of the atom. These qubits, taken individually, have demonstrated world-record coherence times.

Tosi's conceptual breakthrough is the creation of an entirely new type of qubit, using both the nucleus and the electron. In this approach, a qubit '0' state is defined when the spin of the electron is down and the nucleus spin is up, while the '1' state is when the electron spin is up, and the nuclear spin is down.

"We call it the 'flip-flop' qubit," said Tosi. "To operate this qubit, you need to pull the electron a little bit away from the nucleus, using the electrodes at the top. By doing so, you also create an electric dipole."

"This is the crucial point," adds Morello. "These electric dipoles interact with each other over fairly large distances, a good fraction of a micron, or 1,000 nanometres.

"This means we can now place the single-atom qubits much further apart than previously thought possible," he continued. "So there is plenty of space to intersperse the key classical

components such as interconnects, control electrodes and readout devices, while retaining the precise atom-like nature of the quantum bit."

Morello called Tosi's concept as significant as Bruce Kane seminal 1998 paper in Nature. Kane, then a senior research associate at UNSW, hit upon a new architecture that could make a silicon-based quantum computer a reality - triggering Australia's race to build a quantum computer.

"Like Kane's paper, this is a theory, a proposal - the qubit has yet to be built," said Morello. "We have some preliminary experimental data that suggests it's entirely feasible, so we're working to fully demonstrate this. But I think this is as visionary as Kane's original paper."

Building a quantum computer has been called the 'space race of the 21st century' - a difficult and ambitious challenge with the potential to deliver revolutionary tools for tackling otherwise impossible calculations, with a plethora of useful applications in healthcare, defence, finance, chemistry and materials development, software debugging, aerospace and transport. Its speed and power lie in the fact that quantum systems can host multiple 'superpositions' of different initial states, and in the spooky 'entanglement' that only occurs at the quantum level the fundamental particles.

"It will take great engineering to bring quantum computing to commercial reality, and the work we see from this extraordinary team puts Australia in the driver's seat," said Mark Hoffman, UNSW's Dean of Engineering. "It's a great example of how UNSW, like many of the world's leading research universities, is today at the heart of a sophisticated global knowledge system that is shaping our future."

The UNSW team has struck a A$83 million deal between UNSW, telco giant Telstra, Australia's Commonwealth Bank and the Australian and New South Wales governments to develop, by 2022, a 10-qubit prototype silicon quantum integrated circuit - the first step in building the world's first quantum computer in silicon.

In August, the partners launched Silicon Quantum Computing Pty Ltd, Australia's first quantum computing company, to advance the development and commercialisation of the team's unique technologies. The NSW Government pledged A$8.7 million, UNSW A$25 million, the Commonwealth Bank A$14 million, Telstra A$10 million and the Federal Government A$25 million. [20]

New quantum memory device small enough to fit on a chip

A team of researchers from the U.S. and Italy has built a quantum memory device that is approximately 1000 times smaller than similar devices—small enough to install on a chip. In their paper published in the journal Science, the team describes building the memory device and their plans for adding to its functionality.

Scientists have been working steadily toward building quantum computers and networks, and have made strides in both areas in recent years. But one inhibiting factor is the construction of quantum memory devices. Such devices have been built, but until now, they have been too large to put on a chip, a requirement for practical applications. In this new effort, the researchers report developing a quantum memory device that is not only small enough to fit on a chip, but is also able to retrieve data on demand.

The device is very small, approximately 10 by 0.7 micrometers and has an odd shape, like a Toblerone candy bar—long and thin with a notched triangular shape, with mirrors on either end. It is made of yttrium orthovanadate with small amounts of neodymium, which form a cavity. These cavities in turn hold a crystal cavity that traps single photons encoding data information (zero, one or both).

To operate the device, the researchers fired laser pulses at it, causing photons to assemble in the comb, which forced them to be absorbed—the configuration also caused the photons to emerge from the comb after 75 nanoseconds. During the time period when the photons were absorbed, the researchers fired dual laser pulses at the comb to delay the reemergence of the photons for 10 nanoseconds, which allowed for on-demand retrieval of data. During the time period when the photons were held, they existed as dual pulses—early and late.

To show that the device was actually storing data information, the team compared the wavefunction of the photons both before and after storage and found them to be virtually unchanged, meaning they still held their zero, one or both state—it had not been destroyed, which meant the device was truly a quantum memory device. [19]

How to store data on magnets the size of a single atom

The cutting edge of data storage research is working at the level of individual atoms and molecules, representing the ultimate limit of technological miniaturisation.

Magnetism is useful in many ways, and the magnetic memory effect appears even at the atomic level.

There is an adage that says that data will expand to fill all available capacity. Perhaps ten or 20 years ago, it was common to stockpile software programs, MP3 music, films and other files, which may have taken years to collect. In the days when hard disk drives offered a few tens of gigabytes of storage, running out of space was almost inevitable.

Now that we have fast broadband internet and think nothing of downloading a 4.7 gigabyte DVD, we can amass data even more quickly. Estimates of the total amount of data held worldwide are to rise from 4.4 trillion gigabytes in 2013 to 44 trillion gigabytes by 2020. This means that we are generating an average of 15m gigabytes per day. Even though hard disk drives are now measured in thousands of gigabytes rather than tens, we still have a storage problem.

Research and development is focused on developing new means of data storage that are more dense and so can store greater amounts of data, and do so in a more energy efficient way. Sometimes this involves updating established techniques: recently IBM announced a new magnetic tape technology that can store 25 gigabytes per square inch, a new world record for the 60-year-old technology. While current magnetic or solid-state consumer hard drives are more dense at around 200 gigabytes per square inch, magnetic tapes are still frequently used for data back-up.

However, the cutting edge of data storage research is working at the level of individual atoms and molecules, representing the ultimate limit of technological miniaturisation.

The quest for atomic magnets

Current magnetic data storage technologies – those used in traditional hard disks with spinning platters, the standard until a few years ago and still common today – are built using "top-down" methods. This involves making thin layers from a large piece of ferromagnetic material, each containing the many magnetic domains that are used to hold data. Each of these magnetic domains is made of a large collection of magnetised atoms, whose magnetic polarity is set by the hard disk's read/write head to represent data as either a binary one or zero.

An alternative "bottom-up" method would involve constructing storage devices by placing individual atoms or molecules one by one, each capable of storing a single bit of information. Magnetic domains retain their magnetic memory due to communication between groups of neighbouring magnetised atoms.

Single-atom or single-molecule magnets on the other hand do not require this communication with their neighbours to retain their magnetic memory. Instead, the memory effect arises from quantum mechanics. So because atoms or molecules are much, much smaller than the magnetic domains currently used, and can be used individually rather than in groups, they can be packed more closely together which could result in an enormous increase in data density.

Working with atoms and molecules like this is not science fiction. Magnetic memory effects in single-molecule magnets (SMMs) were first demonstrated in 1993, and similar effects for singleatom magnets were shown in 2016.

Raising the temperature

The main problem standing in the way of moving these technologies out of the lab and into the mainstream is that they do not yet work at ambient temperatures. Both single atoms and SMMs require cooling with liquid helium (at a temperature of –269°C), an expensive and limited resource. So research effort over the last 25 years has concentrated on raising the temperature at which magnetic hysteresis – a demonstration of the magnetic memory effect – can be observed. An important target is –196°C, because this is the temperature that can be achieved with liquid nitrogen, which is abundant and cheap.

It took 18 years for the first substantive step towards raising the temperature in which magnetic memory is possible in SMMs – an increase of 10°C achieved by researchers in California. But now our research team at the University of Manchester's School of Chemistry have achieved magnetic hysteresis in a SMM at –213 °C using a new molecule based on the rare earth element dysprosocenium, as reported in a letter to the journal Nature. With a leap of 56°C, this is only 17°C away from the temperature of liquid nitrogen.

Future uses

There are other challenges, however. In order to practically store individual bits of data, molecules must be fixed to surfaces. This has been demonstrated with SMMs in the past, but not for this latest generation of high-temperature SMMs. On the other hand, magnetic memory in single atoms has already been demonstrated on a surface.

Optical control of magnetic memory—New insights into fundamental mechanisms

This is an important clue for our theoretical understanding of optically controlled magnetic data storage media. The findings are published at August 25th in the journal Scientific Reports.

The demands placed on digital storage media are continuously increasing. Rapidly increasing quantities of data and new technological applications demand memory that can store large amounts of information in very little space and permit this information to be utilised dependably with high access speeds.

Re-writeable magnetic data storage devices using laser light appear to have especially good prospects. Researchers have been working on this new technology for several years. "However, there are still unresolved questions about the fundamental mechanisms and the exact manner in which optically controlled magnetic storage devices operate", says Dr. Florian Kronast, assistant head of the Materials for Green Spintronics department at the Helmholtz-Zentrum Berlin (HZB).

A research team led by him has now succeeded in making an important step toward better understanding of this very promising storage technology. The scientists were able to empirically establish for the first time that the warming of the storage material by the energy of the laser light plays an instrumental role when toggling the magnetisation alignments and that the change in the material only takes place under certain conditions.

Making precise measurements in tiny laser spots

The HZB scientists together with those of Freie Universität Berlin and Universität Regensburg studied the microscopic processes at extremely high resolution while irradiating a thin layer of magnetic material using circularly polarised laser light. To do this, they directed the light of an infrared laser onto a nanometre-thick layer of alloy made from the metals terbium and iron (TbFe). What was special about the experimental set-up was that the narrowly focussed spot of

laser light had a diameter of only three microns. "That is far less than was usual in prior experiments", says HZB scientist Ashima Arora, first author of the study. And it provided the researchers with unsurpassed detail resolution for studying the phenomena. The images of the magnetic domains in the alloy that the team created with the help of X-rays from the BESSY II synchrotron radiation source revealed fine features that themselves were only 30 nanometres in size.

The crucial thing occurs in the boundary ring

The results of the measurements prove that a ring-shaped region forms around the tiny laser spot and separates the two magnetically contrasting domains from one another. The extant magnetisation pattern inside the ring is completely erased by the thermal energy of the laser light. Outside the ring, however, it remains in its original state. Within the boundary zone itself, a temperature distribution arises that facilitates a change in magnetisation by displacing the domain boundaries. "It is only there that the toggling of magnetic properties can proceed, permitting a device to store re-writeable data", explains Arora.

Surprising influence of the layer thickness

"These new insights will assist in the development of optically controlled magnetic storage devices having the best possible properties," in the view of Kronast. An additional effect contributes to better understanding the physical processes that are important in this phenomenon, which researchers at HZB unexpectedly observed for the first time. The way the toggling of the magnetisations happens is highly dependent on the layer thickness of the material irradiated by the laser. It changes over an interval of 10 to 20 nanometres thickness.

"This is a clear indication that two contrasting mechanisms are involved and compete with one another", Kronast explains. He and his team suspect two complex physical effects for this. To confirm their suspicions, though, further empirical and theoretical studies are necessary. [17]

Photosensitive perovskites change shape when exposed to light

A crystalline material that changes shape in response to light could form the heart of novel lightactivated devices. Perovskite crystals have received a lot of attention for their efficiency at converting sunlight into electricity, but new work by scientists at KAUST shows their potential uses extend far beyond the light-harvesting layer of solar panels.

Photostriction is the property of certain materials to undergo a change in internal strain, and therefore shape, with exposure to light. Organic photostrictive materials offer the greatest shape change so far reported in response to light—a parameter known as their photostrictive coefficient—but their response is slow and unstable under ambient conditions.

KAUST electrical engineer Jr-Hau He and his colleagues have looked for photostriction in a new family of materials, the perovskites. "Perovskites are one of the hottest optical materials," says He. His work now shows there's more to their interesting optical properties than solar energy

harvesting. The researchers tested a perovskite called MAPbBr3 and revealed it had strong and robust photostriction behavior.

To extensively test the material's photostriction capabilities, the team developed a new method. They used Raman spectroscopy, which probes the molecular vibrations within the structure. When bathed in light, photostriction alters the internal strain in the material, which then shifts the internal pattern of vibrations. By measuring the shift in the Raman signal when the material was placed under mechanical pressure, the team could calibrate the technique and so use it to quantify the effect of photostriction.

"We demonstrated that in situ Raman spectroscopy with confocal microscopy is a powerful characterization tool for conveniently measuring intrinsic photoinduced lattice deformation," says Tzu-Chiao Wei, a member of the team. "The same approach could be applied to measure photostriction in other materials," he adds.

The perovskite material proved to have a significant photostriction coefficient of 1.25%. The researchers also showed that the perovskite's photostriction was partly due to the photovoltaic effect—the phenomenon at the heart of most solar cell operation. The spontaneous generation of positive and negative charges when the perovskite is bathed in light polarizes the material, which induces a movement in the ions the material is made from.

The robust and stable photostriction of perovskite makes it useful for a range of possible devices, says Wei. "We will use this material to fabricate next-generation optoelectronic devices, including wireless remote switchable devices and other light-controlled applications," he says. [16]

Conformal metasurface coating eliminates crosstalk and shrinks waveguides

The properties of materials can behave in funny ways. Tweak one aspect to make a device smaller or less leaky, for example, and something else might change in an undesirable way, so that engineers play a game of balancing one characteristic against another. Now a team of Penn State electrical engineers have a way to simultaneously control diverse optical properties of dielectric waveguides by using a two-layer coating, each layer with a near zero thickness and weight.

"Imagine the water faucet in your home, which is an essential every-day device," said Douglas H. Werner, John L. and Genevieve H. McCain Chair Professor of Electrical Engineering. "Without pipes to carry the water from its source to the faucet, the device is worthless. It is the same with 'waveguides.' They carry electromagnetic or optical signals from the source to the device—an antenna or other microwave, millimeter-wave or terahertz device. Waveguides are an essential component in any electromagnetic or optical system, but they are often overlooked because much of the focus has been on the devices themselves and not the waveguides."

According to Zhi Hao Jiang, former postdoctoral fellow at Penn State and now a professor at Southeast University, Nanjing, China, metasurface coatings allow researchers to shrink the diameter of waveguides and control the waveguiding characteristics with unprecedented flexibility.

The researchers developed a material that is so thin it is almost 2-dimensional, with characteristics that manipulate and enhance properties of the waveguide.

They developed and tested two conformal coatings, one for guiding the signal and one to cloak the waveguide. They created the coatings by judiciously engineering the patterning on the surfaces to enable new and transformative waveguide functionality. The coatings are applied to a rod-shaped, Teflon waveguide with the guiding layer touching the Teflon and the cloaking layer on the outside.

This quasi 2-dimensional conformal coating that is configured as a cloaking material can solve the crosstalk and blockage problem. Dielectric waveguides are not usually used singly, but in bundles. Unfortunately, conventional waveguides leak, allowing the signal from one waveguide to interfere with those located nearby.

The researchers also note in today's (Aug. 25) issue of Nature Communications that "the effectiveness of the artificial coating can be well maintained for waveguide bends by properly matching the dispersion properties of the metasurface unit cells." Although the coating can be applied to a bend in the waveguide, the waveguide cannot be bent after the coating is applied.

Improving the properties of the waveguide to carefully control polarization and other attributes allows the waveguides to be smaller, and alleviating crosstalk allows these smaller waveguides to be more closely bundled. Smaller waveguides more closely bundled could lead to increased miniaturization.

"In terms of applications these would include millimeter-wave/terahertz/infrared systems for sensing, communications, and imaging that need to manipulate polarization, squeeze signals through waveguides with a smaller cross-section, and/or require dense deployment of interconnected components," said Jiang.

Also working on this project was Lei Kang, research associate in electrical engineering, Penn State. [15]

A nano-roundabout for light

Just like in normal road traffic, crossings are indispensable in optical signal processing. In order to avoid collisions, a clear traffic rule is required. A new method has now been developed at TU Wien to provide such a rule for light signals. For this purpose, the two glass fibers were coupled at their intersection point to an optical resonator, in which the light circulates and behaves as in a roundabout. The direction of circulation is defined by a single atom coupled to the resonator. The atom also ensures that the light always leaves the roundabout at the next exit. This rule is

still valid even if the light consists merely of individual photons. Such a roundabout will consequently be installed in integrated optical chips - an important step for optical signal processing.

Signal processing using light instead of electronics

The term "optical circulators" refers to elements at the intersection point of two mutually perpendicular optical fibers which direct light signals from one fiber to the other, so that the direction of the light always changes, for example, by 90° clockwise.

"These components have long been used for freely propagating light beams," says Arno Rauschenbeutel from the Vienna Center for Quantum Science and Technology at the Institute of Atomic and Subatomic Physics of TU Wien. "Such optical circulators are mostly based on the socalled Faraday effect: a strong magnetic field is applied to a transparent material, which is located between two polarization beam splitters which are rotated with respect to each other. The direction of the magnetic field breaks the symmetry and determines in which direction the light is redirected."

However, for technical reasons, components that make use of the Faraday effect cannot be realized on the small scales of nanotechnology. This is unfortunate as such components are important for future technological applications. "Today, we are trying to build optical integrated circuits with similar functions as they are known from electronics," says Rauschenbeutel. Other methods to break the symmetry of the light function only at very high light intensities or suffer from high optical losses. However, in nanotechnology one would like to be able to process very small light signals, ideally light pulses that consist solely of individual photons.

Two glass fibers and a bottle for light

The team of Arno Rauschenbeutel chooses a completely different way: they couple a single rubidium atom to the light field of a so-called "bottle resonator" - a microscopic bulbous glass object on the surface of which the light circulates. If such a resonator is placed in the vicinity of two ultrathin glass fibers, the two systems couple to one another. Without an atom, the light changes from one glass fiber to the other via the bottle resonator. In this way, however, no sense of circulation is defined for the circulator: light, which is deflected by 90° in the clockwise direction, can also travel backwards via the same route, i.e. counter-clockwise.

In order to break this forward/backward symmetry, Arno Rauschenbeutel's team additionally couples an atom to the resonator, which prevents the coupling of the light into the resonator, and thus the overcoupling into the other glass fiber for one of the two directions of circulation. For this trick, a special property of the light is used at TU Wien: the direction of oscillation of the light wave, also known as its polarization.

The interaction between the light wave and the bottle resonator results in an unusual oscillation state. "The polarization rotates like the rotor of a helicopter," Arno Rauschenbeutel explains. The direction of rotation depends on whether the light in the resonator travels clockwise or counter-clockwise: in one case the polarization rotates counter-clockwise, while in the other

case it rotates clockwise. The direction of circulation and the polarization of the light are therefore locked together.

If the rubidium atom is correctly prepared and coupled to the resonator, one can make its interaction with the light differ for the two directions of circulation. "The clockwise circulating light is not affected by the atom. The light in the opposite direction, on the other hand, strongly couples to the atom and therefore cannot enter the resonator," says Arno Rauschenbeutel. This asymmetry of the light-atom coupling with respect to the propagation direction of the light in the resonator allows control over the circulator operation: the desired sense of circulation can be adjusted via the internal state of the atom.

"Because we use only a single atom, we can subtly control the process," says Rauschenbeutel. "The atom can be prepared in a state in which both traffic rules apply at the same time: all light particles then travel together through the circulator in both clockwise and counterclockwise direction." Luckily, this is impossible according to the rules of classical physics, as it would result in chaos in road traffic. In quantum physics however, such superpositions of different states are permitted which opens up entirely new and exciting possibilities for the optical processing of quantum information. [14]

Researchers create hidden images with commercial inkjet printers

Researchers have developed a way to use commercial inkjet printers and readily available ink to print hidden images that are only visible when illuminated with appropriately polarized waves in the terahertz region of the electromagnetic spectrum. The inexpensive method could be used as a type of invisible ink to hide information in otherwise normal-looking images, making it possible to distinguish between authentic and counterfeit items, for example.

"We used silver and carbon ink to print an image consisting of small rods that are about a millimeter long and a couple of hundred microns wide," said Ajay Nahata from the University of Utah, leader of the research team. "We found that changing the fraction of silver and carbon in each rod changes the conductivity in each rod just slightly, but visually, you can't see this modification. Passing terahertz radiation at the correct frequency and polarization through the array allows extraction of information encoded into the conductivity."

In The Optical Society's journal for high impact research, Optica, the researchers demonstrated their new method to hide image information in an array of printed rods that all look nearly identical. They used the technique to conceal both grayscale and 64-color QR codes, and even embedded two QR codes into a single image, with each code viewable using a different polarization. To the naked eye the images look like an array of identical looking lines, but when viewed with terahertz radiation, the embedded QR code image becomes apparent.

"Our very easy-to-use method can print complex patterns of rods with varying conductivity," said Nahata. "This cannot easily be done even using a multimillion dollar nanofabrication facility. An added benefit to our technique is that it can performed very inexpensively."

Printing metamaterials

The new technique allows printing of different shapes that form a type of metamaterial - synthetic materials that exhibit properties that don't usually exist in nature. Although there is a great deal of interest in manipulating metamaterials to better control the propagation of light, most techniques require expensive lithography equipment found in nanofabrication facilities to pattern the material in a way that produces desired properties.

Nahata and his colleagues previously developed a simple method to use an off-the-shelf inkjet printer to apply inks made with silver and carbon, which can be purchased from specialty stores online. They wanted to see if their ink-jet printing technique could create various conductivities, a parameter that is typically difficult to modify because it requires changing the type of metal applied at each spatial location. To do this using standard lithography would be time consuming and expensive because each metal would have to be applied in a separate process.

"As we were printing these rods we saw that, in many cases, we couldn't visually tell the difference between different conductivities," said Nahata. "That led to the idea of using this to encode an image without the need for standard encryption approaches."

Creating hidden images

To see if they could use the method to encode information, the researchers printed three types of QR codes, each 72 by 72 pixels. For one QR code they used arrays of rods to create nine different conductivities, each coding for one gray level. When they imaged this QR code with terahertz illumination, only 2.7 percent of the rods gave values that were different from what was designed. The researchers also used rods printed in a cross formation to create two separate QR codes that could each be read with a different polarization of terahertz radiation.

The team then created a color QR code by using non-overlapping rods of three different lengths to create each pixel. Each pixel in the image contained the same pattern of rods but varied in conductivity. By arranging the rods in a way that minimized errors, the researchers created three overlapping QR codes corresponding to RGB color channels. Because each pixel contained four different conductivities that could each correspond to a color, a total of 64 colors was observed in the final image. The researchers said they could likely achieve even more than 64 colors with improvements in the printing process.

"We have created the capability to fabricate structures that can have adjacent cells, or pixels, with very different conductivities and shown that the conductivity can be read with high fidelity," said Nahata. "That means that when we print a QR code, we see the QR code and not any blurring or bleeding of colors."

With the very inexpensive (under $60) printers used in the paper, the technique can produce images with a resolution of about 100 microns. With somewhat more expensive but still commercially available printers, 20-micron resolution should be achievable. Although the

researchers used QR codes that are relatively simple and small, the technique could be used to embed information into more complex and detailed images using a larger canvas.

Nahata's team used terahertz radiation to read the coded information because the wavelengths in this region are best suited for imaging the resolution available from commercial inkjet printers. The researchers are now working to expand their technique so the images can be interrogated with visible, rather than terahertz, wavelengths. This challenging endeavor will require the researchers to build new printers that can produce smaller rods to form images with higher resolutions.

The researchers are also exploring the possibility of developing additional capabilities that could make the embedded information even more secure. For example, they could make inks that might have to be heated or exposed to light of a certain wavelength before the information would be visible using the appropriate terahertz radiation. [13]

For the first time, magnets are be made with a 3-D printer

Today, manufacturing strong magnets is no problem from a technical perspective. It is, however, difficult to produce a permanent magnet with a magnetic field of a specific pre-determined shape. That is, until now, thanks to the new solution devised at TU Wien: for the first time ever, permanent magnets can be produced using a 3D printer. This allows magnets to be produced in complex forms and precisely customised magnetic fields, required, for example, in magnetic sensors.

Designed on a computer

"The strength of a magnetic field is not the only factor," says Dieter Süss, Head of the ChristianDoppler Advanced Magnetic Sensing and Materials laboratory at TU Wien. "We often require special magnetic fields, with field lines arranged in a very specific way - such as a magnetic field that is relatively constant in one direction, but which varies in strength in another direction."

In order to achieve such requirements, magnets must be produced with a sophisticated geometric form. "A magnet can be designed on a computer, adjusting its shape until all requirements for its magnetic field are met," explains Christian Huber, a doctoral student in Dieter Süss' team.

But once you have the desired geometric shape, how do you go about implementing the design? The injection moulding process is one solution, but this requires the creation of a mould, which is time-consuming and expensive, rendering this method barely worthwhile for producing small quantities.

Tiny magnetic particles in the polymer matrix

Now, there is a much simpler method: the first-ever 3D printer which can be used to produce magnetic materials, created at TU Wien. 3D printers which generate plastic structures have existed for some time, and the magnet printer functions in much the same way. The difference is that the magnet printer uses specially produced filaments of magnetic micro granulate, which is held together by a polymer binding material. The printer heats the material and applies it point by point in the desired locations using a nozzle. The result is a three-dimensional object composed of roughly 90% magnetic material and 10% plastic.

The end product is not yet magnetic, however, because the granulate is deployed in an unmagnetised state. At the very end of the process, the finished article is exposed to a strong external magnetic field, converting it into a permanent magnet.

"This method allows us to process various magnetic materials, such as the exceptionally strong neodymium iron boron magnets," explains Dieter Süss. "Magnet designs created using a computer can now be quickly and precisely implemented - at a size ranging from just a few centimetres through to decimetres, with an accuracy of well under a single millimetre."

A whole world of new possibilities

Not only is this new process fast and cost-effective, it also opens up new possibilities which would be inconceivable with other techniques: you can use different materials within a single magnet to create a smooth transition between strong and weak magnetism, for instance. "Now we will test the limits of how far we can go - but for now it is certain that 3D printing brings something to magnet design which we could previously only dream of," declares Dieter Süss. [12]

New method to make permanent magnets more stable over time

For physicists, loss of magnetisation in permanent magnets can be a real concern. In response, the Japanese company Sumitomo created the strongest available magnet—one offering ten times more magnetic energy than previous versions—in 1983. These magnets are a combination of materials including rare-earth metal and so-called transition metals, and are accordingly referred to as RE-TM-B magnets. A Russian team has now been pushing the boundaries of magnet design, as published in a recent study in EPJ Plus.

They have developed methods to counter the spontaneous loss of magnetisation, based on their understanding of the underlying physical phenomenon. Roman Morgunov from the Institute of Problems of Chemical Physics at the Russian Academy of Sciences and colleagues have now developed a simple additive-based method for ensuring the stability of permanent magnets over time, with no loss to their main magnetic characteristics.

To design magnets that retain their magnetic stability, the authors altered the chemical composition of a RE-TM-B magnet. Their method consists in inserting small amounts of Samarium atoms at random places within the crystalline sub-lattice of the magnet's rare-earth

component. They observed a multi-fold increase in the magnet's stability over time with as little as 1% Samarium. The advantage of using such low quantity of additives to stabilise the magnet is that it does not alter the magnetic properties.

The authors believe this result is linked to Samarium's symmetry. It differs from the crystalline structure of Dysprosium atoms, which enter the composition of the magnet's rare-earth component. As a result, spontaneous magnetisation no longer takes place. This is because the potential barriers separating the magnetisation states of different energies are enhanced by the disrupted symmetry.

Further developments of this research will most likely focus on identifying the discrete magnetisation jumps—elementary events that initiate the reversible magnetisation, leading to a loss in stability. [11]

New method for generating superstrong magnetic fields

Researchers of MEPhI (Russia), the University of Rostock (Germany) and the University of Pisa (Italy) suggest a new method for generating extremely strong magnetic fields of several gigaGauss in the lab. Currently available techniques produce fields of one order of magnitude less than the new method. In nature, such superstrong fields exist only in the space. Therefore, generation of such fields in laboratory conditions provides new opportunities for the modeling of astrophysical processes. The results will contribute to the new research field of laboratory astrophysics.

The Faraday effect has been known for a long time. It refers to the polarization plane of an electromagnetic wave propagating through a non-magnetic medium, which is rotating in the presence of a constant magnetic field. There is also an inverse process of the generation of a magnetic field during the propagation of a circularly polarized wave through a crystal or plasma. It was considered theoretically in the 1960s by Soviet theorist Lew Pitaevsky, a famous representative of Landau's school. The stronger the wave, the higher the magnetic field it can generate when propagating through a medium. However, a peculiarity of the effect is that it requires absorption for its very existence—it does not occur in entirely transparent media. In highly intense electromagnetic fields, electrons become ultrarelativistic, which considerably reduces their collisions, suppressing conventional absorption. The researchers demonstrate that at very high laser wave intensities, the absorption can be effectively provided by radiation friction instead of binary collisions. This specific friction leads to the generation of a superstrong magnetic field.

According to physicist Sergey Popruzhenko, it will be possible to check the calculations in the near future. Several new laser facilities of record power will be completed in the next several years. Three such lasers are now under construction within the European project Extreme Light Infrastructure (ELI) in the Czech Republic, Romania and Hungary. The Exawatt Center for Extreme Light Studies – XCELS is under the development at the Applied Physics Institute RAS at Nizhny Novgorod. These laser facilities will be capable of the intensities required for the

generation of superstrong magnetic fields due to radiation friction and also for the observation of many other fundamental strong-field effects. [10]

Inverse spin Hall effect: A new way to get electricity from magnetism

By showing that a phenomenon dubbed the "inverse spin Hall effect" works in several organic semiconductors - including carbon-60 buckyballs - University of Utah physicists changed magnetic "spin current" into electric current. The efficiency of this new power conversion method isn't yet known, but it might find use in future electronic devices including batteries, solar cells and computers.

"This paper is the first to demonstrate the inverse spin Hall effect in a range of organic semiconductors with unprecedented sensitivity," although a 2013 study by other researchers demonstrated it with less sensitivity in one such material, says Christoph Boehme, a senior author of the study published April 18 in the journal Nature Materials.

"The inverse spin Hall effect is a remarkable phenomenon that turns so-called spin current into an electric current. The effect is so odd that nobody really knows what this will be used for eventually, but many technical applications are conceivable, including very odd new powerconversion schemes," says Boehme, a physics professor.

His fellow senior author, distinguished professor Z. Valy Vardeny, says that by using pulses of microwaves, the inverse spin Hall effect and organic semiconductors to convert spin current into electricity, this new electromotive force generates electrical current in a way different than existing sources.

Coal, gas, hydroelectric, wind and nuclear plants all use dynamos to convert mechanical force into magnetic-field changes and then electricity. Chemical reactions power modern batteries and solar cells convert light to electrical current. Converting spin current into electrical current is another method.

Scientists already are developing such devices, such as a thermoelectric generator, using traditional inorganic semiconductors. Vardeny says organic semiconductors are promising because they are cheap, easily processed and environmentally friendly. He notes that both organic solar cells and organic LED (light-emitting diode) TV displays were developed even though silicon solar cells and nonorganic LEDs were widely used.

A new way to get electricity from magnetism

Vardeny and Boehme stressed that the efficiency at which organic semiconductors convert spin current to electric current remains unknown, so it is too early to predict the extent to which it might one day be used for new power conversion techniques in batteries, solar cells, computers, phones and other consumer electronics.

"I want to invoke a degree of caution," Boehme says. "This is a power conversion effect that is new and mostly unstudied."

Boehme notes that the experiments in the new study converted more spin current to electrical current than in the 2013 study, but Vardeny cautioned the effect still "would have to be scaled up many times to produce voltages equivalent to household batteries."

The new study was funded by the National Science Foundation and the University of Utah-NSF Materials Research Science and Engineering Center. Study co-authors with Vardeny and Boehme were these University of Utah physicists: research assistant professors Dali Sun and Hans Malissa, postdoctoral researchers Kipp van Schooten and Chuang Zhang, and graduate students Marzieh Kavand and Matthew Groesbeck.

From spin current to electric current

Just as atomic nuclei and the electrons that orbit them carry electrical charges, they also have another inherent property: spin, which makes them behave like tiny bar magnets that can point north or south.

Electronic devices store and transmit information using the flow of electricity in the form of electrons, which are negatively charged subatomic particles. The zeroes and ones of computer binary code are represented by the absence or presence of electrons within silicon or other nonorganic semiconductors.

Spin electronics - spintronics - holds promise for faster, cheaper computers, better electronics and LEDs for displays, and smaller sensors to detect everything from radiation to magnetic fields.

The inverse spin Hall effect first was demonstrated in metals in 2008, and then in nonorganic semiconductors, Vardeny says. In 2013, researchers elsewhere showed it occurred in an organic semiconductor named PEDOT:PSS when it was exposed to continuous microwaves that were relatively weak to avoid frying the semiconductor. [9]

New electron spin secrets revealed: Discovery of a novel link between magnetism and electricity

The findings reveal a novel link between magnetism and electricity, and may have applications in electronics.

The electric current generation demonstrated by the researchers is called charge pumping. Charge pumping provides a source of very high frequency alternating electric currents, and its magnitude and external magnetic field dependency can be used to detect magnetic information.

The findings may, therefore, offer new and exciting ways of transferring and manipulating data in electronic devices based on spintronics, a technology that uses electron spin as the foundation for information storage and manipulation.

The research findings are published as an Advance Online Publication (AOP) on Nature Nanotechnology's website on 10 November 2014.

Spintronics has already been exploited in magnetic mass data storage since the discovery of the giant magnetoresistance (GMR) effect in 1988. For their contribution to physics, the discoverers of GMR were awarded the Nobel Prize in 2007.

The basis of spintronics is the storage of information in the magnetic configuration of ferromagnets and the read-out via spin-dependent transport mechanisms.

"Much of the progress in spintronics has resulted from exploiting the coupling between the electron spin and its orbital motion, but our understanding of these interactions is still immature. We need to know more so that we can fully explore and exploit these forces," says Arne Brataas, professor at NTNU and the corresponding author for the paper.

An electron has a spin, a seemingly internal rotation, in addition to an electric charge. The spin can be up or down, representing clockwise and counterclockwise rotations.

Pure spin currents are charge currents in opposite directions for the two spin components in the material.

It has been known for some time that rotating the magnetization in a magnetic material can generate pure spin currents in adjacent conductors.

However, pure spin currents cannot be conventionally detected by a voltmeter because of the cancellation of the associated charge flow in the same direction.

A secondary spin-charge conversion element is then necessary, such as another ferromagnet or a strong spin-orbit interaction, which causes a spin Hall effect.

Brataas and his collaborators have demonstrated that in a small class of ferromagnetic materials, the spin-charge conversion occurs in the materials themselves.

The spin currents created in the materials are thus directly converted to charge currents via the spin-orbit interaction.

In other words, the ferromagnets function intrinsically as generators of alternating currents driven by the rotating magnetization.

"The phenomenon is a result of a direct link between electricity and magnetism. It allows for the possibility of new nano-scale detection techniques of magnetic information and for the generation of very high-frequency alternating currents," Brataas says. [8]

Simple Experiment

Everybody can repeat my physics teacher's - Nándor Toth - middle school experiment, placing aluminum folios in form V upside down on the electric wire with static electric current, and seeing them open up measuring the electric potential created by the charge distribution, caused by the acceleration of the electrons.

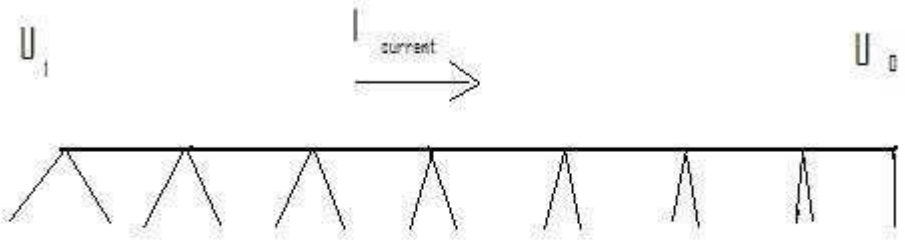


Figure 1.) Aluminium folios shows the charge distribution on the electric wire

He wanted to show us that the potential decreasing linearly along the wire and told us that in the beginning of the wire it is lowering harder, but after that the change is quite linear.

You will see that the folios will draw a parabolic curve showing the charge distribution along the wire, since the way of the accelerated electrons in the wire is proportional with the square of time. The free external charges are moving along the wire, will experience this charge distribution caused electrostatic force and repelled if moving against the direction of the electric current and attracted in the same direction – the magnetic effect of the electric current.

Uniformly accelerated electrons of the steady current

In the steady current **I= dq/dt**, the **q** electric charge crossing the electric wire at any place in the same time is constant. This does not require that the electrons should move with a constant v velocity and does not exclude the possibility that under the constant electric force created by the **E = - dU/dx** potential changes the electrons could accelerating.

If the electrons accelerating under the influence of the electric force, then they would arrive to the $\mathbf{x = 1/2\ at^2}$ in the wire. The **dx/dt = at**, means that every second the accelerating q charge will take a linearly growing length of the wire. For simplicity if a=2 then the electrons would found in the wire at x = 1, 4, 9, 16, 25 …, which means that the dx between them should be 3, 5, 7, 9 …, linearly increasing the volume containing the same q electric charge. It means that the density of the electric charge decreasing linearly and as the consequence of this the U field is decreasing linearly as expected: **-dU/dx = E = const**.

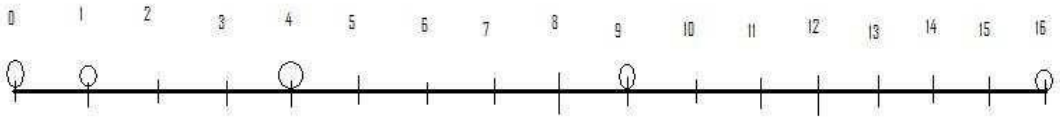


Figure 2.) The accelerating electrons created charge distribution on the electric wire

This picture remembers the Galileo's Slope of the accelerating ball, showed us by the same teacher in the middle school, some lectures before. I want to thank him for his enthusiastic and impressive lectures, giving me the associating idea between the Galileo's Slope and the accelerating charges of the electric current.

We can conclude that the electrons are accelerated by the electric **U** potential, and with this accelerated motion they are maintaining the linear potential decreasing of the **U** potential along they movement. Important to mention, that the linearly decreasing charge density measured in the referential frame of the moving electrons. Along the wire in its referential frame the charge density lowering parabolic, since the charges takes way proportional with the square of time.

The decreasing **U** potential is measurable, simply by measuring it at any place along the wire. One of the simple visualizations is the aluminum foils placed on the wire opening differently depending on the local charge density. The static electricity is changing by parabolic potential giving the equipotential lines for the external moving electrons in the surrounding of the wire.

Magnetic effect of the decreasing U electric potential

One **q** electric charge moving parallel along the wire outside of it with velocity v would experience a changing **U** electric potential along the wire. If it experiencing an emerging potential, it will repel the charge, in case of decreasing **U** potential it will move closer to the

wire. This radial electric field will move the external electric charge on the parabolic curve, on the equipotential line of the accelerated charges of the electric current. This is exactly the magnetic effect of the electric current. A constant force, perpendicular to the direction of the movement of the matter will change its direction to a parabolic curve.

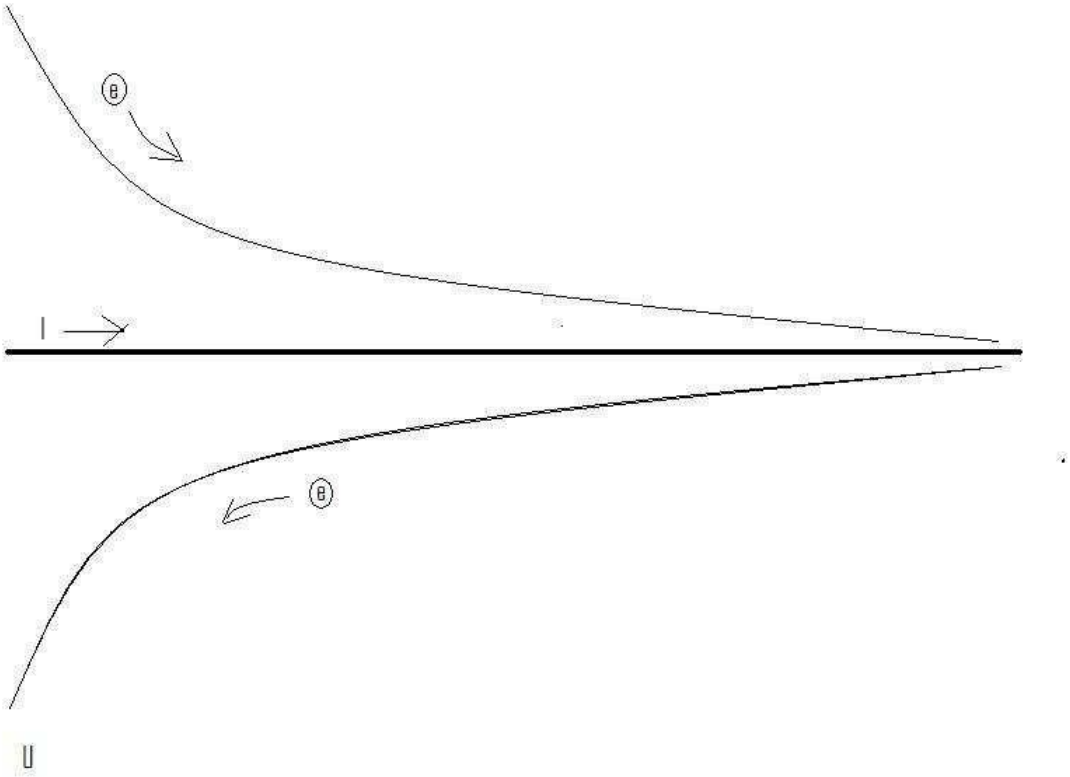


Figure 3.) Concentric parabolic equipotential surfaces around the electric wire causes the magnetic effect on the external moving charges

Considering that the magnetic effect is **F=q v x B**, where the **B** is concentric circle around the electric wire, it is an equipotential circle of the accelerating electrons caused charge distribution. Moving on this circle there is no electric and magnetic effect for the external charges, since **vxB=0**. Moving in the direction of the current the electric charges crosses the biggest potential change, while in any other direction – depending on the angle between the current and velocity of the external charge there is a modest electric potential difference, giving exactly the same force as the **v x B** magnetic force.

Getting the magnetic force from the **F = dp/dt** equation we will understand the magnetic field velocity dependency. Finding the appropriate trajectory of the moving charges we need simply get it from the equipotential lines on the equipotential surfaces, caused by the accelerating charges of the electric current. We can prove that the velocity dependent force causes to move the charges on the equipotential surfaces, since the force due to the potential difference according to the velocity angle – changing only the direction, but not the value of the charge's velocity.

The work done on the charge and the Hamilton Principle

One basic feature of magnetism is that, in the vicinity of a magnetic field, a moving charge will experience a force. Interestingly, the force on the charged particle is always perpendicular to the direction it is moving. Thus magnetic forces cause charged particles to change their direction of motion, but they do not change the speed of the particle. This property is used in high-energy particle accelerators to focus beams of particles which eventually collide with targets to produce new particles. Another way to understand this is to realize that if the force is perpendicular to the motion, then no work is done. Hence magnetic forces do no work on charged particles and cannot increase their kinetic energy. If a charged particle moves through a constant magnetic field, its speed stays the same, but its direction is constantly changing. [2]

In electrostatics, the work done to move a charge from any point on the equipotential surface to any other point on the equipotential surface is zero since they are at the same potential. Furthermore, equipotential surfaces are always perpendicular to the net electric field lines passing through it. [3]

Consequently the work done on the moving charges is zero in both cases, proving that they are equal forces, that is they are the same force.

The accelerating charges self-maintaining potential equivalent with the Hamilton Principle and the Euler-Lagrange equation. [4]

The Magnetic Vector Potential

Also the **A** magnetic vector potential gives the radial parabolic electric potential change of the charge distribution due to the acceleration of electric charges in the electric current.

Necessary to mention that the **A** magnetic vector potential is proportional with a, the acceleration of the charges in the electric current although this is not the only parameter.

The **A** magnetic vector potential is proportional with I=**dQ/dt** electric current, which is proportional with the strength of the charge distribution along the wire. Although it is proportional also with the U potential difference I=U/R, but the R resistivity depends also on the cross-sectional area, that is bigger area gives stronger I and **A**. [7] This means that the bigger potential differences with smaller cross-section can give the same **I** current and **A** vector potential, explaining the gauge transformation.

Since the magnetic field B is defined as the curl of **A**, and the curl of a gradient is identically zero, then any arbitrary function which can be expressed as the gradient of a scalar function may be added to A without changing the value of B obtained from it. That is, A' can be freely substituted for A where

$$\vec{A'} = \vec{A} + \vec{\nabla}\phi$$

Such transformations are called gauge transformations, and there have been a number of "gauges" that have been used to advantage is specific types of calculations in electromagnetic theory. [5]

Since the potential difference and the vector potential both are in the direction of the electric current, this gauge transformation could explain the self maintaining electric potential of the accelerating electrons in the electric current. Also this is the source of the special and general relativity.

The Constant Force of the Magnetic Vector Potential

Moving on the parabolic equipotential line gives the same result as the constant force of gravitation moves on a parabolic line with a constant velocity moving body.

Electromagnetic four-potential

The electromagnetic four-potential defined as:

SI units **cgs units**

$$A^\alpha = (\phi/c, \mathbf{A})\ A^\alpha = (\phi, \mathbf{A})$$

in which ϕ is the electric potential, and **A** is the magnetic vector potential. [6] This is appropriate with the four-dimensional space-time vector (T, **R**) and in stationary current gives that the potential difference is constant in the time dimension and vector potential (and its curl, the magnetic field) is constant in the space dimensions.

Magnetic induction

Increasing the electric current **I** causes increasing magnetic field **B** by increasing the acceleration of the electrons in the wire. Since l=at, if the acceleration of electrons is growing, than the charge density **dQ/dl** will decrease in time, creating a **–E** electric field. Since the resistance of the wire is constant, only increasing U electric potential could cause an increasing electric current **I=U/R=dQ/dt**. The charge density in the static current changes linear in the time coordinates. Changing its value in time will causing a static electric force, negative to the accelerating force change. This explains the relativistic changing mass of the charge in time also.

Necessary to mention that decreasing electric current will decrease the acceleration of the electrons, causing increased charge density and **E** positive field.

The electric field is a result of the geometric change of the **U** potential and the timely change of the **A** magnetic potential:

E = - dA/dt - dU/dr

$$\mathbf{B} = \nabla \times \mathbf{A}, \quad \mathbf{E} = -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t},$$

The acceleration of the electric charges proportional with the A magnetic vector potential in the electric current and also their time dependence are proportional as well. Since the A vector potential is appears in the equation, the proportional **a** acceleration will satisfy the same equation.

Since increasing acceleration of charges in the increasing electric current the result of increasing potential difference, creating a decreasing potential difference, the electric and magnetic vector potential are changes by the next wave - function equations:

$$\frac{1}{c^2}\frac{\partial^2 \varphi}{\partial t^2} - \nabla^2 \varphi = \frac{\rho}{\varepsilon_0}$$

$$\nabla^2 \mathbf{A} - \frac{1}{c^2}\frac{\partial^2 \mathbf{A}}{\partial t^2} = -\mu_0 \mathbf{J}$$

The simple experiment with periodical changing **U** potential and **I** electric current will move the aluminium folios with a moving wave along the wire.

The Lorentz gauge says exactly that the accelerating charges are self maintain their accelerator fields and the divergence (source) of the A vector potential is the timely change of the electric potential.

$$\nabla \cdot \vec{A} + \frac{1}{c^2}\frac{\partial \varphi}{\partial t} = 0.$$

Or

$$\vec{E} = -\nabla \varphi - \frac{\partial \vec{A}}{\partial t}.$$

The timely change of the A vector potential, which is the proportionally changing acceleration of the charges will produce the negative electric field.

Lorentz transformation of the Special Relativity

In the referential frame of the accelerating electrons the charge density lowering linearly because of the linearly growing way they takes every next time period. From the referential frame of the wire there is a parabolic charge density lowering.

The difference between these two referential frames, namely the referential frame of the wire and the referential frame of the moving electrons gives the relativistic effect. Important to say that the moving electrons presenting the time coordinate, since the electrons are taking linearly increasing way every next time period, and the wire presenting the geometric coordinate.

The Lorentz transformations are based on moving light sources of the Michelson - Morley experiment giving a practical method to transform time and geometric coordinates without explaining the source of this mystery.

The real mystery is that the accelerating charges are maintaining the accelerating force with their charge distribution locally. The resolution of this mystery that the charges are simply the results of the diffraction patterns, that is the charges and the electric field are two sides of the same thing. Otherwise the charges could exceed the velocity of the electromagnetic field.

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

Heisenberg Uncertainty Relation

In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass.

This means that the electron and proton are not point like particles, but has a real charge distribution.

Wave – Particle Duality

The accelerating electrons explains the wave – particle duality of the electrons and photons, since the elementary charges are distributed on delta x position with delta p impulse and creating a wave packet of the electron. The photon gives the electromagnetic particle of the

mediating force of the electrons electromagnetic field with the same distribution of wavelengths.

Atomic model

The constantly accelerating electron in the Hydrogen atom is moving on the equipotential line of the proton and it's kinetic and potential energy will be constant. Its energy will change only when it is changing its way to another equipotential line with another value of potential energy or getting free with enough kinetic energy. This means that the Rutherford-Bohr atomic model is

right and only the changing acceleration of the electric charge causes radiation, not the steady acceleration. The steady acceleration of the charges only creates a centric parabolic steady electric field around the charge, the magnetic field. This gives the magnetic moment of the atoms, summing up the proton and electron magnetic moments caused by their circular motions and spins.

Fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.

The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: **1/2 h = dx dp** or **1/2 h = dt dE**, that is the value of the basic energy status, consequently related to the m_o inertial mass of the fermions.

The photon's 1 spin value and the electric charges 1/2 spin gives us the idea, that the electric charge and the electromagnetic wave two sides of the same thing, 1/2 – (-1/2) = 1.

Fine structure constant

The Planck constant was first described as the proportionality constant between the energy ***E*** of a photon and the frequency ***v*** of its associated electromagnetic wave. This relation between the energy and frequency is called the Planck relation or the Planck–Einstein equation:

$$E = h\nu\,.$$

Since the frequency ***v*****,** wavelength ***λ***, and speed of light ***c*** are related by ***λv* = *c***, the Planck relation can also be expressed as

$$E = \frac{hc}{\lambda}.$$

Since this is the source of the Planck constant, the e electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths, since **E = mc^2**.

The expression of the fine-structure constant becomes the abbreviated

$$\alpha = \frac{e^2}{\hbar c}$$

This is a dimensionless constant expression, 1/137 commonly appearing in physics literature.

This means that the electric charge is a result of the electromagnetic waves diffractions, consequently the proton – electron mass rate is the result of the equal intensity of the corresponding electromagnetic frequencies in the Planck distribution law.

Planck Distribution Law

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

The Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms, molecules, crystals, dark matter and energy.

One way dividing the proton to three parts is, dividing his oscillation by the three direction of the space. We can order 1/3 **e** charge to each coordinates and 2/3 **e** charge to one plane oscillation, because the charge is scalar. In this way the proton has two +2/3 **e** plane oscillation and one linear oscillation with -1/3 **e** charge. The colors of quarks are coming from the three directions of coordinates and the proton is colorless. [1]

Electromagnetic inertia and Gravitational attraction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic changing mass.

It looks clear that the growing acceleration results the relativistic growing mass - limited also with the velocity of the electromagnetic wave.

The negatively changing acceleration causes a positive electric field, working as a decreasing mass.

Since $E = h\nu$ and $E = mc^2$, $m = h\nu / c^2$ that is the m depends only on the ν frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_o inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the

atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

If the mass is electromagnetic, then the gravitation is also electromagnetic effect caused by the magnetic effect between the same charges, they would attract each other if they are moving parallel by the magnetic effect.

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths. Also since the particles are diffraction patterns they have some closeness to each other – can be seen as the measured effect of the force of the gravitation, since the magnetic effect depends on this closeness. This way the mass and the magnetic attraction depend equally on the wavelength of the electromagnetic waves.

Conclusions

The generation and modulation of high-frequency currents are central wireless communication devices such as mobile phones, WLAN modules for personal computers, Bluetooth devices and future vehicle radars. [8]

Needless to say that the accelerating electrons of the steady stationary current are a simple demystification of the magnetic field, by creating a decreasing charge distribution along the wire, maintaining the decreasing U potential and creating the **A** vector potential experienced by the electrons moving by **v** velocity relative to the wire. This way it is easier to understand also the time dependent changes of the electric current and the electromagnetic waves as the resulting fields moving by c velocity.

There is a very important law of the nature behind the self maintaining **E** accelerating force by the accelerated electrons. The accelerated electrons created electromagnetic fields are so natural that they occur as electromagnetic waves traveling with velocity c. It shows that the electric charges are the result of the electromagnetic waves diffraction.

One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement . The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. Basing the gravitational force on the magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions.

References

[1] 3 Dimensional String Theory

Author: George Rajna

Publisher: academia.edu
http://www.academia.edu/3834454/3_Dimensional_String_Theory

[2] Magnetic forces on moving charges

http://theory.uwinnipeg.ca/mod_tech/node93.html

[3] Equipotential surface http://en.wikipedia.org/wiki/Equipotential_surface

[4] Hamilton Principle http://en.wikipedia.org/wiki/Hamilton%27s_principle

[5] Magnetic Vector Potential http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magvec.html

[6] Electromagnetic four-potential http://en.wikipedia.org/wiki/Electromagnetic_four-potential

[7] http://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity

[8] New electron spin secrets revealed: Discovery of a novel link between magnetism and electricity http://phys.org/news/2014-11-electron-secrets-revealed-discovery-link.html

[9] Inverse spin Hall effect: A new way to get electricity from magnetism
http://phys.org/news/2016-04-inverse-hall-effect-electricity-magnetism.html

[10] New method for generating superstrong magnetic fields http://phys.org/news/2016-08-method-superstrong-magnetic-fields.html [11] New method to make permanent magnets more stable over time http://phys.org/news/2016-10-method-permanent-magnets-stable.html [12] For the first time, magnets are be made with a 3-D printer http://phys.org/news/2016-10-magnets-d-printer.html

[13] Researchers create hidden images with commercial inkjet printers
http://phys.org/news/2016-12-hidden-images-commercial-inkjet-printers.html

[14] A nano-roundabout for light http://phys.org/news/2016-12-nano-roundabout.html

[15] Conformal metasurface coating eliminates crosstalk and shrinks waveguides

https://phys.org/news/2017-08-conformal-metasurface-coating-crosstalk-waveguides.html

[16] Photosensitive perovskites change shape when exposed to light

https://phys.org/news/2017-08-photosensitive-perovskites-exposed.html

[17] Optical control of magnetic memory—New insights into fundamental mechanisms

https://phys.org/news/2017-08-optical-magnetic-memorynew-insights-fundamental.html

[18] How to store data on magnets the size of a single atom

https://cosmosmagazine.com/technology/how-to-store-data-on-magnets-the-size-of-a-singleatom

[19] New quantum memory device small enough to fit on a chip https://phys.org/news/2017-09-quantum-memory-device-small-chip.html [20] Flip-flop qubits: Radical new quantum computing design invented https://phys.org/news/2017-09-flip-flop-qubits-radical-quantum.html

[21] New tool for characterizing quantum simulators https://phys.org/news/2017-09-tool-characterizing-quantum-simulators.html [22] Engineers develop key mathematical formula for driving quantum experiments

https://phys.org/news/2017-09-key-mathematical-formula-quantum.html

[23] Graphene single photon detectors https://phys.org/news/2017-09-graphene-photon-detectors.html

[24] Sustainable solvent platform for photon upconversion increases solar utilization efficiency

https://phys.org/news/2017-12-sustainable-solvent-platform-photon-upconversion.html

[25] Detecting the birth and death of a phonon

https://phys.org/news/2018-06-birth-death-phonon.html

[26] How to measure quantum behaviour in nanocrystals

https://physicsworld.com/a/how-to-measure-quantum-behaviour-in-nanocrystals/

[27] Tiny defects in semiconductors created 'speed bumps' for electrons—researchers cleared the path

https://phys.org/news/2018-06-tiny-defects-semiconductors-electronsresearchers-path.html

[28] New optical sensor can determine if molecules are left or right 'handed'

https://phys.org/news/2018-06-optical-sensor-molecules-left.html

[29] Core electron topologies in chemical bonding

https://phys.org/news/2018-06-core-electron-topologies-chemical-bonding.html

[30] The photoelectric effect in stereo

https://phys.org/news/2018-06-photoelectric-effect-stereo.html

[31] Controlling photons with a photon

https://phys.org/news/2018-06-photons-photon.html

[32] Scientists develop unique trap for light

https://phys.org/news/2018-07-scientists-unique.html

[33] Researchers develop first-of-its-kind optic isolator

https://phys.org/news/2018-07-first-of-its-kind-optic-isolator.html

[34] Optical fibers that can sense the materials around them

https://phys.org/news/2018-07-optical-fibers-materials.html

[35] A breakthrough of monitoring energy storage at work using optical fibers

https://phys.org/news/2018-07-breakthrough-energy-storage-optical-fibers.html

[36] High-resolution imaging of nanoparticle surface structures is now possible

https://phys.org/news/2018-08-high-resolution-imaging-nanoparticle-surface.html

[37] Proof-of-concept technique makes nanoparticles attractive for new medications

https://phys.org/news/2018-08-proof-of-concept-technique-nanoparticles-medications.html

[38] On-chip excitation of nanodiamonds embedded in plasmonic waveguides

https://phys.org/news/2018-10-on-chip-nanodiamonds-embedded-plasmonic-waveguides.html

[39] Hidden gapless states on the path to semiconductor nanocrystals

https://phys.org/news/2018-10-hidden-gapless-states-path-semiconductor.html

[40] Study provides insight into how nanoparticles interact with biological systems

https://phys.org/news/2018-10-insight-nanoparticles-interact-biological.html

[41] Animal simulations and smart drug design: Nanomaterial transport to individual cells

https://phys.org/news/2020-02-animal-simulations-smart-drug-nanomaterial.html