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Symmetric graphene quantum dots for future qubits

INVESTMENT

IBM and Google give $150 million for quantum computing research

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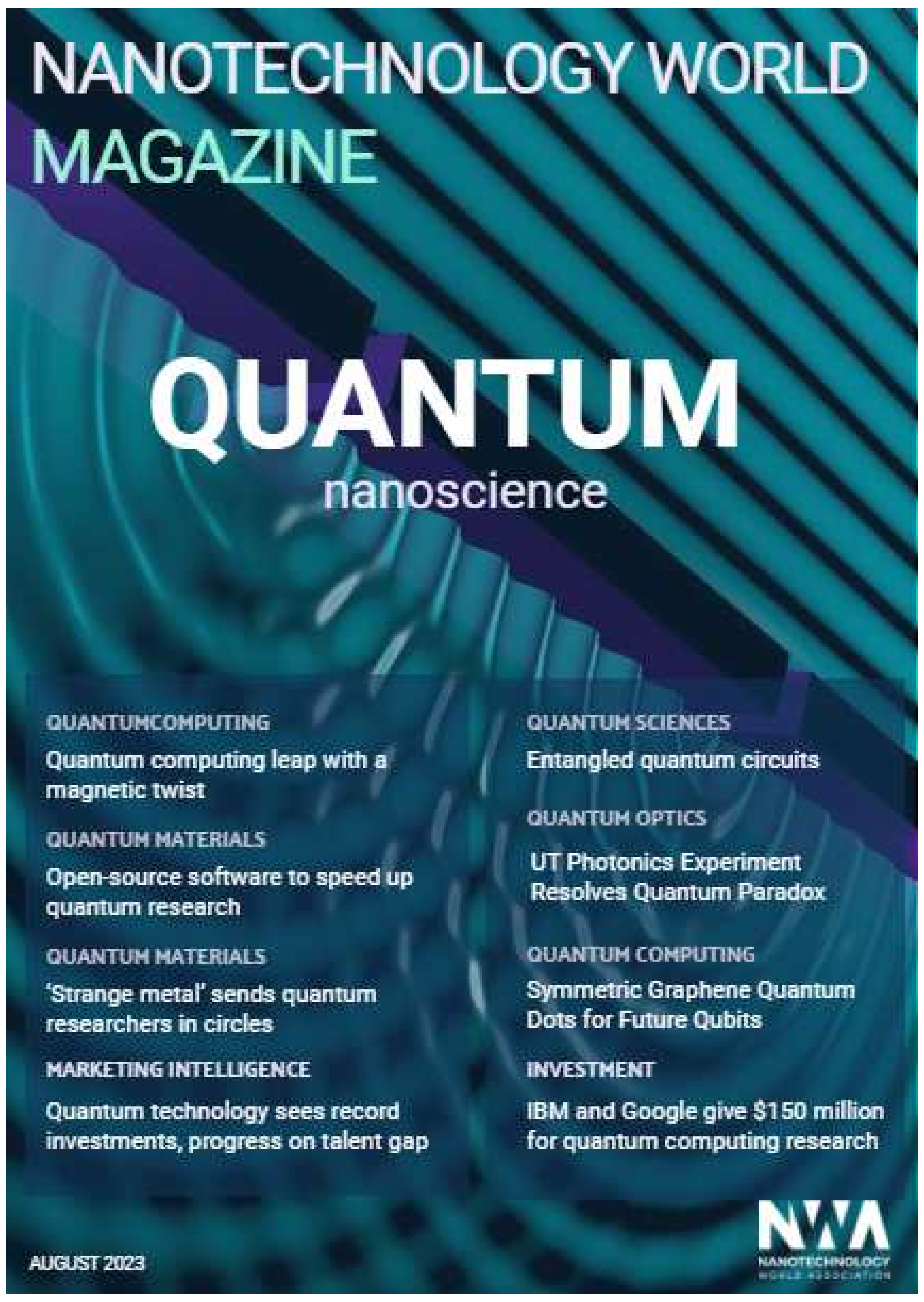


Nanotechnology World Magazine
August 2023

Nanotechnology enables precise manipulation of matter at nanoscale, enhancing quantum technology components and applications for unprecedented advancements.

Next issue:
November 2023

Nanomedicine

FEATURES

Nanotech and Quantum's entanglement

The essence of quantum technology lies in its ability to harness the enigmatic properties of quantum mechanics, enabling the processing, storage, and transmission of information with unprecedented efficiency and inviolable security. Yet, the actualization of these capabilities hinges upon the precise manipulation and management of quantum systems, a role in which nanotechnology emerges as a pivotal player.

The nanoscale realm serves as an arena where quantum mechanical effects reign supreme, providing a fertile ground for their meticulous orchestration and utilization in the design of quantum devices. Nanotechnology presents an array of tools and methodologies that empower the engineering and construction of structures at this scale.

Emphasizing the dynamic synergy between nanotechnology and quantum technology, one finds the likes of semiconductor quantum dots. These diminutive wonders exhibit distinctive attributes that endow them with the potential to serve as prime candidates for qubits, the fundamental carriers of quantum information. These qubits, characterized by their delicately poised quantum states, are acutely sensitive to imperfections and external influences, thereby necessitating the precision and finesse that nanoscale manipulation affords.

The pursuit of resilient qubits and error-correction strategies requires a level of innovation that stretches the boundaries of contemporary knowledge. The collaborative interplay between quantum physicists and nanotechnologists emerges as a keystone which will allow to unlock the full potential of quantum technology.

The narrative of quantum communication, replete with the promise of ultra-secure data transmission through quantum key distribution, further solidifies the nexus between nanotechnology and quantum technology. The finesse of nanotechnology manifests in the creation of photonic circuits that wield the power to generate, manipulate, and detect individual photons - the building blocks of quantum cryptographic protocols. This synergy charts a trajectory towards revolutionary advancements in computation, communication, and beyond.

The precision afforded by nanotechnology in sculpting, manipulating, and directing matter at the nanoscale is the cornerstone upon which the edifice of quantum technology will be erected.

Marine Le Bouar
Founder and CEO, Nanotechnology World Association
Editor in Chief, Nanotechnology World Magazine

UPCOMING EVENTS

Workshop: Materials Aspects of Novel Quantum Systems
September 10-13, 2023
Weinstadt-Beutelsbach, Germany

IEEE Quantum Week 2023
September 17-22, 2023
Bellevue WA, USA

Quantum World Congress
September 26-28, 2023
Tysons VA, USA

Quantum Effects
October 10-11, 2023
Stuttgart, Germany

Quantum Engineering and Technology Conference 2023
October 30-31, 2023
London, UK

10th International Workshop of Quantum Simulation and Quantum Walks
November 10-12, 2023
Tsukuba, Japan

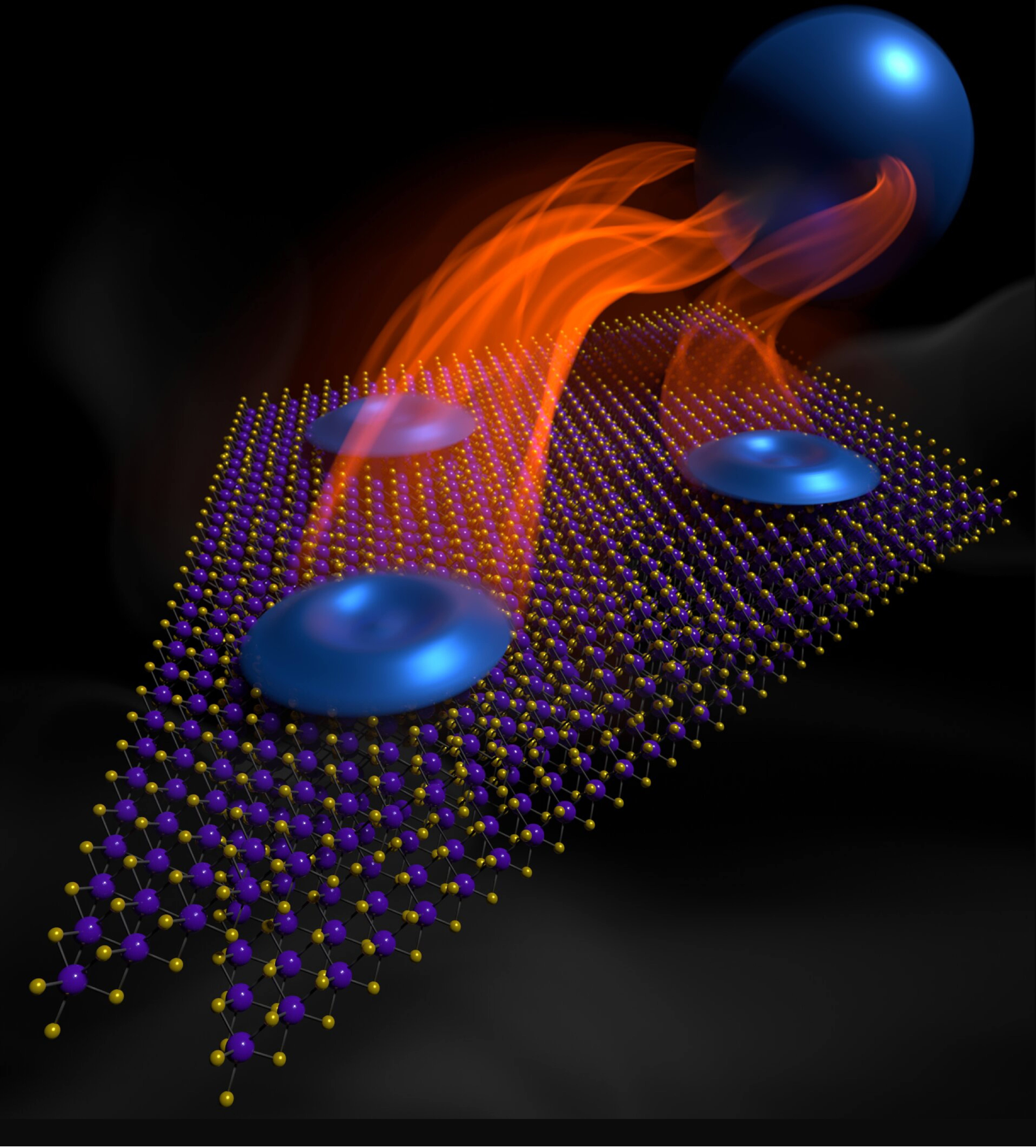
Quantum Techniques in Machine Learning
November 19-24, 2023
CERN, Switzerland

GDR TeQ Colloquium
November 22-24, 2023
Montpellier, France

International Conference on Quantum Energy
December 04-06, 2023
Melbourne, Australia

Quantum computing leap with a magnetic twist

James Urton,
University of Washington



Quantum computing could revolutionize our world. For specific and crucial tasks, it promises to be exponentially faster than the zero-or-one binary technology that underlies today's machines, from supercomputers in laboratories to smartphones in our pockets. But developing quantum computers hinges on building a stable network of qubits — or quantum bits — to store information, access it and perform computations. Yet the qubit platforms unveiled to date have a common problem: they tend to be delicate and vulnerable to outside disturbances. Even a stray photon can cause trouble. Developing fault-tolerant qubits — which would be immune to external perturbations — could be the ultimate solution to this challenge.

A team led by scientists and engineers at the University of Washington has announced a significant advancement in this quest. In a pair of papers published June 14 in Nature and June 22 in Science, they report that, in experiments with flakes of semiconductor materials — each only a single layer of atoms thick — they detected signatures of "fractional quantum anomalous Hall" (FQAH) states. The team's discoveries mark a first and promising step in constructing a type of fault-tolerant qubit because FQAH states can host anyons — strange "quasiparticles" that have only a fraction of an electron's charge. Some types of anyons can be used to make what are called "topologically protected" qubits, which are stable against any small, local disturbances.

"This really establishes a new paradigm for studying quantum physics with fractional excitations in the future," said Xiaodong Xu, the lead researcher behind these discoveries, who is also the Boeing Distinguished Professor of Physics and a professor of materials science and engineering at the UW.

FQAH states are related to the fractional quantum Hall state, an exotic phase of matter that exists in two-dimensional systems. In these states, electrical conductivity is constrained to precise fractions of a constant known as the conductance quantum. But fractional quantum Hall systems typically require massive magnetic fields to keep them stable, making them impractical for applications in quantum computing. The FQAH state has no such requirement — it is stable even "at zero magnetic field," according to the team.

Hosting such an exotic phase of matter required the researchers to build an artificial lattice with exotic properties. They stacked two atomically thin flakes of the semiconductor material molybdenum ditelluride ($MoTe_2$) at small, mutual "twist" angles relative to one another. This configuration formed a synthetic "honeycomb lattice" for electrons. When researchers cooled the stacked slices to a few degrees above absolute zero, an intrinsic magnetism arose in the system. The intrinsic magnetism takes the place of the strong magnetic field typically required for the fractional quantum Hall state. Using lasers as probes, the researchers detected signatures of the FQAH effect, a major step forward in unlocking the power of anyons for quantum computing.

The team — which also includes scientists at the University of Hong Kong, the National Institute for Materials Science in Japan, Boston College and the Massachusetts Institute of Technology — envisions their system as a powerful platform to develop a deeper understanding of anyons, which have very different properties from everyday particles like electrons. Anyons are quasiparticles — or particle-like "excitations" — that can act as fractions of an electron. In future work with their experimental system, the researchers hope to discover an even more exotic version of this type of quasiparticle: "non-Abelian" anyons, which could be used as topological qubits. Wrapping — or "braiding" — the non-Abelian anyons around each other In this quantum state, information is essentially "spread out" over the entire system and resistant to local disturbances — forming the basis of topological qubits and a major advancement over the capabilities of current quantum computers.

"This type of topological qubit would be fundamentally different from those that can be created now," said UW physics doctoral student Eric Anderson, who is lead author of the Science paper and co-lead author of the Nature paper. "The strange behavior of non-Abelian anyons would make them much more robust as a quantum computing platform."

Three key properties, all of which existed simultaneously in the researchers' experimental setup, allowed FQAH states to emerge:

Magnetism: Though $MoTe_2$ is not a magnetic material, when they loaded the system with positive charges, a "spontaneous spin order" — a form of magnetism called ferromagnetism — emerged.
Topology: Electrical charges within their system have "twisted bands," similar to a Möbius strip, which helps make the system topological.
Interactions: The charges within their experimental system interact strongly enough to stabilize the FQAH state.
The team hopes that, using their approach, non-Abelian anyons await for discovery.

"The observed signatures of the fractional quantum anomalous Hall effect are inspiring," said UW physics doctoral student Jiaqi Cai, co-lead author on the Nature paper and co-author of the Science paper. "The fruitful quantum states in the system can be a laboratory-on-a-chip for discovering new physics in two dimensions, and also new devices for quantum applications."

"Our work provides clear evidence of the long-sought FQAH states," said Xu, who is also a member of the Molecular Engineering and Sciences Institute, the Institute for Nano-Engineered Systems and the Clean Energy Institute, all at UW. "We are currently working on electrical transport measurements, which could provide direct and unambiguous evidence of fractional excitations at zero magnetic field."

The team believes that, with their approach, investigating and manipulating these unusual FQAH states can become commonplace — accelerating the quantum computing journey.

Additional co-authors on the papers are William Holtzmann and Yinong Zhang in the UW Department of Physics; Di Xiao, Chong Wang, Xiaowei Zhang, Xiaoyu Liu and Ting Cao in the UW Department of Materials Science & Engineering; Feng-Ren Fan and Wang Yao at the University of Hong Kong and the Joint Institute of Theoretical and Computational Physics at Hong Kong; Takashi Taniguchi and Kenji Watanabe from the National Institute of Materials Science in Japan; Ying Ran of Boston College; and Liang Fu at MIT. The research was funded by the U.S. Department of Energy, the Air Force Office of Scientific Research, the National Science Foundation, the Research Grants Council of Hong Kong, the Croucher Foundation, the Tencent Foundation, the Japan Society for the Promotion of Science and the University of Washington.

Signatures of Fractional Quantum Anomalous Hall States in Twisted $MoTe_2$
Jiaqi Cai, Eric Anderson, Chong Wang, Xiaowei Zhang, Xiaoyu Liu, William Holtzmann, Yinong Zhang, Fengren Fan, Takashi Taniguchi, Kenji Watanabe, Ying Ran, Ting Cao, Liang Fu, Di Xiao, Wang Yao & Xiaodong Xu
Nature (2023) Article

Image: This artistic depiction shows electron fractionalization — in which strongly interacting charges can "fractionalize" into three parts — in the fractional quantum anomalous Hall phase. Eric Anderson

University of Washington

UChicago, Tohoku University announce new 'quantum alliance'

Japan's Tohoku University and the University of Chicago are launching a collaboration to fuel quantum research and grow the international quantum workforce. The newly formed Chicago-Tohoku Quantum Alliance will focus on research in quantum sensing, quantum communication, and new materials development, and work to promote student exchange, industry partnerships and start-ups.
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Business News

US

IBM, Google Give $150 Million for U.S.-Japan Quantum-Computing Push

The U.S.-Japan partnership comes as both nations work to continue to outpace China in quantum advancements.

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EUROPE

$18M to advance materials research for quantum computing, sustainable plastics and more

New center builds a campus-wide ecosystem for designing and manufacturing materials of the future at U-M while training a more representative workforce.

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US

DOE pumps $11.7m into quantum computing research

The US Department of Energy (DOE) is providing $11.7 million in funding for six collaborative projects looking at the possibilities of quantum computing. Funding will be split across four years, with $4.8 million delivered this fiscal year.

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Quantum Silicon Production Project awarded $5.1m funding under the Defence Trailblazer Program

Silex Systems Limited is pleased to announce the award of $5.1m in funding from the Defence Trailblazer

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Silicon Quantum Computing raises $50.4m

Silicon Quantum Computing (SQC) has closed a $50.4m Series A capital raising to fund its ongoing quest to manufacture the world's first scalable, error corrected quantum computer.

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ASIA

Russian scientists eye BRICS quantum lab with India-China role

Russian scientists have asserted their interest in in building close quantum technology collaborations with India and China.

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ASIA

IBM Launches $100 Million Partnership with Global Universities to Develop Novel Technologies Towards a 100,000-Qubit Quantum-Centric Supercomputer

At the G7 Summit in Japan, IBM announced a 10-year, $100 million initiative with the University of Tokyo and the University of Chicago to develop a quantum-centric supercomputer powered by 100,000 qubits.

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EUROPE

IonQ Partners With BearingPoint to Offer Quantum-System Consulting

BearingPoint will advise clients on the benefits and potential applications of quantum computing using IonQ's systems, according to a statement

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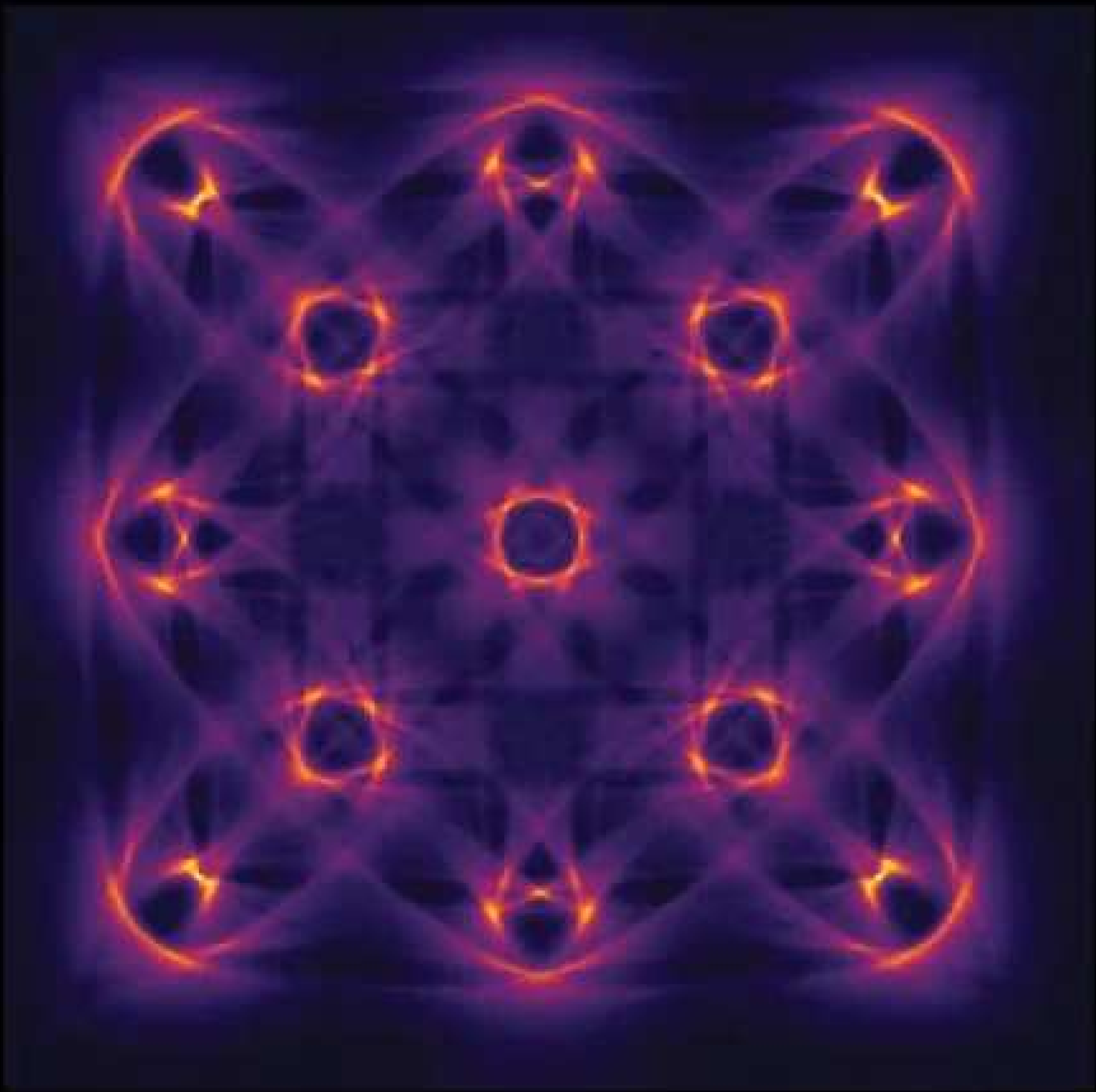
Open-source software to speed up quantum research



By Lovisa Håkansson/translation agency Ordmån

Quantum technology is expected to fundamentally change many key areas of society. Researchers are convinced that there are many more useful quantum properties and applications to explore than those we know today. A team of researchers at Chalmers University of Technology in Sweden have now developed open-source, freely available software that will pave the way for new discoveries in the field and accelerate quantum research significantly.

Within a few decades, quantum technology is expected to become a key technology in areas such as health, communication, defence and energy. The power and potential of the technology lie in the odd and very special properties of quantum particles. Of particular interest to researchers in the field are the superconducting properties of quantum particles that give components perfect conductivity with unique magnetic properties. These superconducting properties are considered conventional today and have already paved the way for entirely new technologies used in applications such as magnetic resonance imaging equipment, maglev trains and quantum computer components. However, years of research and development remain before a quantum computer can be expected to solve real computing problems in practice, for example. The research community is convinced that there are many more revolutionary discoveries to be made in quantum technology than those we know today.

We are specifically interested in unconventional superconductors

Open-source code to explore new superconducting properties

Basic research in quantum materials is the foundation of all quantum technology innovation, from the birth of the transistor in 1947, through the laser in the 1960s to the quantum computers of today. However, experiments on quantum materials are often very resource-intensive to develop and conduct, take many years to prepare and mostly produce results that are difficult to interpret. Now, however, a team of researchers at Chalmers have developed the open-source software SuperConga, which is free for everyone to use, and specifically designed to perform advanced simulations and analyses of quantum components. The programme operates at the mesoscopic level*, which means that it can carry out simulations that are capable of ‘picking up’ the strange properties of quantum particles, and also apply them in practice. The open-source code is the first of its kind in the world and is expected to be able to explore completely new superconducting properties and eventually pave the way for quantum computers that can use advanced computing to tackle societal challenges in several areas.

“We are specifically interested in unconventional superconductors, which are an enigma in terms of how they even work and what their properties are. We know that they have some desirable properties that allow quantum information to be protected from interference and fluctuations. Interference is what currently limits us from having a quantum computer that can be used in practice. And this is where basic research into quantum materials is crucial if we are to make any progress,” says Mikael Fogelström, Professor of Theoretical Physics at Chalmers.

These new superconductors continue to be highly enigmatic materials – just as their conventional siblings once were when they were discovered in a laboratory more than a hundred years ago. After that discovery, it would be more than 40 years before researchers could describe them in theory. The Chalmers researchers now hope that their open-source code can contribute to completely new findings and areas of application.

“We want to find out about all the other exciting properties of unconventional superconductors. Our software is powerful, educational and user-friendly, and we hope that it will help generate new understanding and suggest entirely new applications for these unexplored superconductors,” says Patric Holmvall, postdoctoral researcher in condensed matter physics at Uppsala University.

Desire to make life easier for quantum researchers and students

To be able to explore revolutionary new discoveries, tools are needed that can study and utilise the extraordinary quantum properties at the minimal particle level, and can also be scaled up large enough to be used in practice. Researchers need to work at mesoscopic scale*. This lies at the interface between the microscopic scale, i.e. the atomic level at which the quantum properties of the particles can still be utilised, and the macroscopic scale which measures everyday objects in our world which, unlike quantum particles, are subject to the laws of classical physics. On account of the software’s ability to work at this mesoscopic level, the Chalmers researchers now hope to make life easier for researchers and students working with quantum physics.

“Extremely simplified models based on either the microscopic or macroscopic scale are often used at present. This means that they do not manage to identify all the important physics or that they cannot be used in practice. With this free software, we want to make it easier for others to accelerate and improve their quantum research without having to reinvent the wheel every time,” says Tomas Löfwander, Professor of Applied Quantum Physics at Chalmers.

CHALMERS

More about the research:

The scientific article SuperConga: An open-source framework for mesoscopic superconductivity has been published in Applied Physics Reviews and was written by Patric Holmvall, the Department of Physics and Astronomy, Uppsala University, and Niclas Wall Wennerdal, Mikael Håkansson, Pascal Stadler, Oleksii Shevtsov, Tomas Löfwander and Mikael Fogelström, the Department of Microtechnology and Nanoscience at Chalmers University of Technology, Sweden.

SuperConga is open-source software and is free to download.

***More on the microscopic, mesoscopic and macroscopic scales**

The mesoscopic regime is at the interface between the macroscopic and microscopic regimes. In the macroscopic regime (typically millimetres and larger), classical physics dominates, describing everyday objects such as footballs, cats or perhaps a coffee maker. This contrasts with the microscopic regime, where quantum physics prevails, and much smaller objects can be measured, such as electrons, atoms and other particles. The odd properties of quantum particles can be explored on this tiny scale – properties that allow them to be in two places at once or to be perfectly conducting. Mesoscopic quantum components (typically micrometres down to nanometres) are so small that the strange properties of quantum particles can be accessed and used, but also large enough that they can be applied in practice. Open-source codes already exist for simulations at either the microscopic or more macroscopic level. SuperConga is the first freely available software in the world capable of simulating superconductors at the mesoscopic level.

For more information, please contact:

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+46 31 772 80 31 tomas.lofwander@chalmers.se

Tech Brief

Research group detects a quantum entanglement wave for the first time using real-space measurements

A team from Aalto University and the University of Jyväskylä have created an artificial quantum magnet featuring a quasiparticle made of entangled electrons, the triplon.

New quantum device generates single photons and encodes information

A new approach to quantum light emitters generates a stream of circularly polarized single photons, or particles of light, that may be useful for a range of quantum information and communication applications.

Switching 'spin' on and off (and up and down) in quantum materials at room temperature

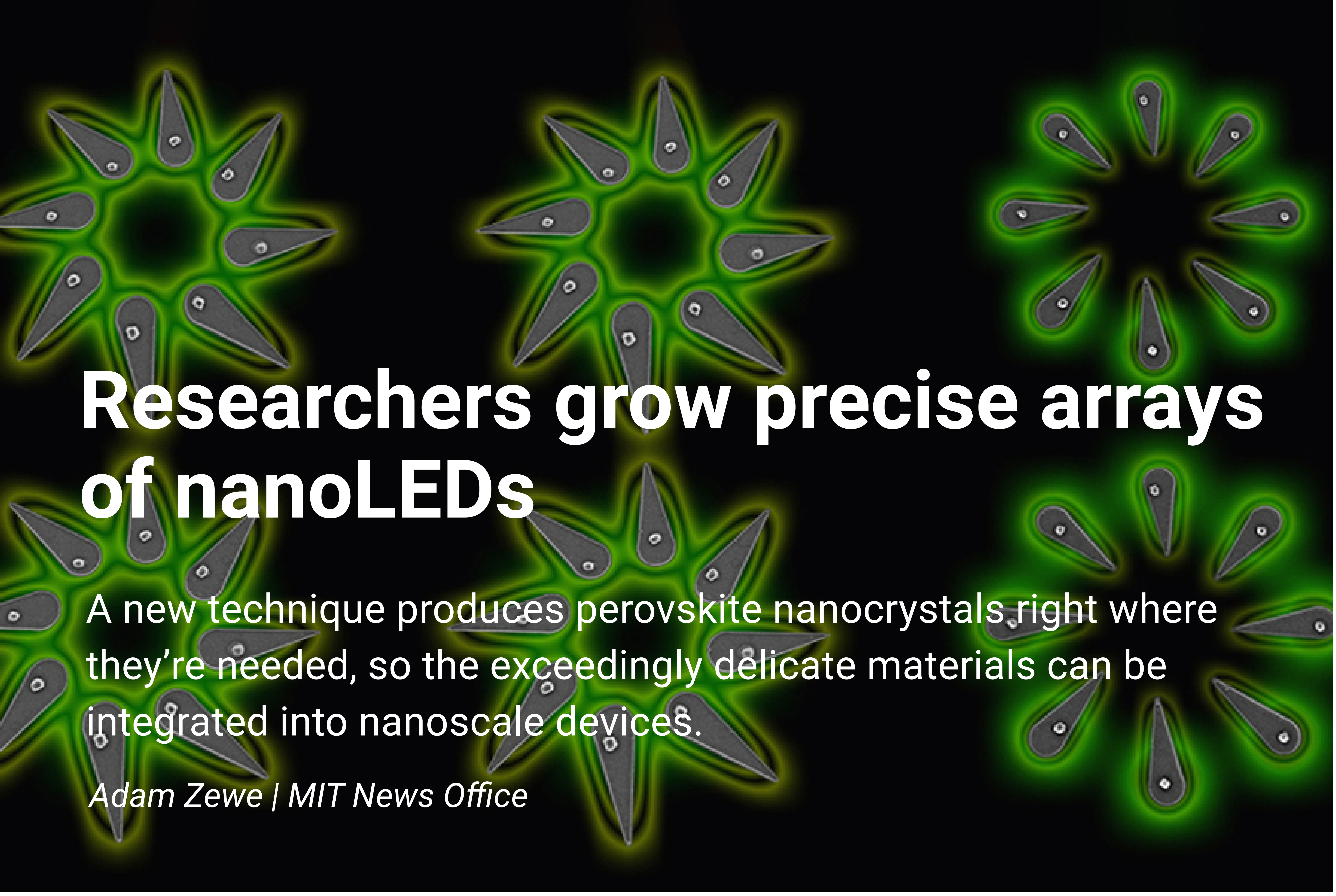
Researchers have found a way to control the interaction of light and quantum 'spin' in organic semiconductors, that works even at room temperature.

Visualizing the microscopic phases of magic-angle twisted bilayer graphene

A Princeton University-led team of scientists has imaged the precise microscopic underpinnings responsible for many quantum phases observed in a material known as magic-angle twisted bilayer graphene (MATBG).

Carbon-based quantum technology

Researchers have succeeded in attaching electrodes to individual atomically precise nanoribbons, paving the way for precise characterization of the fascinating ribbons and their possible use in quantum technology.



Researchers grow precise arrays of nanoLEDs

A new technique produces perovskite nanocrystals right where they're needed, so the exceedingly delicate materials can be integrated into nanoscale devices.

Adam Zewe | MIT News Office

Halide perovskites are a family of materials that have attracted attention for their superior optoelectronic properties and potential applications in devices such as high-performance solar cells, light-emitting diodes, and lasers.

These materials have largely been implemented into thin-film or micron-sized device applications. Precisely integrating these materials at the nanoscale could open up even more remarkable applications, like on-chip light sources, photodetectors, and memristors. However, achieving this integration has remained challenging because this delicate material can be damaged by conventional fabrication and patterning techniques.

To overcome this hurdle, MIT researchers created a technique that allows individual halide perovskite nanocrystals to be grown on-site where needed with precise control over location, to within less than 50 nanometers. (A sheet of paper is 100,000 nanometers thick.) The size of the nanocrystals can also be precisely controlled through this technique, which is important because size affects their characteristics. Since the material is grown locally with the desired features, conventional lithographic patterning steps that could introduce damage are not needed.

The technique is also scalable, versatile, and compatible with conventional fabrication steps, so it can enable the nanocrystals to be integrated into functional nanoscale devices. The researchers used this to fabricate arrays of nanoscale light-emitting diodes (nanoLEDs) — tiny crystals that emit light when electrically activated. Such arrays could have applications in optical communication and computing, lensless microscopes, new types of quantum light sources, and high-density, high-resolution displays for augmented and virtual reality.

“As our work shows, it is critical to develop new engineering frameworks for integration of nanomaterials into functional nanodevices. By moving past the traditional boundaries of nanofabrication, materials engineering, and device design, these techniques can allow us to manipulate matter at the extreme nanoscale dimensions, helping us realize unconventional device platforms important to addressing emerging technological needs,” says Farnaz Niroui, the EE Landsman Career Development Assistant Professor of Electrical Engineering and Computer Science (EECS), a member of the Research Laboratory of Electronics (RLE), and senior author of a new paper describing the work.

Niroui’s co-authors include lead author Patricia Jastrzebska-Perfect, an EECS graduate student; Weikun “Spencer” Zhu, a graduate student in the Department of Chemical Engineering; Mayuran Saravanapavanantham, Sarah Spector, Roberto Brenes, and Peter Satterthwaite, all EECS graduate students; Zheng Li, an RLE postdoc; and Rajeev Ram, professor of electrical engineering. The research is published today in Nature Communications.

Tiny crystals, huge challenges

Integrating halide perovskites into on-chip nanoscale devices is extremely difficult using conventional nanoscale fabrication techniques. In one approach, a thin film of fragile perovskites may be patterned using lithographic processes, which require solvents that may damage the material. In another approach, smaller crystals are first formed in solution and then picked and placed from solution in the desired pattern.

In both cases there is a lack of control, resolution, and integration capability, which limits how the material can be extended to nanodevices,” Niroui says.

Instead, she and her team developed an approach to “grow” halide perovskite crystals in precise locations directly onto the desired surface where the nanodevice will then be fabricated.

Core to their process is to localize the solution that is used in the nanocrystal growth. To do so, they create a nanoscale template with small wells that contain the chemical process through which crystals grow. They modify the surface of the template and the inside of the wells, controlling a property known as “wettability” so a solution containing perovskite material won't pool on the template surface and will be confined inside the wells.

"Now, you have these very small and deterministic reactors within which the material can grow," she says.

And that is exactly what happens. They apply a solution containing halide perovskite growth material to the template and, as the solvent evaporates, the material grows and forms a tiny crystal in each well.

A versatile and tunable technique

The researchers found that the shape of the wells plays a critical role in controlling the nanocrystal positioning. If square wells are used, due to the influence of nanoscale forces, the crystals have an equal chance of being placed in each of the well's four corners. For some applications, that might be good enough, but for others, it is necessary to have a higher precision in the nanocrystal placement.

By changing the shape of the well, the researchers were able to engineer these nanoscale forces in such a way that a crystal is preferentially placed in the desired location.

As the solvent evaporates inside the well, the nanocrystal experiences a pressure gradient that creates a directional force, with the exact direction being determined using the well's asymmetric shape.

"This allows us to have very high precision, not only in growth, but also in the placement of these nanocrystals," Niroui says.

They also found they could control the size of the crystal that forms inside a well. Changing the size of the wells to allow more or less growth solution inside generates larger or smaller crystals.

They demonstrated the effectiveness of their technique by fabricating precise arrays of nanoLEDs. In this approach, each nanocrystal is made into a nanopixel which emits light. These high-density nanoLED arrays could be used for on-chip optical communication and computing, quantum light sources, microscopy, and high-resolution displays for augmented and virtual reality applications.

In the future, the researchers want to explore more potential applications for these tiny light sources. They also want to test the limits of how small these devices can be, and work to effectively incorporate them into quantum systems. Beyond nanoscale light sources, the process also opens up other opportunities for developing halide perovskite-based on-chip nanodevices.

Their technique also provides an easier way for researchers to study materials at the individual nanocrystal level, which they hope will inspire others to conduct additional studies on these and other unique materials.

> “As our work shows, it is critical to develop new engineering frameworks for integration of nanomaterials into functional nanodevices.

“Studying nanoscale materials through high-throughput methods often requires that the materials are precisely localized and engineered at that scale,” Jastrzebska-Perfect adds. “By providing that localized control, our technique can improve how researchers investigate and tune the properties of materials for diverse applications.”

“The team has developed a very clever method for deterministic synthesis of individual perovskite nanocrystals on substrates. They can control the exact placement of the nanocrystals in an unprecedented scale, thus enabling a platform for fabrication of highly efficient, nanoscale LEDs based on single nanocrystals,” says Ali Javey, professor of electrical engineering and computer sciences at the University of California at Berkeley, who was not involved with this research. “It is an exciting work as it overcomes a fundamental challenge in the field.”

This work was supported, in part, by the National Science Foundation and the MIT Center for Quantum Engineering. The fabrication and characterization procedures were carried out, in part, using MIT.nano's shared facilities.

Reference

On-site growth of perovskite nanocrystal arrays for integrated nanodevices
Patricia Jastrzebska-Perfect, Weikun Zhu, Mayuran Saravanapavanantham, Zheng Li, Sarah O. Spector, Roberto Brenes, Peter F. Satterthwaite, Rajeev J. Ram & Farnaz Niroui
Nature Communications volume 14, Article number: 3883 (2023) - Open Access

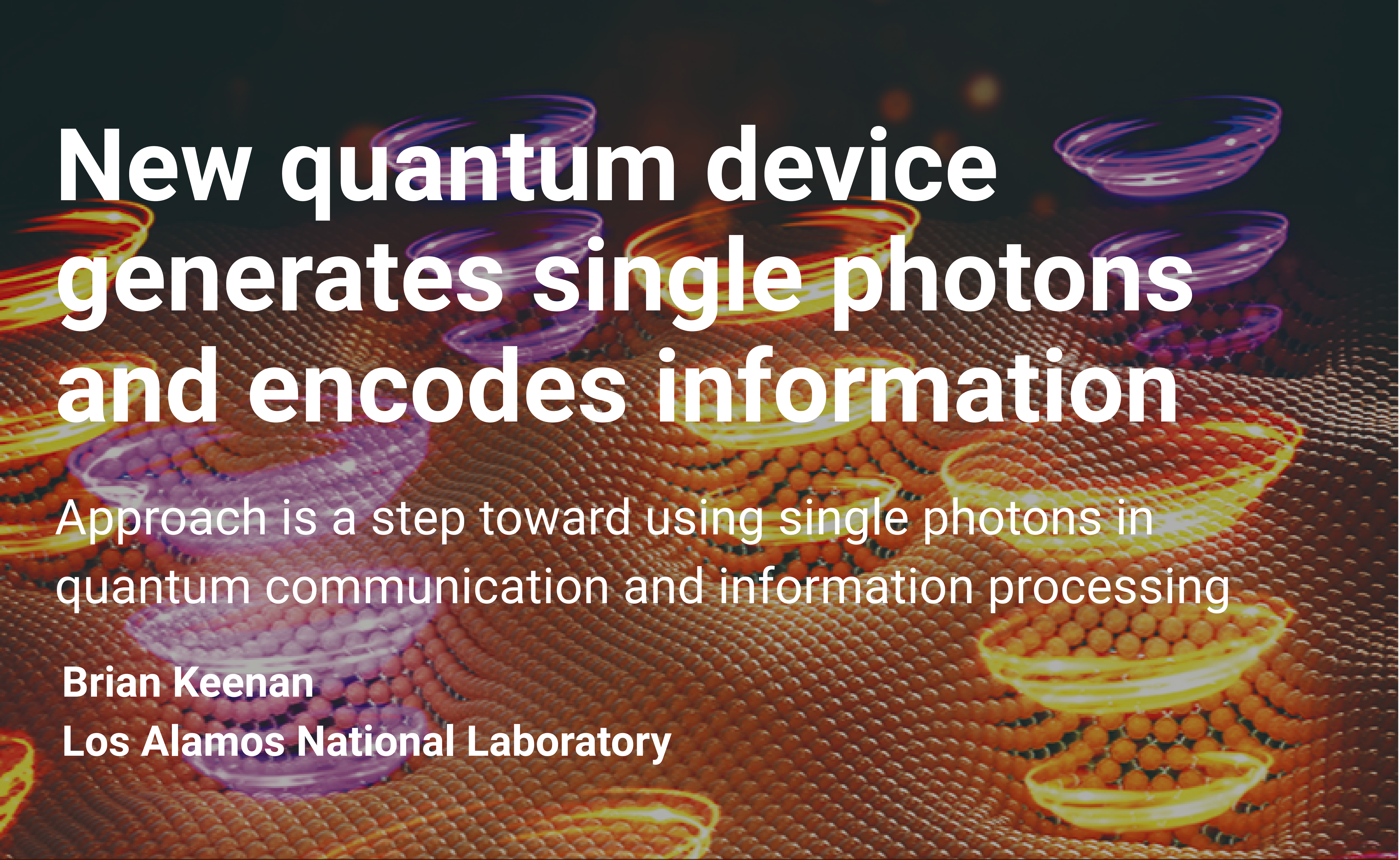
Image:

A new MIT platform enables researchers to “grow” halide perovskite nanocrystals with precise control over the location and size of each individual crystal, integrating them into nanoscale light-emitting diodes. Pictured is a rendering of a nanocrystal array emitting light.
Courtesy of Sampson Wilcox, RLE

New quantum device generates single photons and encodes information

Approach is a step toward using single photons in quantum communication and information processing

Brian Keenan
Los Alamos National Laboratory



Formed within wells indented into the stack of two different layered materials, a monolayer semiconductor and an anti-ferromagnetic crystal, the chiral quantum light emissions rise up out of the material and could be used for quantum information and communication applications.

A new approach to quantum light emitters generates a stream of circularly polarized single photons, or particles of light, that may be useful for a range of quantum information and communication applications. A Los Alamos National Laboratory team stacked two different atomically thin materials to realize this chiral quantum light source.

“Our research shows that it is possible for a monolayer semiconductor to emit circularly polarized light without the help of an external magnetic field,” said Han Htoon, scientist at Los Alamos National Laboratory. “This effect has only been achieved before with high magnetic fields created by bulky superconducting magnets, by coupling quantum emitters to very complex nanoscale photonics structures or by injecting spin-polarized carriers into quantum emitters. Our proximity-effect approach has the advantage of low-cost fabrication and reliability.”

The polarization state is a means of encoding the photon, so this achievement is an important step in the direction of quantum cryptography or quantum communication.

“With a source to generate a stream of single photons and also introduce polarization, we have essentially combined two devices in one,” Htoon said.

Indentation key to photoluminescence

As described in Nature Materials, the research team worked at the Center for Integrated Nanotechnologies to stack a single-molecule-thick layer of tungsten diselenide semiconductor onto a thicker layer of nickel phosphorus trisulfide magnetic semiconductor. Xiangzhi Li, postdoctoral research associate, used atomic force microscopy to create a series of nanometer-scale indentations on the thin stack of materials. The indentations are approximately 400 nanometers in diameter, so over 200 of such indents can easily be fit across the width of a human hair.

The indentations created by the atomic microscopy tool proved useful for two effects when a laser was focused on the stack of materials. First, the indentation forms a well, or depression, in the potential energy landscape. Electrons of the tungsten diselenide monolayer fall into the depression. That stimulates the emission of a stream of single photons from the well.

The nanoindentation also disrupts the typical magnetic properties of the underlying nickel phosphorus trisulfide crystal, creating a local magnetic moment pointing up out of the materials. That magnetic moment circularly polarizes the photons being emitted. To provide experimental confirmation of this mechanism, the team first performed high magnetic field optical spectroscopy experiments in collaboration with National High Magnetic Field Laboratory's Pulsed Field Facility at Los Alamos. The team then measured the minute magnetic field of the local magnetic moments in collaboration with the University of Basel in Switzerland.

The experiments proved that the team had successfully demonstrated a novel approach to control the polarization state of a single photon stream.

Encoding quantum information

The team is currently exploring ways to modulate the degree of circular polarization of the single photons with the application of electrical or microwave stimuli. That capability would offer a way to encode quantum information into the photon stream.

Further coupling of the photon stream into waveguides — microscopic conduits of light — would provide the photonic circuits that allow the propagation of photons in one direction. Such circuits would be the fundamental building blocks of an ultra-secure quantum internet.

Reference

Proximity-induced chiral quantum light generation in strain-engineered WSe2/NiPS3 heterostructures
Xiangzhi Li, Andrew C. Jones, Junho Choi, Huan Zhao, Vigneshwaran Chandrasekaran, Michael T. Pettes, Andrei Piryatinski, Märta A. Tschudin, Patrick Reiser, David A. Broadway, Patrick Maletinsky, Nikolai Sinitsyn, Scott A. Crooker & Han Htoon
Nature Materials (2023)

QTCAD: The world's first commercial finite-element modeling software for spin qubits

In May 2022, the Montreal-based software company Nanoacademic Technologies Inc. released its spin-qubit modeling tool QTCAD® to the quantum academic community.

After a few years of development, Nanoacademic's expertise in quantum transport simulations, large-scale atomistic software development, and computational quantum physics crystallized into an advanced simulation tool addressing the specific needs of quantum hardware designers. QTCAD® has been commercially available for a bit more than 1 year now for academic, government, and corporate quantum researchers worldwide and we are proud to count already several corporate and university customers in different countries in Europe and Asia. In addition to distributing this state-of-the-art code, Nanoacademic is now committed to supporting its customers' R&D by facilitating their quantum device design workflows and developing new QTCAD® features at an accelerated pace based on continuous feedbacks from its users and beta-testing partners.

What is the software QTCAD®?

Quantum-Technology Computer-Aided Design (hence "QTCAD®", a trademark of Nanoacademic Technologies Inc.) is a finite-element simulator used to predict the performance of spin-qubit devices at sub-kelvin temperatures before prototype and series manufacturing operations. This unique tool is a significant cost-saver enabling exploration of many design scenarios in semiconductors.

QTCAD® calculates the envelope functions and energy levels of electrons or holes confined in nanostructures within k•p theory using non-linear Poisson, Schrödinger, and many-body solvers. QTCAD® enables the prediction of key qubit performance metrics such as electron or hole confinement, charging energies in Coulomb blockade, or quantum-logic gate fidelity.

The development of QTCAD® critically benefitted from scientific collaborations with world-renowned organizations such as STMicroelectronics, Institut quantique, McGill University, the National Research

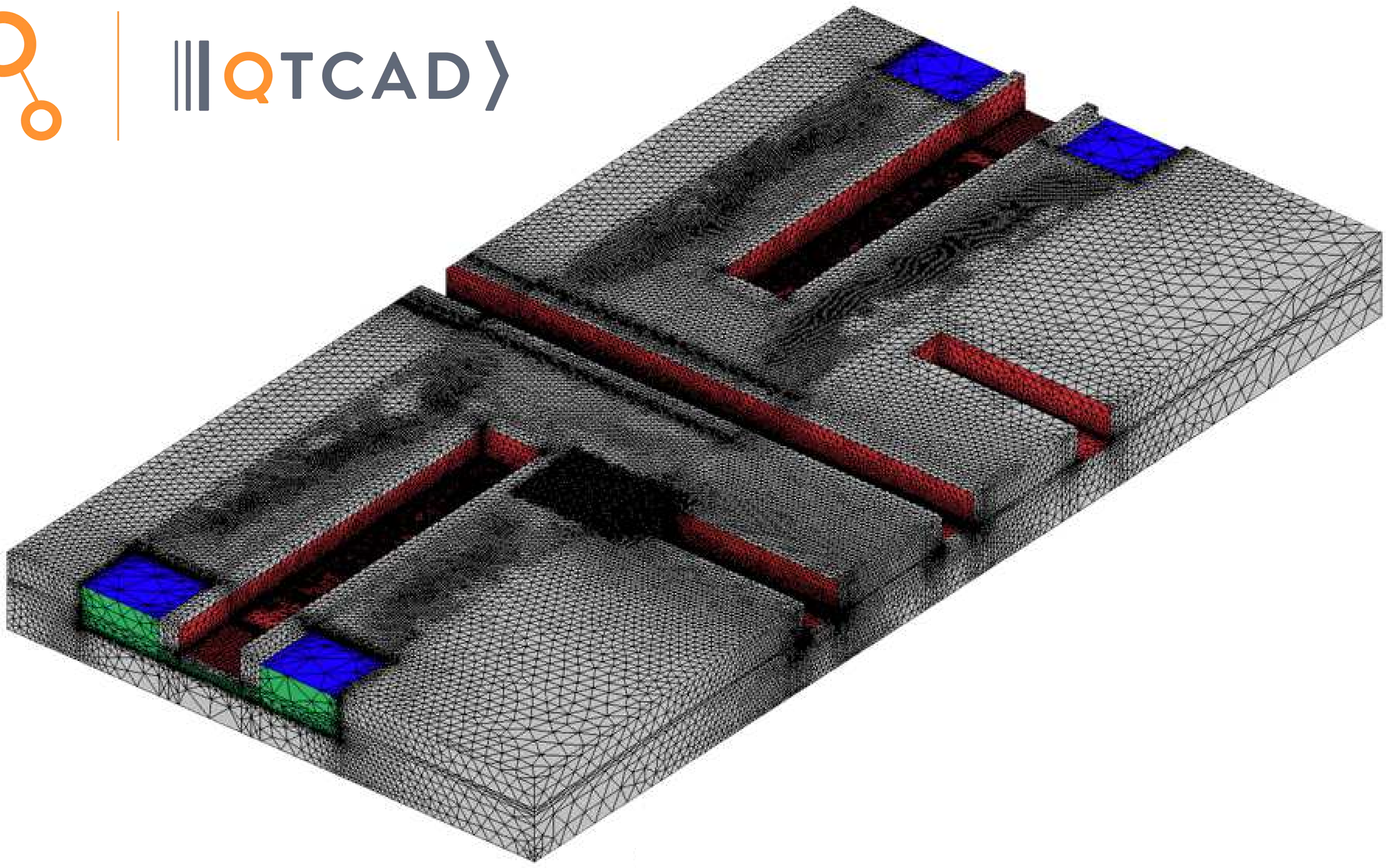


Fig 1: *3D CAD model of an industrially fabricated gated quantum dot device with adaptive meshing (UTBB FD-SOI 28nm transistor)*

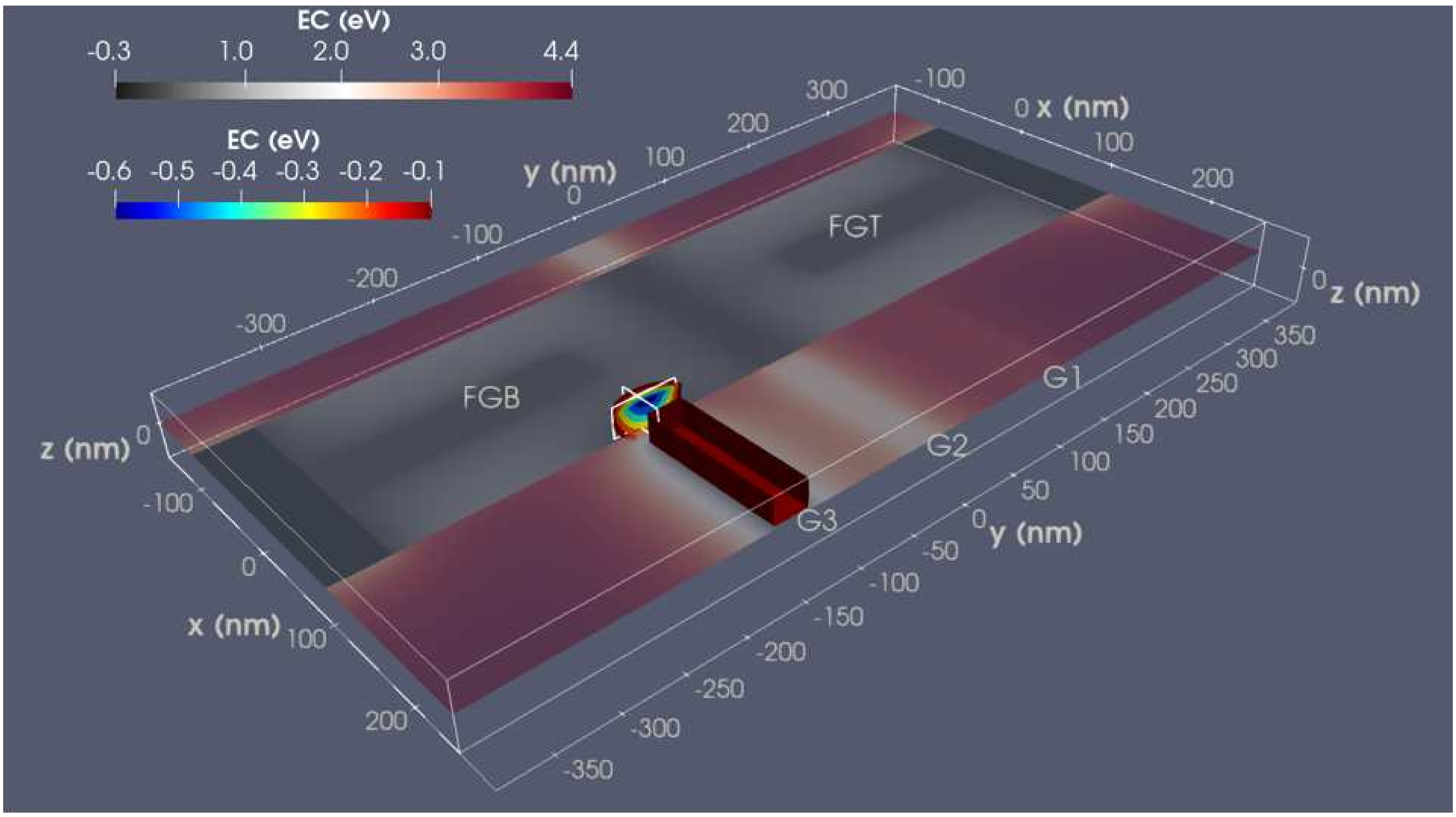


Fig 2: *QTCAD® simulation of the conduction band edge at cryogenic temperature (100 mK)*

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Council of Canada (NRC), Tohoku Institute of Technology and Osaka University. Most of these partnerships are still ongoing, with some additional ones (private companies and some famous National labs) under confidential terms (NDA), enabling to prioritize future feature developments and benchmark the code's performance in the very right hands.

QTCAD® has recently been under the spotlight in several scientific papers (published in Solid-State Electronics and Applied Physics Letters over the last 2 years with many others under review, links below [1], [2] [3] and [4]) in which the tool played a pivotal role in exploring the behavior of gated quantum dots in a standard-process 28-nm Ultra-Thin Body and Buried oxide (UTBB) Fully-Depleted Silicon-On-Insulator (FDSOI) transistor fabricated by STMicroelectronics in Grenoble, France, and characterized at cryogenic temperature at Institut quantique in Sherbrooke, Québec, Canada. In a nutshell, a realistic 3D Computer-Aided Design (CAD) model of the device was produced directly from its layout according to STMicroelectronics' design rules; QTCAD® was then used to elucidate the electrostatic properties of the structure at cryogenic temperatures and calculate confinement potentials (see figures 1 & 2).

Computing the corresponding electron wave functions led to a quantitative understanding of quantum confinement in the nanostructure, ultimately enabling the identification of design bottlenecks. In the near future, this shall result in improved designs with optimized gate geometries and bias configurations for a technology whose demonstrated performance at cryogenic temperature leads to several promising design applications.

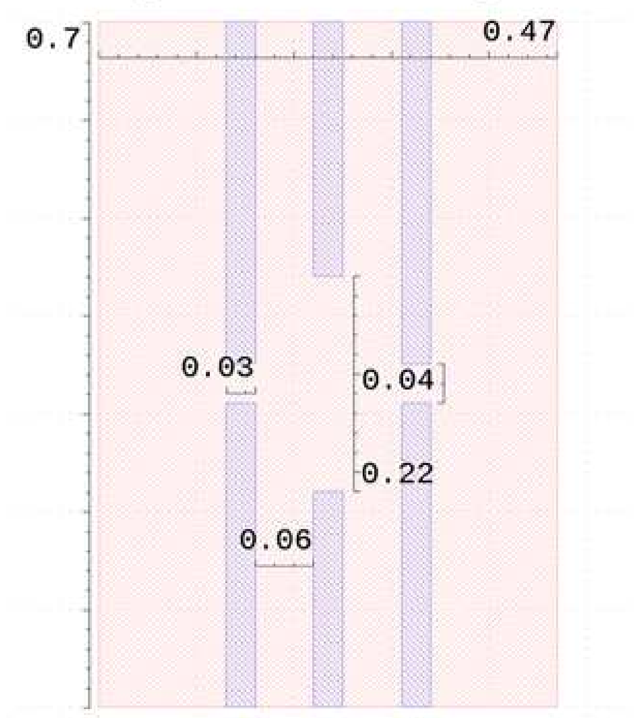
To help quantum engineers conveniently design the elementary components of future quantum technologies, QTCAD® includes several unique features that are necessary to capture operational principles of spin qubits. In particular, QTCAD® builds on Nanoacademic's open-source code devicegen, which automates 3D CAD model generation from layouts stored in conventional GDS files, thus supporting the implementation of scriptable and customizable simulation workflows. Following CAD model generation, a proprietary adaptive meshing technology enables robust convergence of device electrostatics at cryogenic temperatures at which spin qubits are operated, enabling to avoid a tedious and time-consuming manual meshing step. Electron or hole confinement potentials resulting from electrostatic calculations can then be used to solve single-particle and many-body wave functions to predict gate geometries and bias configurations leading to the formation of several quantum dots. Finally, QTCAD® includes specialized solvers to simulate several important phenomena such as

Coulomb blockade, electrostatic effects from parasitic surface charges, strain effects, magnetic effects from orbital or Zeeman terms, spin-orbit coupling, electronic dipole spin resonance (EDSR), and more. Ultimately, QTCAD® enables to go all the way from device layout to meaningful qubit performance metrics such as the quantum-logic gate fidelity or the Rabi oscillation rate (see figures below).

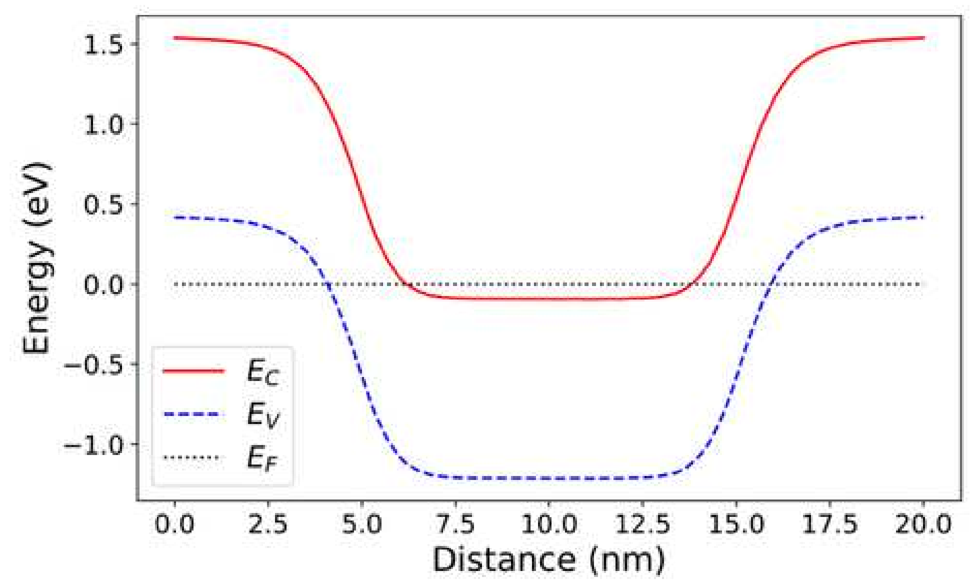
QTCAD® is professionally developed, maintained, and continuously improved and supplemented with additional features thanks to user feedback, and a dedicated team of research scientists and software developers.

We offer single-user and research group licenses to fit quantum scientists' needs, and system configuration-wise, a good laptop or average workstation can run QTCAD® and get reasonable convergence times. In the next release (v1.3) planned for Fall 2023, the code will be significantly upgraded again to improve its predictive performance with among other additions, exchange interaction feature for both electrons and holes and support of transport simulations for holes. We are still closely working with some beta-testing groups around the planet who benefit first from these new features. Note that we are open to extending the beta-testers club so please contact us to discuss and review your objectives.

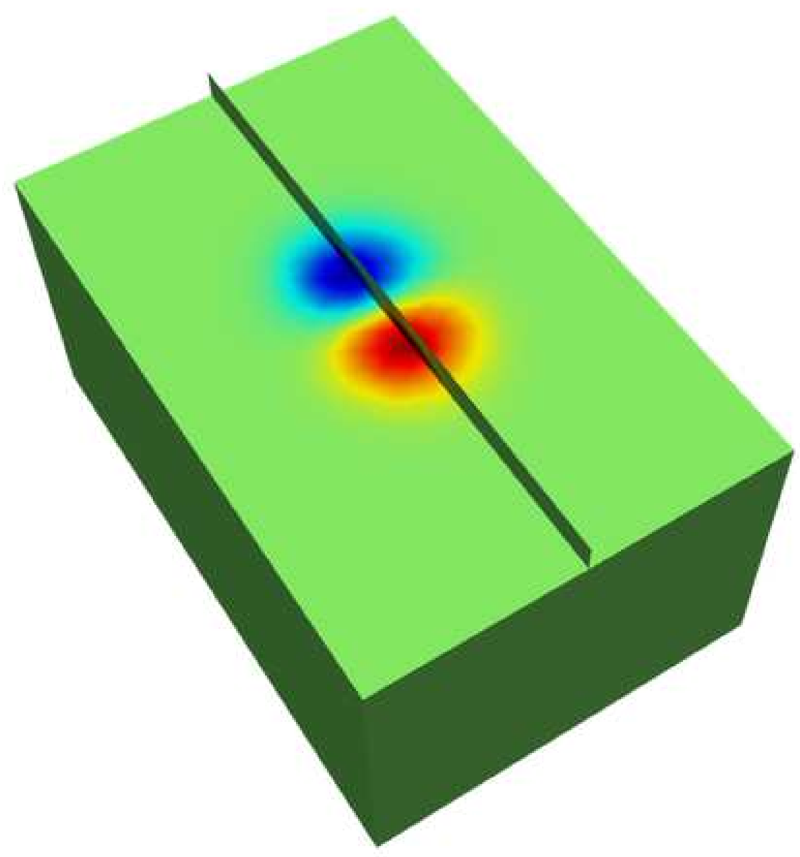
Start from a GDS layout



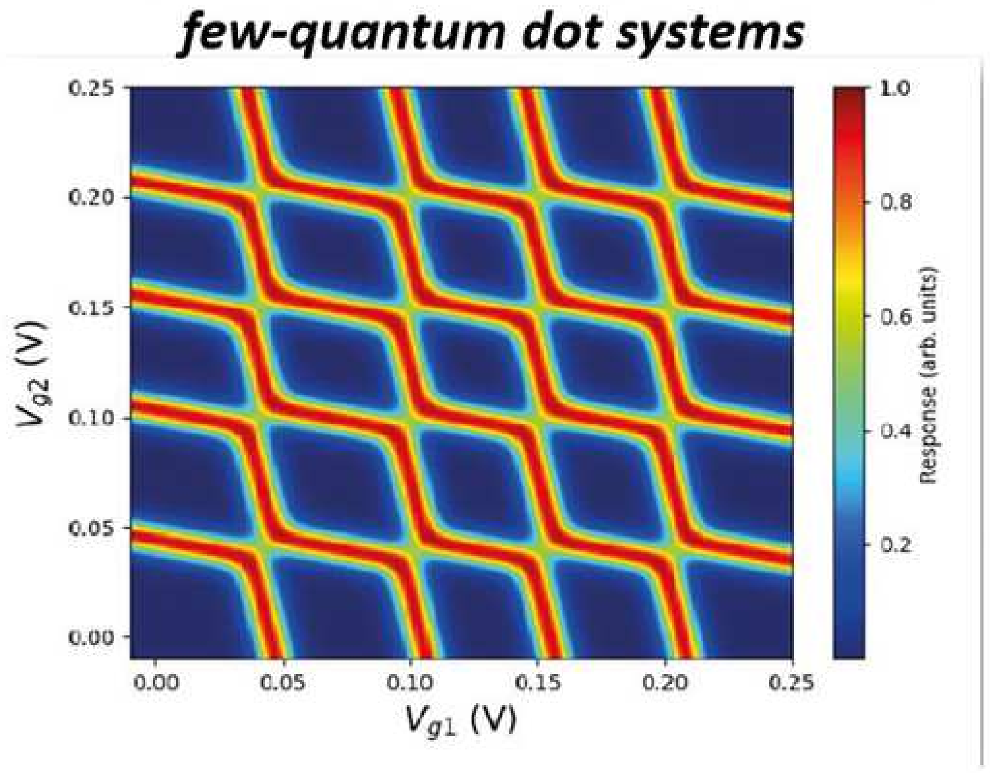
Calculate electron or hole confinement potentials



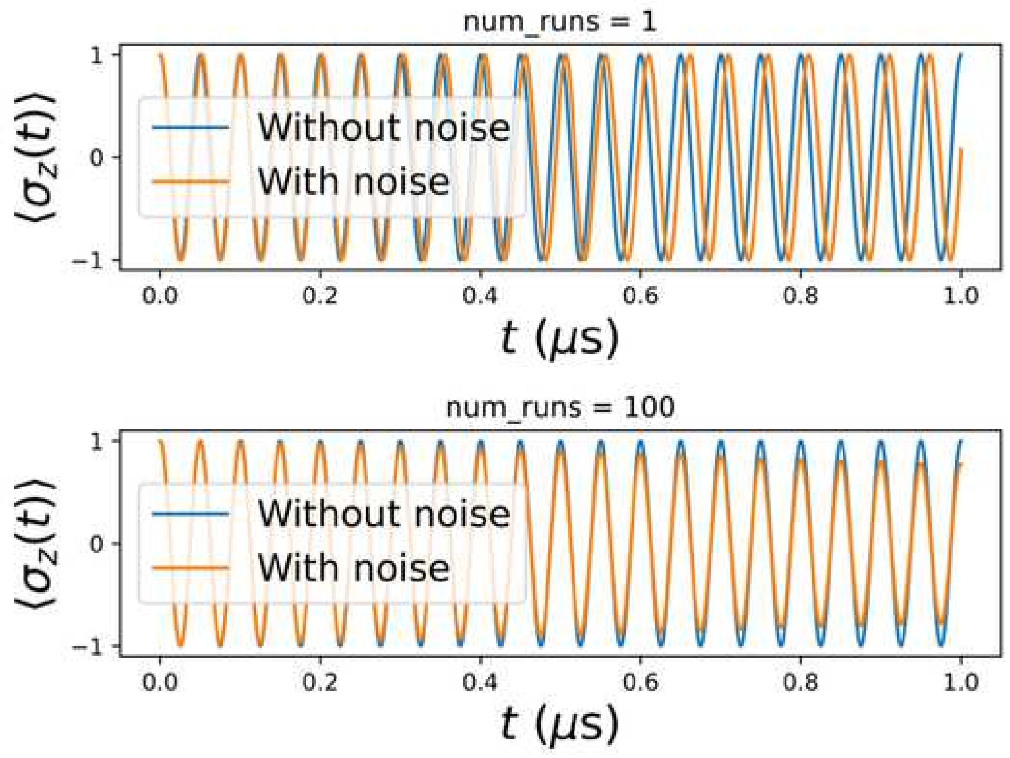
Solve for wave functions



Compute charge-stability diagrams of few-quantum dot systems



Simulate quantum-logic gates



QTCAD

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As a reminder, last version of QTCAD® (v1.2.2 now) consisted mainly of the following updates: cross-capacitance effects between dots, a streamlined and accelerated workflow for charge stability diagrams in multiple dot systems, a quantum well solver for more accurate description of quantum confinement in source and drain reservoirs, a strain feature required for accurate electronic structure calculations in many state-of-the-art systems such as Si/SiGe heterostructures.

Through the development and commercialization of QTCAD®, Nanoacademic aims to set the reference for computer-aided design of quantum hardware. Akin to TCAD software in the semiconductor industry, we believe that QTCAD® will lead to tighter sample design that will reduce trial and error and shorten prototype turnover, ultimately accelerating the development of world-changing quantum technologies.

Furthermore, we have on-going developments and roadmaps to extend this tool far beyond its current reach, scale-wise and technology-wise using advanced and innovative methods, involving some of our other DFT-based codes to provide our users with a multi-scale approach and a much deeper understanding of materials structures in quantum systems.

To learn how to benefit from this unique tool, we invite academic and industrial spin-qubit designers to download a free 30-day trial version available on our Client Portal and get acquainted with the software by exploring the extensive collection of tutorials (we update with new ones on a regular basis) presented in our online documentation.

Further information:

www.nanoacademic.com
Documentation portal to QTCAD®

References

[1] **Solid-State Electronics (2022)**
Interpretation of 28 nm FD-SOI quantum dot transport data taken at 1.4 K using 3D quantum TCAD simulations

[2] **Applied Physics Letters (2022)**
Robust technology computer-aided design of gated quantum dots at cryogenic temperature

[3] **Solid-State Electronics (2023)**
Understanding conditions for the single electron regime in 28 nm FD-SOI quantum dots: Interpretation of experimental data with 3D quantum TCAD simulations

[4] **Nature (2024) Under review**
Single PbS colloidal quantum dot transistor

IBM Quantum:
IBM is a trailblazer in quantum computing, offering cloud-based access to quantum processors and simulators to organizations and individuals.

Google Quantum AI:
Google's Quantum AI team achieved quantum supremacy by demonstrating that their quantum processor could perform a task faster than the world's most powerful supercomputers.

Rigetti Computing:
Rigetti focuses on providing access to quantum computers through its cloud-based platform, Forest.

IonQ:
IonQ is a frontrunner in trapped-ion quantum computing, aiming to build the world's first practical quantum computer.

Honeywell Quantum Solutions:
Honeywell leverages its expertise in precision control systems to develop quantum hardware.

D-Wave Systems:
D-Wave is a pioneer in quantum annealing, a form of quantum computing tailored for optimization problems.

Microsoft Quantum:
Microsoft's quantum efforts are centered around the development of a topological qubit, known for its potential stability against decoherence.

Zapata Computing:
Zapata focuses more on quantum software, offering tools and platforms for quantum algorithm development.

PsiQuantum:
PsiQuantum is working on building fault-tolerant, large-scale quantum computers using photon-based qubits.

Xanadu:
Xanadu specializes in quantum photonic hardware and software.

Entangled quantum circuits

ETH Zurich researchers have succeeded in demonstrating that quantum mechanical objects that are far apart can be much more strongly correlated with each other than is possible in conventional systems. For this experiment, they used superconducting circuits for the first time.

Felix Würsten | ETH Zurich

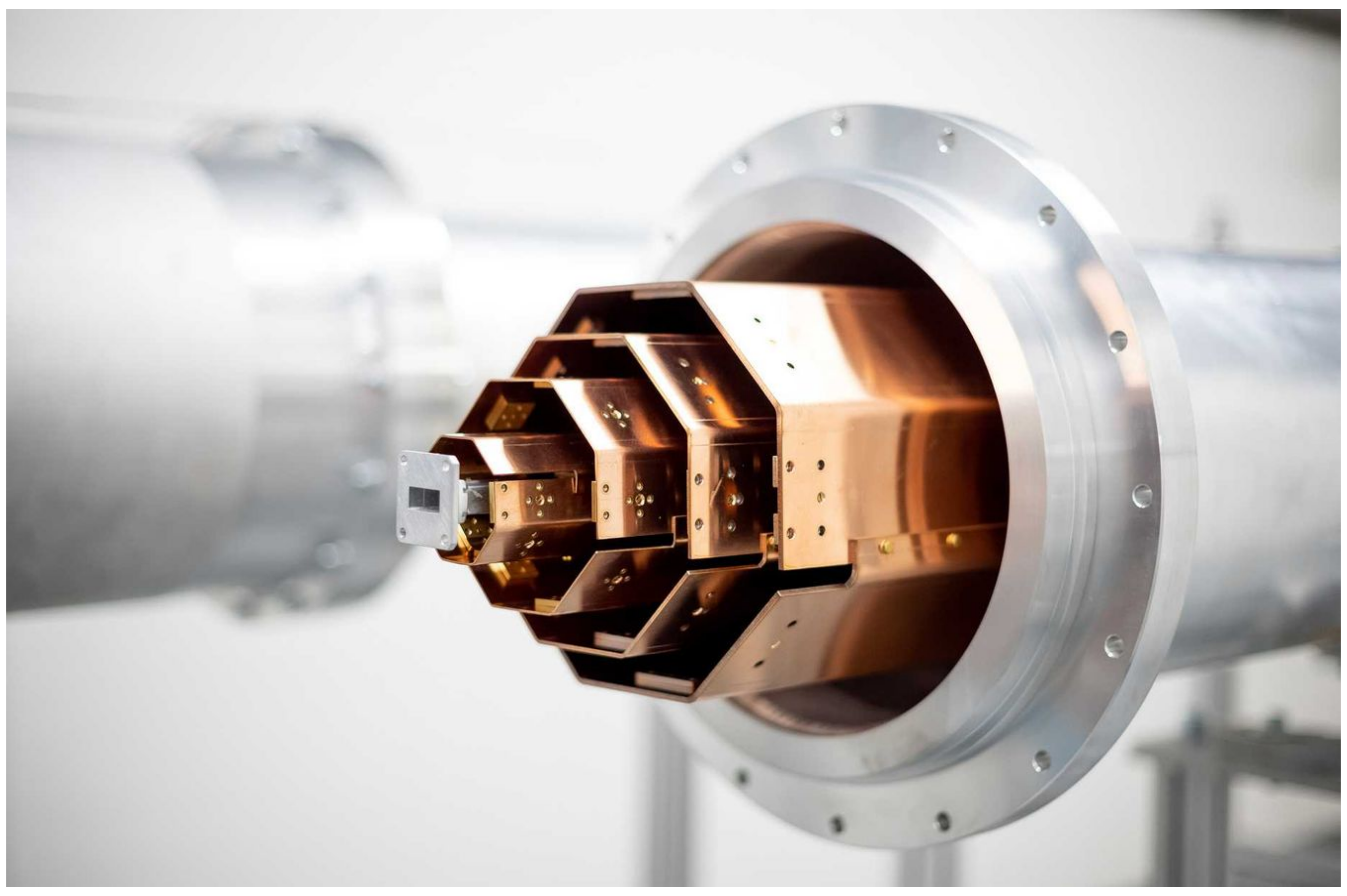
Partial section of the 30-metre-long quantum connection between two superconducting circuits. The vacuum tube (centre) contains a microwave waveguide that is cooled to around –273°C and connects the two quantum circuits. (Photograph: ETH Zurich / Daniel Winkler)

A group of researchers led by Andreas Wallraff, Professor of Solid State Physics at ETH Zurich, has performed a loophole-free Bell test to disprove the concept of "local causality" formulated by Albert Einstein in response to quantum mechanics. By showing that quantum mechanical objects that are far apart can be much more strongly correlated with each other than is possible in conventional systems, the researchers have provided further confirmation for quantum mechanics. What's special about this experiment is that the researchers were able for the first time to perform it using superconducting circuits, which are considered to be promising candidates for building powerful quantum computers.

An old dispute

A Bell test is based on an experimental setup that was initially devised as a thought experiment by British physicist John Bell in the 1960s. Bell wanted to settle a question that the greats of physics had already argued about in the 1930s: Are the predictions of quantum mechanics, which run completely counter to everyday intuition, correct, or do the conventional concepts of causality also apply in the atomic microcosm, as Albert Einstein believed?

To answer this question, Bell proposed to perform a random measurement on two entangled particles at the same time and check it against Bell's inequality. If Einstein's concept of local causality is true, these experiments will always satisfy Bell's inequality. By contrast, quantum mechanics predicts that they will violate it.



A view inside a section of the 30-metre-long quantum connection. An aluminium waveguide (centre), cooled to almost absolute zero, connects the two quantum circuits. Several layers of copper shielding protect the conductor from thermal radiation.

The last doubts dispelled

In the early 1970s, John Francis Clauser, who was awarded the Nobel Prize in Physics last year, and Stuart Freedman carried out a first practical Bell test. In their experiments, the two researchers were able to prove that Bell's inequality is indeed violated. But they had to make certain assumptions in their experiments to be able to conduct them in the first place. So, theoretically, it might still have been the case that Einstein was correct to be sceptical of quantum mechanics.

Over time, however, more and more of these loopholes could be closed. Finally, in 2015, various groups succeeded in conducting the first truly loophole-free Bell tests, thus finally settling the old dispute.

Promising applications

Wallraff's group can now confirm these results with a novel experiment. The work by the ETH researchers published in the renowned scientific journal Nature shows that research on this topic is not concluded, despite the initial confirmation seven years ago. There are several reasons for this. For one thing, the ETH researchers' experiment confirms that superconducting circuits operate according to the laws of quantum mechanics too, even though they are much bigger than microscopic quantum objects such as photons or ions. The several hundred micrometre-sized electronic circuits made of superconducting materials and operated at microwave frequencies are referred to as macroscopic quantum objects.

For another thing, Bell tests also have a practical significance. “Modified Bell tests can be used in cryptography, for example, to demonstrate that information is actually transmitted in encrypted form,” explains Simon Storz, a doctoral student in Wallraff’s group. “With our approach, we can prove much more efficiently than is possible in other experimental setups that Bell’s inequality is violated. That makes it particularly interesting for practical applications.”

The search for a compromise

However, the researchers need a sophisticated test facility for this. Because for the Bell test to be truly loophole-free, they must ensure that no information can be exchanged between the two entangled circuits before the quantum measurements are complete. Since the fastest that information can be transmitted is at the speed of light, the measurement must take less time than it takes a light particle to travel from one circuit to another.

So, when setting up the experiment, it’s important to strike a balance: the greater the distance between the two superconducting circuits, the more time is available for the measurement – and the more complex the experimental setup becomes. This is because the entire experiment must be conducted in a vacuum near absolute zero.

The ETH researchers have determined the shortest distance over which to perform a successful loophole-free Bell test to be around 33 metres, as it takes a light particle about 110 nanoseconds to travel this distance in a vacuum. That’s a few nanoseconds more than it took the researchers to perform the experiment.

Thirty-metre vacuum

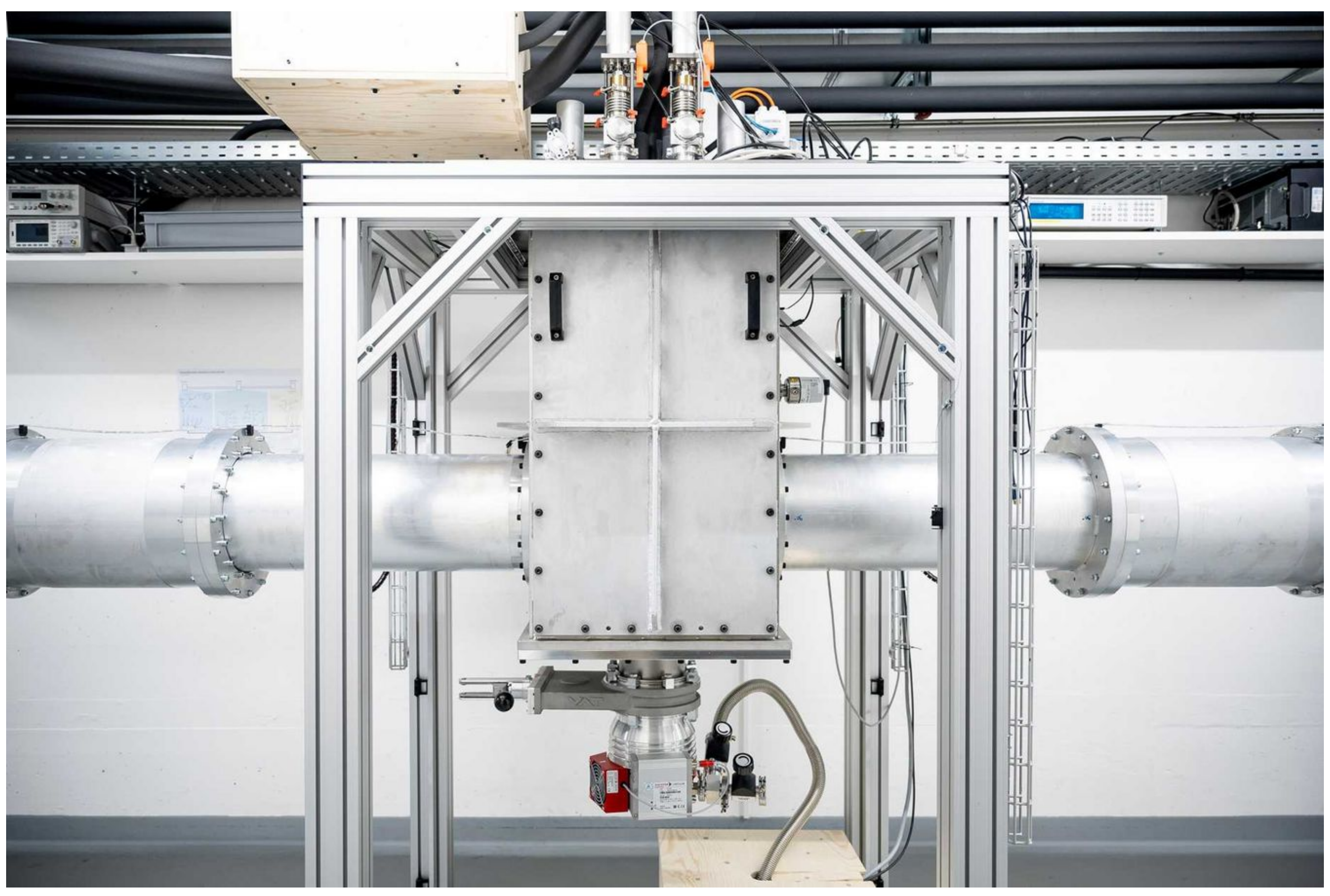
Wallraff’s team has built an impressive facility in the underground passageways of the ETH campus. At each of its two ends is a cryostat containing a superconducting circuit. These two cooling apparatuses are connected by a 30-metre-long tube whose interior is cooled to a temperature just above absolute zero (–273.15°C).

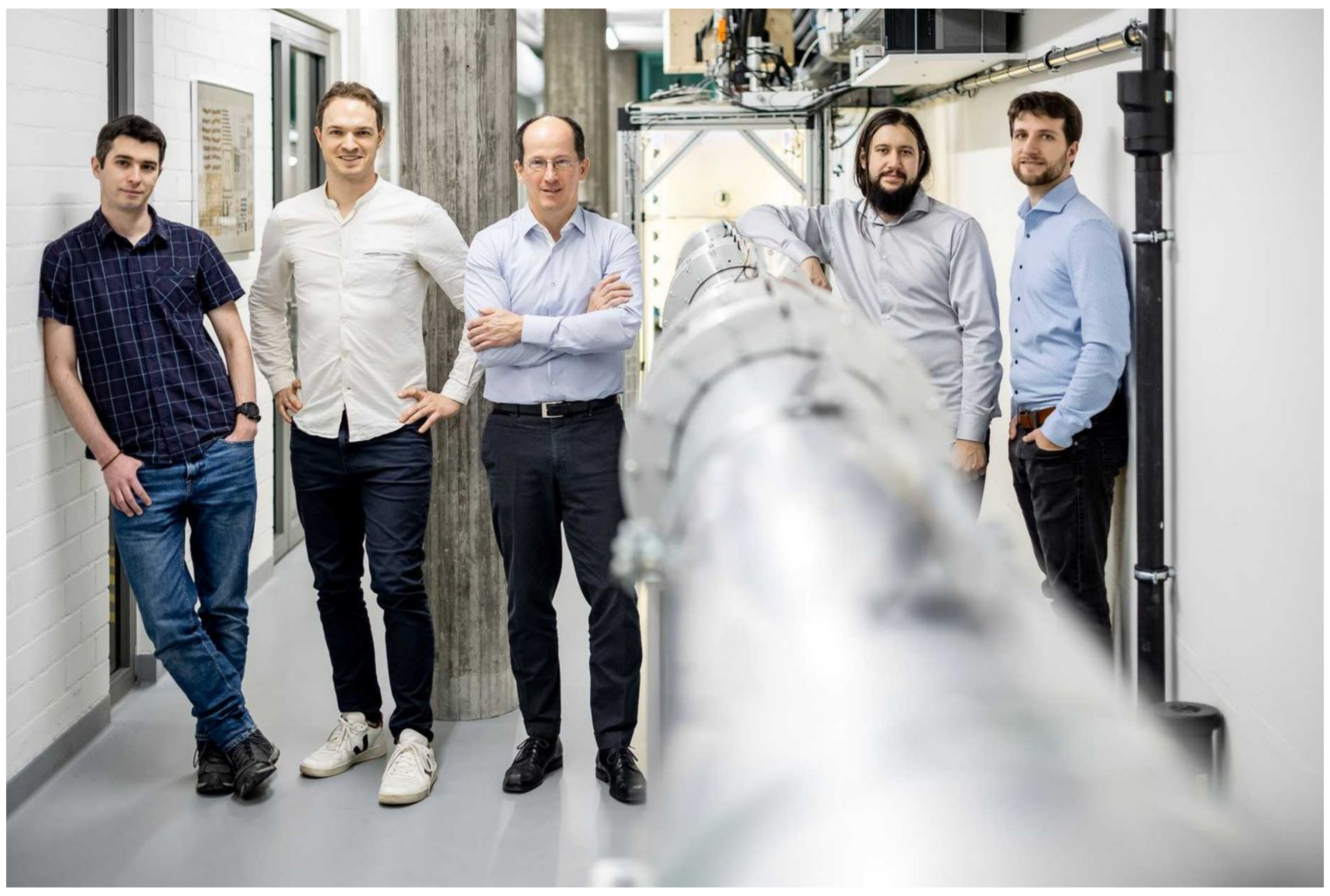
Before the start of each measurement, a microwave photon is transmitted from one of the two superconducting circuits to the other so that the two circuits become entangled. Random number generators then decide which measurements are made on the two circuits as part of the Bell test. Next, the measurement results on both sides are compared.

Large-scale entanglement

After evaluating more than one million measurements, the researchers have shown with very high statistical certainty that Bell’s inequality is violated in this experimental setup. In other words, they have confirmed that quantum mechanics also allows for non-local correlations in macroscopic electrical circuits and consequently that superconducting circuits can be entangled over a large distance. This opens up interesting possible applications in the field of distributed quantum computing and quantum cryptography.

Building the facility and carrying out the test was a challenge, Wallraff says. “We were able to finance the project over a period of six years with funding from an ERC Advanced Grant.” Just cooling the entire experimental setup to a temperature close to absolute zero takes considerable effort. “There are 1.3 tonnes of copper and 14,000 screws in our machine, as well as a great deal of physics knowledge and engineering know-how,” Wallraff says. He believes that it would in principle be possible to build facilities that overcome even greater distances in the same way. This technology could, for instance, be used to connect superconducting quantum computers over great distances.





The core team from the Quantum Device Laboratory at ETH Zurich who performed the experiment. From left to right: Anatoly Kulikov, Simon Storz, Andreas Wallraff, Josua Schär, Janis Lütolf.

Loophole-free Bell inequality violation with superconducting circuits
Simon Storz, Josua Schär, Anatoly Kulikov, Paul Magnard, Philipp Kurpiers, Janis Lütolf, Theo Walter, Adrian Copetudo, Kevin Reuer, Abdulkadir Akin, Jean-Claude Besse, Mihai Gabureac, Graham J. Norris, Andrés Rosario, Ferran Martin, José Martinez, Waldimar Amaya, Morgan W. Mitchell, Carlos Abellan, Jean-Daniel Bancal, Nicolas Sangouard, Baptiste Royer, Alexandre Blais & Andreas Wallraff
Nature volume 617, pages265–270 (2023)

Photograph: Daniel Winkler

ETH Zurich

The researchers have developed their own cryostat to cool the 30-metre-long quantum connection efficiently. This is installed in the middle of the quantum link.

Preparing for a quantum leap: researchers chart future for use of quantum computing in particle physics

Today, researchers have published an important white paper identifying activities in particle physics where burgeoning quantum-computing technologies could be applied. The paper, authored by experts from CERN, DESY, IBM Quantum and over 30 other organisations, is now available on ArXiv.

With quantum-computing technologies rapidly improving, the paper sets out where these could be applied within particle physics, in order to help tackle computing challenges related not only to the Large Hadron Collider's ambitious upgrade programme, but also to other colliders and low energy experiments worldwide.

The paper was produced by a working group set up at the first-of-its-kind "QT4HEP" conference, held at CERN last November. Over the last eight months, the 46 people in this working group have worked hard to identify areas where quantum-computing technologies could provide a significant boon.

The areas identified relate to both theoretical and experimental particle physics. The paper then maps these areas to "problem formulations" in quantum computing. This is an important step in ensuring that the particle physics community is well positioned to benefit from the massive potential of breakthrough new quantum computers when they come online.

"Quantum computing is very promising, but not every problem in particle physics is suited to this mode of computing," says Alberto Di Meglio, head of the CERN Quantum Technology Initiative (CERN QTI). "It's important to ensure that we are ready and that we can accurately identify the areas where these technologies have the potential to be most useful for our community."

In terms of theoretical particle physics, the authors identify promising areas related to evolution of the quantum states, lattice-gauge theory, neutrino oscillations, and quantum field theories in general as well.

The considered applications include quantum dynamics, hybrid quantum/classical algorithms for static problems in lattice gauge theory, optimisation, and classification. The lead authors of the paper CERN QTI's Alberto Di Meglio, DESY's Karl Jansen, and IBM Quantum's Ivano Tavernelli, state that "with quantum computing we address problems in those areas that are very hard – or even impossible to tackle with classical methods. "In this way," Jansen says, "we can explore the physical systems to which we still do not have access."

On the experimental side, the authors identify areas related to jet and track reconstruction, extraction of rare signals, for-and-beyond Standard Model problems, parton showers, and experiment simulation. These are then mapped to classification, regression, optimisation, and generation problems.

Members of the working group behind this paper will now begin a process of selecting specific use cases from the activities listed in the paper to be taken forward through the CERN's and DESY's participation in the IBM Quantum Network, and collaboration with IBM Quantum, under its "100x100 Challenge". IBM Quantum is long-standing collaborator to CERN QTI and the Center for Quantum Technologies and Applications (CQTA) at DESY.

Experts from CERN, DESY, IBM Quantum and others publish white paper identifying activities in particle physics that could benefit from the application of quantum-computing technologies

IBM's 100x100 Challenge will see the company provide a tool capable of calculating unbiased observables of circuits with 100 qubits and depth-100 gate operations in 2024. This will provide an important testbed for taking forward promising selected use cases, both from particle physics and other research fields.

The working group behind the paper will meet again at CERN for a special workshop on 16 and 17 November, immediately before the Quantum Techniques in Machine Learning Conference is held at the laboratory on 19-24 November.

"This white paper — and the many discussions we had as part of its creation — will be important in shaping the work to be carried out in CERN QTI's second phase, which was recently given support by the CERN Council," says Di Meglio, who also leads CERN's new IT Innovation section. "I'd like to thank all of the world-leading experts who contributed to this paper, which provides a thorough assessment of the potential of this game-changing new technology for our field."

IBM's 100x100 Challenge will see the company provide a tool capable of calculating unbiased observables of circuits with 100 qubits and depth-100 gate operations in 2024.

Quantum Computing for High-Energy Physics: State of the Art and Challenges. Summary of the QC4HEP Working Group
Alberto Di Meglio, Karl Jansen, Ivano Tavernelli, Constantia Alexandrou, Srinivasan Arunachalam, Christian W. Bauer, Kerstin Borras, Stefano Carrazza, Arianna Crippa, Vincent Croft, Roland de Putter, Andrea Delgado, Vedran Dunjko, Daniel J. Egger, Elias Fernandez-Combarro, Elina Fuchs, Lena Funcke, Daniel Gonzalez-Cuadra, Michele Grossi, Jad C. Halimeh, Zoe Holmes, Stefan Kuhn, Denis Lacroix, Randy Lewis, Donatella Lucchesi, Miriam Lucio Martinez, Federico Meloni, Antonio Mezzacapo, Simone Montangero, Lento Nagano, Voica Radescu, Enrique Rico Ortega, Alessandro Roggero, Julian Schuhmacher, Joao Seixas, Pietro Silvi, Panagiotis Spentzouris, Francesco Tacchino, Kristan Temme, Koji Terashi, Jordi Tura, Cenk Tuysuz, Sofia Vallecorsa, Uwe-Jens Wiese, Shinjae Yoo, Jinglei Zhang

arXiv:2307.03236 [quant-ph]
https://doi.org/10.48550/arXiv.2307.03236

Qubrid Joins NVIDIA Inception to Accelerate Hybrid Quantum-Classical Computing for AI
Qubrid, a leading quantum computing company solving complex real world problems using its hybrid quantum-classical computing cloud platform, algorithms, applications and research, today announced it has joined NVIDIA Inception, a program that supports companies innovating in artificial intelligence (AI), quantum computing, GPU computing and more.

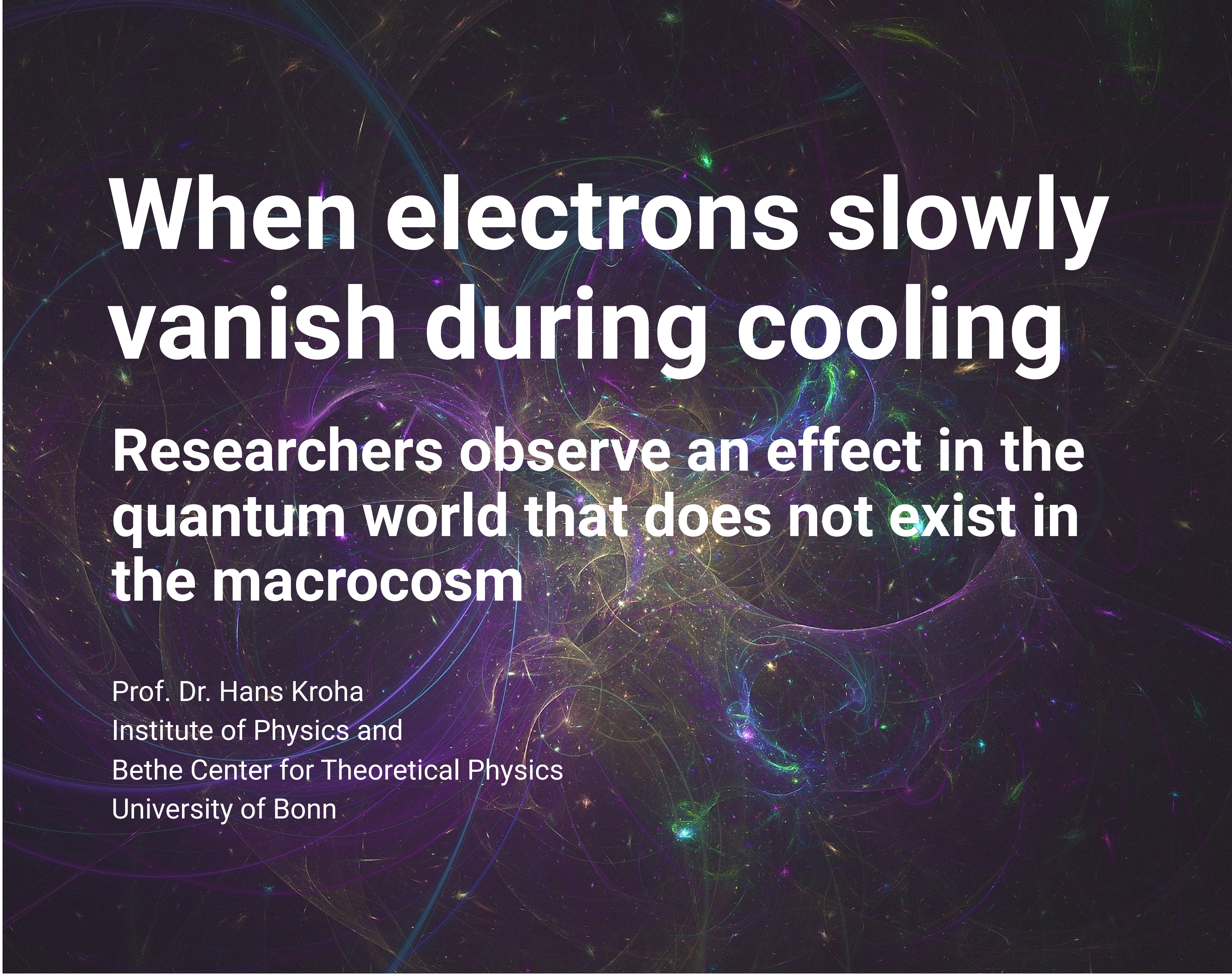
Google's Quantum Error Correction: Opening The Door
Google successfully used quantum error correction in practice, opening the door to large quantum computers with vast capabilities. The team used a surface code to improve qubit error rates and demonstrated that quantum error correction works in practice.

Quantum Computing Inc. Launches the First Quantum Photonic Vibrometer, Featuring Groundbreaking Capabilities in Detecting Highly Obscured and Non-Line-of-Sight Objects at Great Distances
The Quantum Photonic Vibrometer from Quantum Computing Inc. is a nanophotonic-based quantum technology for remote vibration detection, sensing, and inspection.

BMW Group, Airbus and Quantinuum Collaborate to Fast-Track Sustainable Mobility Research Using Cutting-Edge Quantum Computers
Airbus, BMW Group and Quantinuum, world leaders in mobility and quantum technologies, have developed a hybrid quantum-classical workflow to speed up future research using quantum computers to simulate quantum systems, focusing on the chemical reactions of catalysts in fuel cells.

A quantum leap in tech: Thales’ Chief Scientific Officer speaks
Thales, a company engaged in aerospace, defence, and security, is one of the entities actively investigating quantum technologies. With efforts in areas such as quantum sensing and quantum encryption, Thales is part of the broader industry movement exploring how these technologies might change the way we live and work.

IBM has just made error correction easier for quantum computers
The difficulty of quantum error correction has been a major stumbling block for quantum computers, but IBM researchers have developed a way to make it far more efficient.



When electrons slowly vanish during cooling

Researchers observe an effect in the quantum world that does not exist in the macrocosm

Prof. Dr. Hans Kroha
Institute of Physics and
Bethe Center for Theoretical Physics
University of Bonn

Many substances change their properties when they are cooled below a certain critical temperature. Such a phase transition occurs, for example, when water freezes. However, in certain metals there are phase transitions that do not exist in the macrocosm. They arise because of the special laws of quantum mechanics that apply in the realm of nature's smallest building blocks. It is thought that the concept of electrons as carriers of quantized electric charge no longer applies near these exotic phase transitions. Researchers at the University of Bonn and ETH Zurich have now found a way to prove this directly. Their findings allow new insights into the exotic world of quantum physics. The publication has now been released in the journal Nature Physics.

If you cool water below zero degrees Celsius, it solidifies into ice. In the process, it abruptly changes its properties. As ice, for example, it has a much lower density than in a liquid state - which is why icebergs float. In physics, this is referred to as a phase transition.

But there are also phase transitions in which characteristic features of a substance change gradually. If, for example, an iron magnet is heated up to 760 degrees Celsius, it loses its attraction to other pieces of metal - it is then no longer ferromagnetic, but paramagnetic. However, this does not happen abruptly, but continuously: The iron atoms behave like tiny magnets. At low temperatures, they are oriented parallel to each other. When heated, they fluctuate more and more around this rest position until they are completely randomly aligned, and the material loses its magnetism completely. So while the metal is being heated, it can be both somewhat ferromagnetic and somewhat paramagnetic.

Matter particles cannot be destroyed

The phase transition thus takes place gradually, so to speak, until finally all the iron is paramagnetic. Along the way, the transition slows down more and more. This behavior is characteristic of all continuous phase transitions. “We call it ‘critical slowing down,’“ explains Prof. Dr. Hans Kroha of the Bethe Center for Theoretical Physics at the University of Bonn. “The reason is that with continuous transitions, the two phases get energetically closer and closer together.”

It is similar to placing a ball on a ramp: it then rolls downhill, but the smaller the difference in altitude, the more slowly it rolls. When iron is heated, the energy difference between the phases decreases more and more, in part because the magnetization disappears progressively during the transition.

Such a “slowing down” is typical for phase transitions based on the excitation of bosons. Bosons are particles that “generate” interactions (on which, for example, magnetism is based). Matter, on the other hand, is not made up of bosons but of fermions. Electrons, for example, belong to the fermions.

Phase transitions are based on the fact that particles (or also the phenomena triggered by them) disappear. This means that the magnetism in iron becomes smaller and smaller as fewer atoms are aligned in parallel. “Fermions, however, cannot be destroyed due to fundamental laws of nature and therefore cannot disappear,” Kroha explains. “That’s why normally they are never involved in phase transitions.”

Electrons turn into quasi-particles

Electrons can be bound in atoms; they then have a fixed place which they cannot leave. Some electrons in metals, on the other hand, are freely mobile - which is why these metals can also conduct electricity. In certain exotic quantum materials, both varieties of electrons can form a superposition state. This produces what are known as quasiparticles. They are, in a sense, immobile and mobile at the same time – a feature that is only possible in the quantum world. These quasiparticles - unlike “normal” electrons - can be destroyed during a phase transition. This means that the properties of a continuous phase transition can also be observed there, in particular, critical slowing down.

So far, this effect could be observed only indirectly in experiments. Researchers led by theoretical physicist Hans Kroha and Manfred Fiebig’s experimental group at ETH Zurich have now developed a new method, which allows direct identification of the collapse of quasiparticles at a phase transition, in particular the associated critical slowing down.

“This has enabled us to show for the first time directly that such a slowdown can also occur in fermions,” says Kroha, who is also a member of the Transdisciplinary Research Area “Matter” at the University of Bonn and the Cluster of Excellence “Matter and Light for Quantum Computing” of the German Research Foundation. The result contributes to a better understanding of phase transitions in the quantum world. On the long term, the findings might also be useful for applications in quantum information technology.

The study was carried out in collaboration of ETH Zurich and the University of Bonn. The work was funded by the Swiss National Science Foundation (SNF) and the German Research Foundation (DFG).

Critical slowing down near a magnetic quantum phase transition with fermionic breakdown
Chia-Jung Yang, Kristin Kliemt, Cornelius Krellner, Johann Kroha, Manfred Fiebig & Shovon Pal
Nature Physics (2023)

University of Bonn

InstituteQ launches new doctoral school in quantum technology

The Finnish quantum community InstituteQ received funds to boost doctoral education in quantum science and technology. The Doctoral School in Quantum Technology and the industrial doctorates are now in operation, further integrating academy and industry while researching topics such as quantum computers, photonics and quantum materials

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— Future-shaping projects

THE MEANING OF QUANTUM

Three perspectives on working within the quantum sector

The legendary theoretical physicist Richard Feynman once said: "I think I can safely say that no one understands quantum mechanics."

In reality, Feynman probably understood quantum physics better than most people alive at that time. But he was making a point: the quantum universe is mysterious, complex, and counterintuitive.

Describing quantum systems and explaining how they might change the world is, therefore, no easy task. But for Clément Brauner, managing consultant in emerging technologies and quantum at Capgemini Invent, Iftikhar Ahmed, senior business enterprise architect at Capgemini, and Franziska Wolff, quantum technology consultant and project manager with Capgemini Engineering, it's all in a day's work.

The quantum conundrum
Clément Brauner, managing consultant in emerging technologies and quantum at Capgemini Invent

Enter the quantum labyrinth
Iftikhar Ahmed, senior business enterprise architect at Capgemini

Inventing quantum vaccines
Franziska Wolff, quantum technology consultant and project manager with Capgemini Engineering

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‘Strange metal’ sends quantum researchers in circles

By Jim Shelton, Yale

A Yale-led team of physicists has discovered a circular pattern in the movement of electrons in a group of quantum materials known as “strange metals.”

“Strange metal,” that rogue phenomenon of the electrical realm, just became a little less enigmatic.

Identified more than 40 years ago, strange metal is a state of matter found in many quantum materials — including certain superconductors that scientists say may be vital for high-tech products of the future. The “strange” part of strange metal is its electrons: they defy the traditional rules for electron movement and conductivity.

(Generative AI image)

Unlike most metals, in which electrical resistance increases with the square of temperature, strange metals have an electrical resistance that increases in proportion to temperature. This "linear-in-temperature" behavior defies physicists' understanding of how electrons move in solids.

"This strange metal behavior is seen in many different materials, where at first glance, you wouldn't think there is anything that ties them together," said Eduardo H. da Silva Neto, an assistant professor of physics in Yale's Faculty of Arts and Sciences and corresponding author of a new study in the journal Science Advances. "Most of the previous work investigating the strange metal phenomenon has focused on its 'symptoms' — its linear temperature resistance, for instance — rather than directly measuring the exact movement between electrons."

There is no established theory for the strange metal phenomenon, da Silva Neto said, but most researchers believe that the linear-in-temperature behavior results from electrons that must be able to scatter in all directions. However, in the study, da Silva Neto and his colleagues found a discernable, circular scattering pattern in the way electrons move within strange metal.

The new study is an extension of da Silva Neto's earlier work examining electron interactions in copper oxides. In that work, he and his colleagues discovered a similar circular pattern. Using a method called resonant inelastic X-ray scattering (RIXS), they saw that electrons created fluctuating waves of electrical charge in all directions.

"What we realized was that our previous results in 2021 could be relevant to understanding strange metal," da Silva Neto said. "However, for our circular pattern to be relevant for the strange metal phenomenon, we had to show that these circles existed at low energies."

For the new study, the researchers devised a methodology for directly measuring electron scattering at low energy in strange metal. They used state-of-the-art RIXS instruments at the National Synchrotron Light Source II at Brookhaven National Laboratory and at Diamond Light Source in England.

The next step for researchers is to measure electron movement in more examples of strange metal.

"Strange metal seems to be inexorably connected to quantum materials with great societal benefit, potentially," said da Silva Neto, who is affiliated with the Energy Sciences Institute at Yale's West Campus. "Furthering our understanding of their behavior has importance both intellectually and in terms of practical applications."

Kirsty Scott, a Yale graduate student in physics, is first author of the new study. Co-authors include researchers from the University of California-San Diego, the Institut National de la Recherche Scientifique in Canada, and North Carolina State University.

Funding and resources for the study came, in part, from the National Science Foundation, the U.S. Department of Energy Office of Science, and the Alfred P. Sloan Fellowship.

Top Quantum Computing Stocks to Watch

Quantum computing, a rapidly-emerging technology that harnesses the laws of quantum mechanics, is gaining attention as potential big profits await companies in this field. While it's difficult to predict the ultimate winner, here are seven leading quantum computing stocks that investors should keep an eye on.

1. IonQ (IONQ)
IonQ is the only pure-play quantum computing investment available on a public stock exchange. Although the company has achieved impressive gains, there are risks associated with investing in a startup that currently has little revenue and no profits.

2. Nvidia (NVDA)
Nvidia, known for its dominant position in AI chip manufacturing, has made strides in the quantum computing industry. The company's collaboration with Quantum Machines resulted in the creation of DGX Quantum, the first system to combine GPUs and quantum computing. Given Nvidia's strong position in the GPU market, it is poised to benefit from the growth of quantum computing.

3. IBM (IBM)
IBM Quantum is the largest quantum computing fleet in the world, offering quantum hardware to developers through its IBM Quantum division. The company has also developed Qiskit Runtime, a quantum computing service that enables businesses to run algorithms at scale. With a wide customer base, including Fortune 500 companies, IBM has an advantage over smaller competitors.

4. Honeywell (HON)
Honeywell Quantum Solutions, now part of Quantinuum after a merger with Cambridge Quantum, is the world's largest integrated quantum computing company. The company aims to develop quantum applications in various industries, including pharmaceuticals, finance, defense, and more.

5. Microsoft (MSFT)
As a leader in the tech industry, Microsoft is actively involved in quantum computing. The company's Azure Quantum Cloud Service offers a comprehensive package of hardware, software, and solutions. Microsoft is also working on developing a fault-tolerant quantum machine capable of performing 1 quintillion operations with minimal errors.

6. Alphabet (GOOGL)
Alphabet, the parent company of Google, has been exploring quantum computing since 2018 with the release of its 72-qubit quantum processor, Bristlecone. In early 2023, Alphabet announced a breakthrough in solving the error problem associated with quantum computing. The company's technical expertise and innovative approach make it an attractive long-term investment option.

7. FormFactor (FORM)
FormFactor plays a crucial role in the quantum computing industry by providing cryogenic environments necessary for qubit and quantum processing unit development. Although it is a smaller company, its expertise in creating ultra-low temperatures and its involvement in quantum computer deployment make it an interesting player to watch.

While there are no guarantees, these top quantum computing stocks are likely to experience growth and be at the forefront of advancements in this groundbreaking field.

UT Photonics Experiment Resolves Quantum Paradox

It seems quantum mechanics and thermodynamics cannot be true simultaneously. In a new publication, UT researchers use photons in an optical chip to demonstrate how both theories can be true at the same time. They recently published their results in the scientific journal Nature Communications.

In quantum mechanics, time can be reversed and information is always preserved. That is, one can always find back the previous state of particles. It was long unknown how this could be true at the same time as thermodynamics. There, time has a direction and information can also be lost. "Just think of two photographs that you put in the sun for too long, after a while you can no longer distinguish them”, explains author Jelmer Renema.

There was already a theoretical solution to this quantum puzzle and even an experiment with atoms, but now the UT researchers have also demonstrated it with photons. “Photons have the advantage that it is quite easy to reverse time with them,” explains Renema. In the experiment, the researchers used an optical chip with channels through which the photons could pass. At first, they could determine exactly how many photons there were in each channel, but after that, the photons shuffled positions.

Entanglement of subsystems

"When we looked at the individual channels, they obeyed the laws of thermodynamics and built up disorder. Based on measurements on one channel, we didn't know how many photons were still in that channel, but the overall system was consistent with quantum mechanics", says Renema. The various channels – also known as subsystems – were entangled. The missing information in one subsystem 'disappears' to the other subsystem.

More information

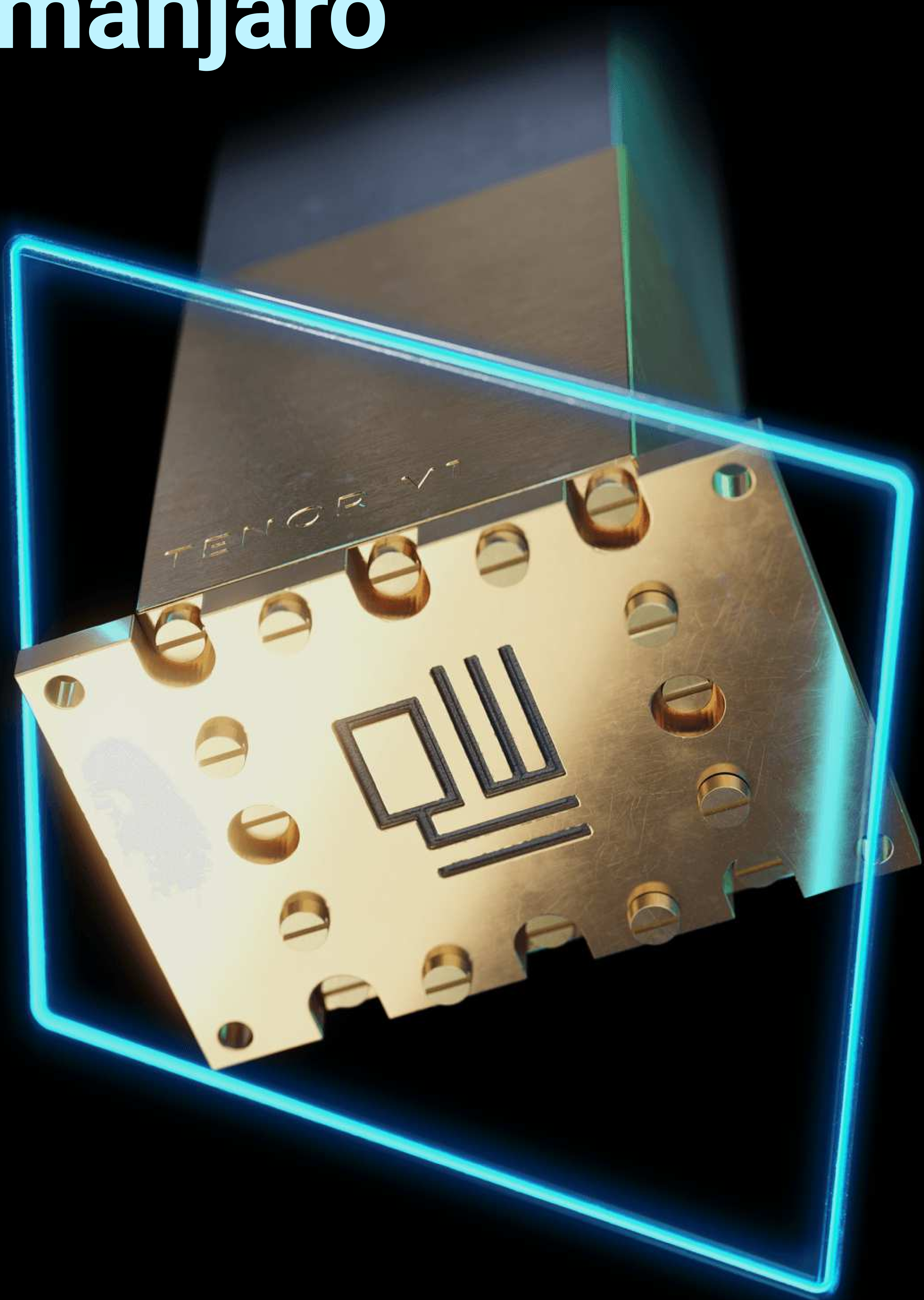
Dr. Jelmer Renema is assistant professor in the Adaptive Quantum Optics research group. He is also one of the featured scientists at the University of Twente. He did the research with a team, including the research group of Prof. Dr. Jens Eisert of the Freie Universität Berlin, who played an important role in demonstrating the reversibility of the experiment. They recently published their article entitled 'Quantum simulation of thermodynamics in an integrated quantum photonic processor' in the scientific journal Nature Communications.

Quantum simulation of thermodynamics in an integrated quantum photonic processor

F. H. B. Somhorst, R. van der Meer, M. Correa Anguita, R. Schadow, H. J. Snijders, M. de Goede, B. Kassenberg, P. Venderbosch, C. Taballione, J. P. Epping, H. H. van den Vlekkert, J. Timmerhuis, J. F. F. Bulmer, J. Lugani, I. A. Walmsley, P. W. H. Pinkse, J. Eisert, N. Walk & J. J. Renema
Nature Communications volume 14, Article number: 3895 (2023)

Photons have the advantage that it is quite easy to reverse time with them

Quantware's Soprano Qpu Powers Spain's First Working Quantum Computer Built By Qilimanjaro



QuantWare, a global leader in superconducting quantum processors, proudly announces the successful activation of its 5-qubit Soprano quantum processor at Qilimanjaro's facilities, situated within Barcelona's renowned Quantum Computing Technology laboratory of the Institut de Fisica d'Altes Energies (IFAE).

This seminal achievement marks the advent of Spain's inaugural quantum computer, built by a joint-venture between Qilimanjaro and GMV, and plays a crucial role in the ambitious quantum computing initiative pioneered by the Barcelona Supercomputing Center (BSC) and Quantum Spain.

In line with the emerging Open Architecture approach, in this project, Qilimanjaro integrates components from various suppliers to build the quantum computer. QuantWare's 5-qubit Soprano is a vital part of this quantum computer. This mirrors the successful model used in the creation of Israel's first quantum computer, which also utilizes QuantWare's quantum processors. Significantly, this project will be among the first worldwide where a quantum computer is integrated within a high-performance computing (HPC) system.

"QuantWare is thrilled to be at the heart of this landmark project, powering Spain's first quantum computer and initiating the Spanish ecosystem with an Open Architecture approach," said Matthijs Rijlaarsdam, CEO of QuantWare. "Thanks to our scalable technology, the consortium can quickly escalate the system's capabilities over time, promising the near-term integration of a quantum computer into one of Europe's leading HPC centers."

QuantWare is thrilled to be at the heart of this landmark project, powering Spain's first quantum computer and initiating the Spanish ecosystem with an Open Architecture approach.

Matthijs Rijlaarsdam, CEO of QuantWare

“This first delivery marks a significant moment as Qilimanjaro becomes the pioneer in providing access to the first quantum computer in Spain through an HPC center. We take immense pride in not only accomplishing this feat but also in partnering with an exceptional group of European providers, such as QuantWare”, said Marta Estarellas, CEO of Qilimanjaro, “Together, we have demonstrated the power of collaboration and innovation in pushing the boundaries of quantum technology.”

About QuantWare

QuantWare is striving to become the 'Intel of quantum computing', providing increasingly powerful and affordable quantum processors to organizations around the world and enabling them to build quantum computers for 1/10th the cost of competing solutions. Committed to an open architecture approach, QuantWare develops technology that will massively scale the number of qubits in a single processor, to create processors that can perform useful quantum computation in the near term.

www.QuantWare.eu

About Qilimanjaro

Qilimanjaro brings practical applications of quantum computing to the market in a shorter timeframe than digital quantum computers, by using a different but complementary model of quantum computation: the analog model. Qilimanjaro creates a coherent quantum annealer accessible via our cloud to run real-world applications such as optimisation tasks in the logistics, finance, and energy sector, among others, and quantum simulation of chemical and physical processes, very present in the materials and pharmaceutical research industries. Qilimanjaro aims at providing our clients with a faster, more accurate and sustainable solution to their computing problems.

www.qilimanjaro.tech

D-Wave Demonstrates First-Ever Coherent Quantum Spin Glass Dynamics on More than 5,000 Qubits

Evidence shows computational advantage, with quantum dynamics speedup over classical in 3D spin glasses, an intractable class of optimization problems

D-Wave, a leader in quantum computing systems, software, and services—and the only provider building both annealing and gate-model quantum computers, today published a peer-reviewed milestone paper showing the performance of its 5,000 qubit Advantage™ quantum computer is significantly faster than classical compute on 3D spin glass optimization problems, an intractable class of optimization problems. This paper also represents the largest programmable quantum simulation reported to date.

The paper---a collaboration between scientists from D-Wave and Boston University---entitled “Quantum critical dynamics in a 5,000-qubit programmable spin glass,” was published in the peer-reviewed journal Nature today and is available here. Building upon research conducted on up to 2,000 qubits last September, the study shows that the D-Wave quantum processor can compute coherent quantum dynamics in large-scale optimization problems. This work was done using D-Wave’s commercial-grade annealing-based quantum computer, which is accessible for customers to use today.

With immediate implications to optimization, the findings show that coherent quantum annealing can improve solution quality faster than classical algorithms. The observed speedup matches the theory of coherent quantum annealing and shows a direct connection between coherence and the core computational power of quantum annealing.

Read More

Charting the course to 100,000

IBM Quantum's vision is to scale quantum processors to a size v challenging problems.

IBM has set a significant milestone in quantum computing: aiming for a 100,000-qubit system by 2033. To achieve this goal, they are partnering with the University of Tokyo and the University of Chicago on targeted research projects. The objective is to develop a quantum system capable of addressing some of the world's most complex problems that even today's most advanced supercomputers may struggle to solve.

The choice of 100,000 qubits is based on the progress made at the IBM Quantum Summit 2022, where they showcased a 433-qubit processor called IBM Quantum Osprey. While scaling quantum processors to thousands of qubits seems achievable, going beyond this point poses challenges related to footprint, cost, chip yield, energy consumption, and supply chain issues. Overcoming these hurdles requires collaboration and fundamental research across multiple fields such as physics, engineering, and computer science.

IBM has outlined four key areas critical for advancing towards the 100,000-qubit supercomputer: quantum communication, middleware for quantum, quantum algorithms and error correction (capable of using multiple quantum processors and quantum processors and quantum communication), and components with a reliable supply chain. To progress in these areas, IBM is sponsoring research at the University of Tokyo and the University of Chicago.

The University of Tokyo will focus on identifying, scaling, and demonstrating quantum algorithms. They will also work on developing the supply chain for essential components required for such a large quantum system. The university has already shown leadership in quantum computing through the Quantum Innovation Initiative Consortium (QIIC) and is actively researching algorithms and applications for quantum computing.

On the other hand, the University of Chicago will lead efforts to bring quantum communication into quantum computation and improve middleware for quantum. Their expertise in quantum communication and software techniques, demonstrated through the Chicago Quantum Exchange, positions them to drive advancements in these areas.

Despite the challenges ahead, IBM believes that together with the University of Tokyo and the University of Chicago, achieving 100,000 connected qubits by 2033 is feasible. They will continue following their development roadmap to

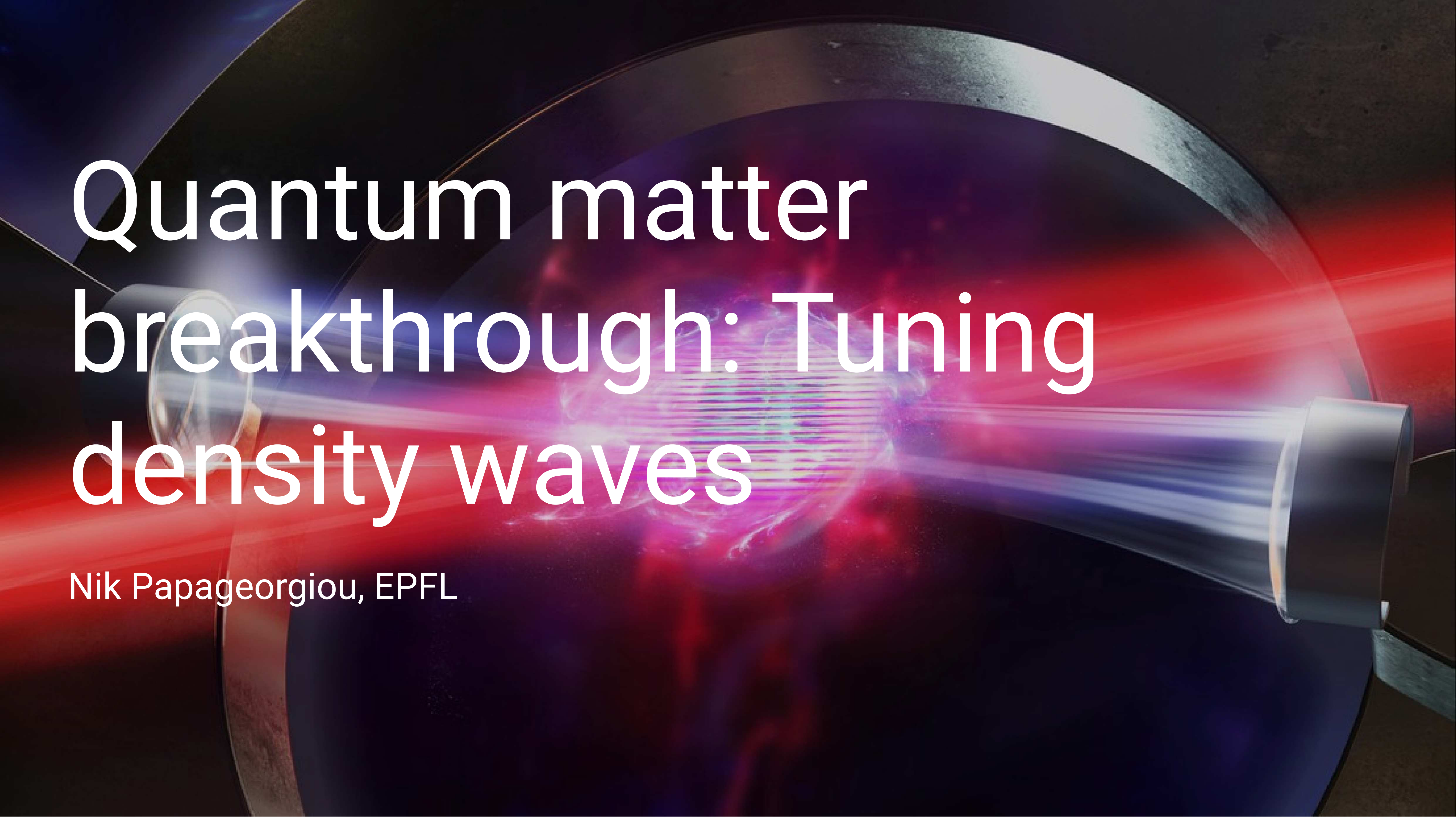
qubits

where they're capable of solving the world's most

The 100,000 Qubit Quantum-Centric Supercomputer of 2033 @ IBM

to realize quantum-centric supercomputing while enabling the community to pursue progressive performance improvements. The goal is to leverage quantum advantages over classical processors, treating quantum and classical computing as complementary components of a broader high-performance computing paradigm. Through this holistic approach, they aim to bring useful quantum computing to the world.

Circuit knitting techniques allow for partitioning large quantum circuits into subcircuits that fit on smaller devices.



Quantum matter breakthrough: Tuning density waves

Nik Papageorgiou, EPFL

Scientists at EPFL have found a new way to create a crystalline structure called a "density wave" in an atomic gas. The findings can help us better understand the behavior of quantum matter, one of the most complex problems in physics.

“Cold atomic gases were well known in the past for the ability to ‘program’ the interactions between atoms,” says Professor Jean-Philippe Brantut at EPFL. “Our experiment doubles this ability!” Working with the group of Professor Helmut Ritsch at the University of Innsbruck, they have made a breakthrough that can impact not only quantum research but quantum-based technologies in the future.

Density waves

Scientists have long been interested in understanding how materials self-organize into complex structures, such as crystals. In the often-arcane world of quantum physics, this sort of self-organization of particles is seen in ‘density waves’, where particles arrange themselves into a regular, repeating pattern or ‘order’; like a group of people with different colored shirts on standing in a line but in a pattern where no two people with the same color shirt stand next to each other.

Density waves are observed in a variety of materials, including metals, insulators, and superconductors. However, studying them has been difficult, especially when this order (the patterns of particles in the wave) occurs with other types of organization such as superfluidity – a property that allows particles to flow without resistance.

It's worth noting that superfluidity is not just a theoretical curiosity; it is of immense interest for developing materials with unique properties, such as high-temperature superconductivity, which could lead to more efficient energy transfer and storage, or for building quantum computers.

Tuning a Fermi gas with light

To explore this interplay, Brantut and his colleagues, the researchers created a "unitary Fermi gas", a thin gas of lithium atoms cooled to extremely low temperatures, and where atoms collide with each other very often.

The researchers then placed this gas in an optical cavity, a device used to confine light in a small space for an extended period of time. Optical cavities are made of two facing mirrors that reflect incoming light back and forth between them thousands of times, allowing light particles, photons, to build up inside the cavity.

In the study, the researchers used the cavity to cause the particles in the Fermi gas to interact at long distance: a first atom would emit a photon that bounces onto the mirrors, which is then reabsorbed by second atom of the gas, regardless how far it is from the first. When enough photons are emitted and reabsorbed – easily tuned in the experiment – the atoms collectively organize into a density wave pattern.

"The combination of atoms colliding directly with each other in the Fermi gas, while simultaneously exchanging photons over long distance, is a new type of matter where the interactions are extreme," says Brantut. "We hope what we will see there will improve our understanding of some of the most complex materials encountered in physics."

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Density-wave ordering in a unitary Fermi gas with photon-mediated interactions
Victor Helson, Timo Zwettler, Farokh Mivehvar, Elvia Colella, Kevin Roux, Hideki Konishi, Helmut Ritsch, Jean-Philippe Brantut.
Nature 24 May 2023. DOI: 10.1038/s41586-023-06018-3

A breakthrough that can impact not only quantum research but quantum-based technologies in the future.

Symmetric Graphene Quantum Dots for Future Qubits

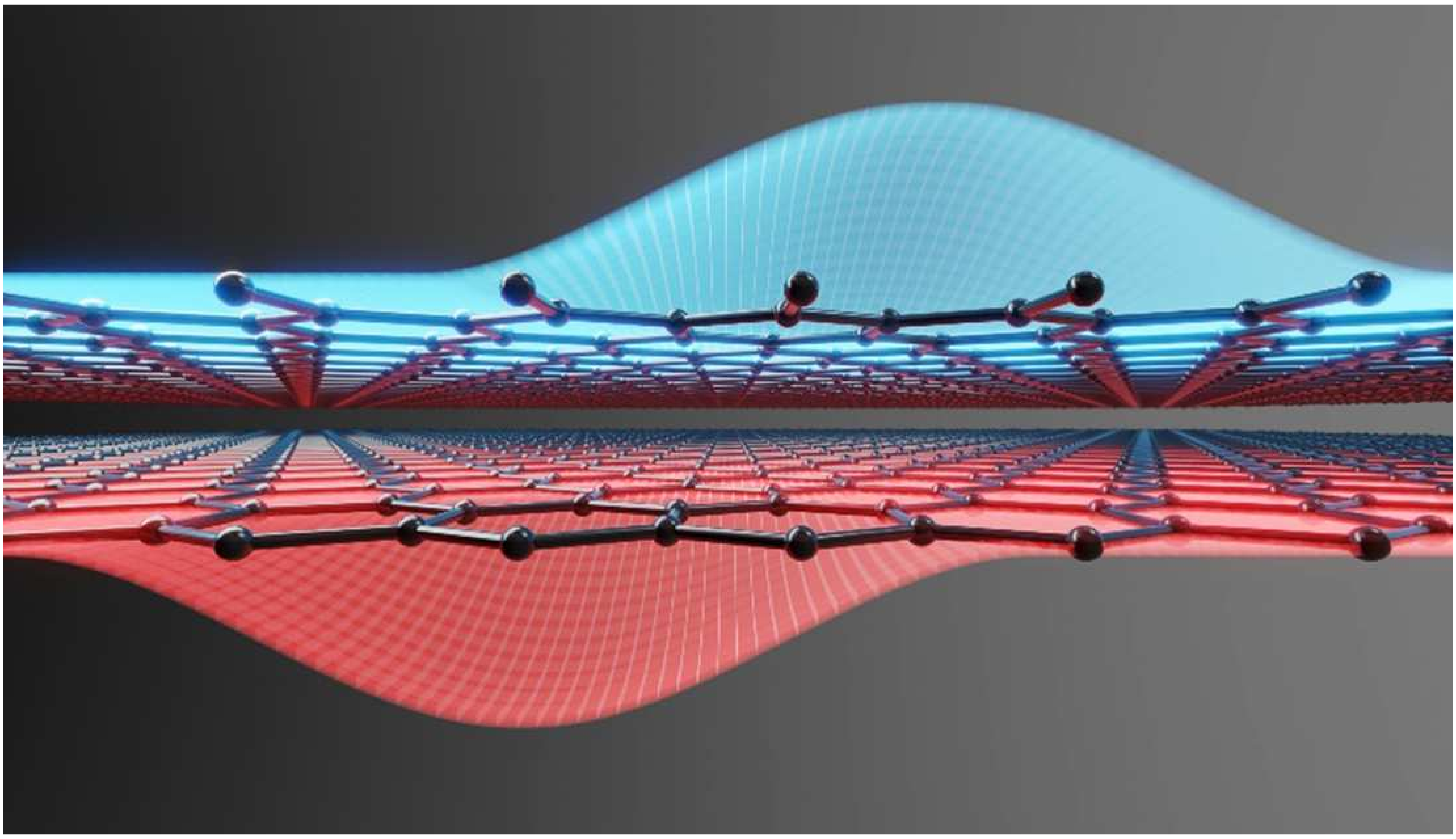
Quantum dots in semiconductors such as silicon or gallium arsenide have long been considered hot candidates for hosting quantum bits in future quantum processors. Scientists at Forschungszentrum Jülich and RWTH Aachen University have now shown that bilayer graphene has even more to offer here than other materials. The double quantum dots they have created are characterized by a nearly perfect electron-hole-symmetry that allows a robust read-out mechanism – one of the necessary criteria for quantum computing. The results were published in the renowned journal Nature.

The development of robust semiconductor spin qubits could help the realization of large-scale quantum computers in the future. However, current quantum dot based qubit systems are still in their infancy. In 2022, researchers at QuTech in the Netherlands were able to create 6 silicon-based spin qubits for the first time. With graphene, there is still a long way to go. The material, which was first isolated in 2004, is highly attractive to many scientists. But the realization of the first quantum bit has yet to come.

"Bilayer graphene is a unique semiconductor," explains Prof. Christoph Stampfer of Forschungszentrum Jülich and RWTH Aachen University. "It shares several properties with single-layer graphene and also has some other special features. This makes it very interesting for quantum technologies."

One of these features is that it has a bandgap that can be tuned by an external electric field from zero to about 120 milli-electronvolt. The band gap can be used to confine charge carriers in individual areas, so-called quantum dots. Depending on the applied voltage, these can trap a single electron or its counterpart, a hole – basically a missing electron in the solid-state structure. The possibility of using the same gate structure to trap both electrons and holes is a feature that has no counter part in conventional semiconductors.

"Bilayer graphene is still a fairly new material. So far, mainly experiments that have already been realized with other semiconductors have been carried out with it. Our current experiment now goes really beyond this for the first time," Christoph Stampfer says. He and his colleagues have created a so-called



Artist's impression of bilayer graphene with an electron-hole symmetric double quantum dot, where the electron and the hole are in different layers. (Copyright: Sebastian Staacks)

double quantum dot: two opposing quantum dots, each housing an electron and a hole whose spin properties mirror each other almost perfectly.

Wide range of applications

"This symmetry has two remarkable consequences: it is almost perfectly preserved even when electrons and holes are spatially separated in different quantum dots," Stampfer said. This mechanism can be used to couple qubits to other qubits over a longer distance. And what's more, "the symmetry results in a very robust blockade mechanism which could be used to read out the spin state of the dot with high fidelity."

"This goes beyond what can be done in conventional semiconductors or any other two-dimensional electron systems," says Prof. Fabian Hassler of the JARA Institute for Quantum Information at Forschungszentrum Jülich and RWTH Aachen University, co-author of the study. "The near-perfect symmetry and strong selection rules are very attractive not only for operating qubits, but also for realizing single-particle terahertz detectors. In addition, it lends itself to coupling quantum dots of bilayer graphene with superconductors, two systems in which electron-hole symmetry plays an important role. These hybrid systems could be used to create efficient sources of entangled particle pairs or artificial topological systems, bringing us one step closer to realizing topological quantum computers."

The research results were published in the journal Nature. The data supporting the results and the codes used for the analysis are available in a Zenodo repository. The research was funded, among others, by the European Union's Horizon 2020 research and innovation program (Graphene Flagship) and by the European Research Council (ERC), as well as by the German Research Foundation (DFG) as part of the Matter of Light for Quantum Computing (ML4Q) cluster of excellence.

Reference

Particle–hole symmetry protects spin-valley blockade in graphene quantum dots
L. Banszerus, S. Möller, K. Hecker, E. Icking, K. Watanabe, T. Taniguchi, F. Hassler, C. Volk & C. Stampfer
Nature volume 618, pages 51–56 (2023)

Quantrolox Launches Automation Software Integrated with Qblox Control Stack to Accelerate the Development of Quantum Technologies

UKRI awards £45 million to develop quantum technologies

Science Minister announces new funding to further advance UK's quantum tech research and innovation during London Tech Week.

UK Research and Innovation

The funding includes:

£8 million to fund 12 projects exploring quantum technologies for position, navigation and timing (PNT)
£6 million for 11 projects working on software enabled quantum computation
£6 million for 19 projects' feasibility studies in quantum computing applications
£25 million for seven projects quantum-enabled PNT via the Small Business Research Initiative (SBRI)
Talking at an event during this year's London Tech Week, UK Science Minister, George Freeman, today announced new funding to support universities and businesses working in the UK's quantum technologies sector.

These new investments, through the UK Research and Innovation (UKRI) Technology Missions Fund, will build upon the country's National Quantum Technologies Programme which has been running for nearly a decade.

Harnessing quantum physics

One of the 12 projects researching PNT announced today is led by Dr Joseph Cotter from Imperial College London. It aims to harness quantum physics to develop a new type of sensor technology that can be used underwater or underground.

It will explore how quantum sensors can complement the use of the global navigation satellite systems (GNSS) that much of society currently relies upon.

GNSS enables real-time access to the location of items for delivery and supports the transportation of goods and services including maritime and road transit. However, it can be vulnerable to adverse weather conditions, jamming and has limited capability underwater and underground.

The Imperial team are developing new navigation sensor technology that will provide superior position accuracy in the networks beneath our feet and a more resilient and secure alternative to GNSS.

Partnering with Transport for London (TfL), the team will test the new technology on trains. With 45% of TfL's network underground.

This group of projects has also been supported by £400,000 from the Defence Science and Technology Laboratory.

Read More

UConn, Yale Collaboration Aims to Make CT the Quantum Technology Leader

The state's two premiere research universities - Yale and UConn - are heading a coalition seeking funds to establish the state as a quantum technologies leader.

The coalition, Quantum-CT, received a $1 million Engines Development Award from the National Science Foundation (NSF) this spring for a two-year development effort , with the goal of positioning Connecticut to become the nation's accelerator for quantum technologies and providing the opportunity to compete for an NSF Engines award of up to $160 million over 10 years, UConn Today recently reported.

Quantum technology is tech developed through quantum mechanical principles that govern the atomic and subatomic world. Quantum technologies are poised to influence hundreds of applications, including smartphones, navigation systems, advanced computers, and hundreds of other applications impacting many of Connecticut's key manufacturing, energy, and infrastructure industries.

The UConn-Yale partnership recruited an expansive coalition of public, private, and state officials that aims to establish Connecticut as an innovation engine powered by quantum technologies, UConn Today reported. Collaborators on the grant include the Governor's office, the cities of Hartford, New Haven, Stamford, and Waterbury, the Connecticut State Colleges and Universities (CSCU), the Connecticut Conference of Independent Colleges (CCIC), and the Connecticut Business and Industry Association (CBIA), among others.

Innovation and venture partners, including Connecticut Innovations, CT Next, Advance CT, Yale Ventures, and UConn's Technology Innovation Program, will work to together ensure that emerging quantum technologies are quickly transferred to real-world applications, according to officials.

"Connecticut is a microcosm of the challenges and opportunities facing our nation," said UConn President Radenka Maric. "Our proud industrial base has stayed strong in the face of international competition, offshore manufacturing, and the mass retirement of skilled workers. Likewise, our cities and towns have persevered through tremendous adversity.

UConn is honored to join Yale as leaders in the effort to make Connecticut America's accelerator by transforming a diverse, compact region into an economic development powerhouse using quantum tech."

The Quantum-CT planning initiative is complex, incorporating all sectors that stand to be impacted by the economic revitalization spurred through quantum technology translation. In addition to state offices and the network of universities, technology adopters in the pharmaceutical, defense, financial services, and computing sectors all stand to benefit.

"Yale has a stellar reputation in quantum science and a blossoming start-up community in quantum technologies," said Michael Crair, Yale's vice provost for research and co-principal investigator for the NSF grant. "This will be a multi-billion-dollar industry, and we'd love for Yale and UConn, with partners around the state, to nucleate a national quantum corridor in Connecticut."

UConn's involvement includes more than a dozen researchers spanning several schools, colleges, and services, including the School of Engineering, College of Liberal Arts and Sciences, and the Technology Commercialization Services wing of the University's research enterprise, school officials explained.

"Quantum science and technologies hold so many keys to the future of Connecticut and the nation," said Pamir Alpay, UConn's interim vice president for research, innovation, and entrepreneurship and one of the lead investigators on the project. "Bringing together the expertise and research excellence of UConn, Yale, and many partners, Quantum-CT has the potential to be transformative for science, our economy, and workforce. This program extends opportunities to communities and sectors left behind by recent economic downturn and promotes equitability across the state."

NSF Regional Innovations Engines awarded more than 40 of the prestigious, first-ever awards to collaborations formed to create economic, societal, and technological opportunities for their regions.

"Quantum technology represents the future of computers and science, and through a partnership fused between UConn and Yale, Connecticut is ready, determined, and eager to become the nationwide hub and central force of this technological revolution," emphasized Governor Ned Lamont.

One step closer to highly secure quantum communication

The communication of the future is to become more secure with the help of light particles. This is the goal of the QuNET initiative by the BMBF.

QuNET-Initiative at Fraunhofer IOF

Researchers from Jena, Berlin, Erlangen-Nuremberg and Wessling have successfully distributed quantum keys between two points using a combination of free-space and fiber links under everyday conditions. On a heterogeneous test bed in Jena, they achieved key rates in the kilobit range per second in daylight. The experiment was implemented as part of the QuNET initiative, a pilot project funded by the German Federal Ministry of Education and Research (BMBF) to develop highly secure communication systems based on quantum technologies.

The communication of the future is to become more secure with the help of light particles. This is the goal of the QuNET initiative by the BMBF. The initiative's partners - the Max Planck Institute for the Physics of Light, Friedrich Alexander University Erlangen-Nuremberg, the DLR Institute of Communications and Navigation, and the two Fraunhofer Institutes for Applied Optics and Precision Engineering IOF and the Heinrich Hertz Institute HHI - have now taken an important step toward quantum-safe networks: with a key experiment, they have shown how multiple quantum-secured point-to-point links can be realized and combined for future scalable quantum-safe networks. They not only combined transmissions of quantum keys via free-space and fiber links, but also achieved transmission rates in the kilobit range per second in daylight.

"One goal of the key experiment was to demonstrate the distribution of quantum keys in heterogeneous ad-hoc links in daylight," explains Dr. Thorsten Goebel, coordinator in the QuNET Office at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF. "Heterogeneous in this case means that we distribute quantum keys between two points with a combination of free-space and fiber links to bridge fiber gaps. And all of this with an ad-hoc character, i.e., establishing the connection as quickly as possible."

Test bed over two kilometers in the urban area of Jena

In this specific case, the researchers established a quantum-secured connection on a nearly two-kilometer-long test track in Jena. The quantum key distribution was implemented in two stages: The journey began on the roof of the Jena public utility company. There is a green container with a telescope for sending quantum keys in its belly. From here, light particles, which form the basis for generating a highly secure quantum key, first fly over 1.7 kilometers as the crow flies to the Beutenberg Campus Jena. There, they are picked up by a receiving station in another container on the grounds of the Fraunhofer Institute. From this intermediate node, the signal is fed into a fiber link and forwarded via 300 meters of fiber to a building adjacent to the institute. There, a quantum key is finally generated from the measurements on the light particles.

Even in the case of longer transmission distances i.e., when a direct distribution of quantum keys is not possible, the researchers have taken precautions: By suitably combining keys at trusted intermediate stations along these longer distances, the key distribution becomes possible over even greater distances.

Mobile quantum link allows bridging of fiber gaps

"Our key experiment thus demonstrates how the combination of multiple links can succeed in bridging fiber gaps, i.e., distances where the lack of lines makes fully fiber-based transmission impossible," Dr. Goebel continues. "An often-cited example here would be a summit in rural regions with patchy fiber infrastructure." But natural boundaries, such as bridging a river, are also a conceivable application scenario for a point-to-point connection between transmitter and receiver that can be established for a short time.

Another important aspect of the experiment is its mobile character. The two quantum containers used by the researchers, also called QuBUSes, are basically transportable. They could, for example, be taken to any location by a vehicle and could establish a quantum-secured connection there as needed. In this way, quantum communication can be implemented at the most diverse locations.

Researchers achieve key generation rates in the kilobit range

With their experiment, the researchers also achieved key generation rates in the kilobit range per second, even in direct midday sunlight. The researchers thus also achieved an important criterion for practical use, because intense solar radiation usually impairs the exchange of quantum-based keys. In many experiments, the quantum keys were therefore distributed at night and pre-stored for daytime communication. With the development of special filters, daytime key generation is now possible.

In addition, one aspect of this experiment was the demonstration of hybrid quantum key distribution. This involves the simultaneous implementation of different protocols for key distribution, which was thus able to demonstrate the agility of the developed infrastructure, in particular the QuBUS platform, in terms of the protocols used. This is important, since the development of quantum key distribution still offers many possibilities for expansion, and these should not be restricted by the infrastructure used. Thus, the developed infrastructure is also future-proof and can be used for any protocols of quantum key distribution without major adaptations.

For this purpose, protocols for quantum key distribution were also tested, which measure the electric fields instead of

On the roof of the QuBUS, which is located on the premises of the Fraunhofer IOF, is the unit for receiving the quantum keys sent via free-space from the Jena public utility. © Fraunhofer IOF

individual light particles. The researchers were able to show that this approach, which is very close to the technology used in classical telecommunications, is suitable for quantum key distribution without additional filters even in the case of fluctuating transmission channels of the free-space link in daylight.

First quantum-secured videoconference already realized in 2021

The experiment in Jena is the second public demonstration of technology development in the QuNET initiative: QuNET researchers had already successfully implemented a quantum-secured videoconference between two federal agencies in August 2021. At that time, a connection between the Federal Ministry of Education and Research and the Federal Office for Information Security (BSI) was implemented.

Read More

BRICS Considers Venturing in Quantum Technology

Kazan, a Russian city, is set to host the upcoming BRICS summit on April 3, 2024. During the event, scientists from the member states (Brazil, Russia, India, China, South Africa) will present intriguing cases on quantum tech. The city of Kazan in Russia is gearing up to play host to the forthcoming BRICS summit on April 3, 2024. A focal point of this summit will be the presentation of intriguing quantum technology cases by scientists hailing from the member states of BRICS. Notably, Russian scientists are strongly inclined towards establishing robust quantum technology collaborations, particularly with India and China.

At the forefront of these efforts is Alexey Fedorov, who leads the "Quantum Information Technologies" group at Moscow's Quantum Center. Reflecting on a productive trip to India the previous year, Fedorov emphasized the immense potential for collaboration that exists and proposed the establishment of a network of Brics quantum laboratories.

This network would operate cohesively under a joint research program, pooling resources and brainpower to collectively address intricate challenges in quantum computing and sensing. Fedorov highlighted the synergistic strength of collaborative endeavors in fortifying the Brics alliance and propelling advancements.

With the mantle of the BRICS presidency set to pass to Vladimir Putin, the president anticipates substantive discussions on specific projects within the realm of cutting-edge computing, encompassing data processing, storage, and transmission technologies. Additionally, Putin has unveiled a forward-looking "national technology project" slated for 2030, outlining a comprehensive roadmap for advancing Russia's prowess in the realm of quantum technology. The upcoming summit stands as an opportune moment for participating nations to synergize their efforts, foster innovation, and reinforce technological bonds.

Quantum technology sees record investments, progress on talent gap

Investors buoy established quantum start-ups, technological progress continues—though at a slower pace—and more academic institutions offer quantum programs.

McKinsey & Company

Last year, quantum technologies moved closer to fulfilling their promise to resolve challenges that are impossible or prohibitively expensive to tackle with today's technologies. Our updated analysis for the 2023 Quantum Technology Monitor shows that the four industries likely to see the earliest economic impact from quantum computing—automotive, chemicals, financial services, and life sciences—stand to potentially gain up to $1.3 trillion in value by 2035.

Pursuing a share of that value, in 2022 investors poured $2.35 billion into quantum technology start-ups, which include companies in quantum computing, communications, and sensing. The total edged out 2021's record for the highest annual level of quantum technology start-up investment. In fact, four of the biggest deals in the 2000s closed last year.

Behind many quantum technology start-ups are technical breakthroughs, and 2022 saw several notable ones. A few examples include the awarding of the Nobel Prize in Physics to pioneering researchers in quantum entanglement, a company that presented a quantum processor with hundreds of quantum bits (qubits) and a road map to build one with thousands of qubits by 2025, and another company that demonstrated quantum advantage in a sampling problem using its photonic quantum computer.

Talent with relevant expertise can propel the industry to future technical breakthroughs.

While the quantum technology talent gap has narrowed, there is still a shortage; upskilling graduates in quantum technology-relevant field can help.

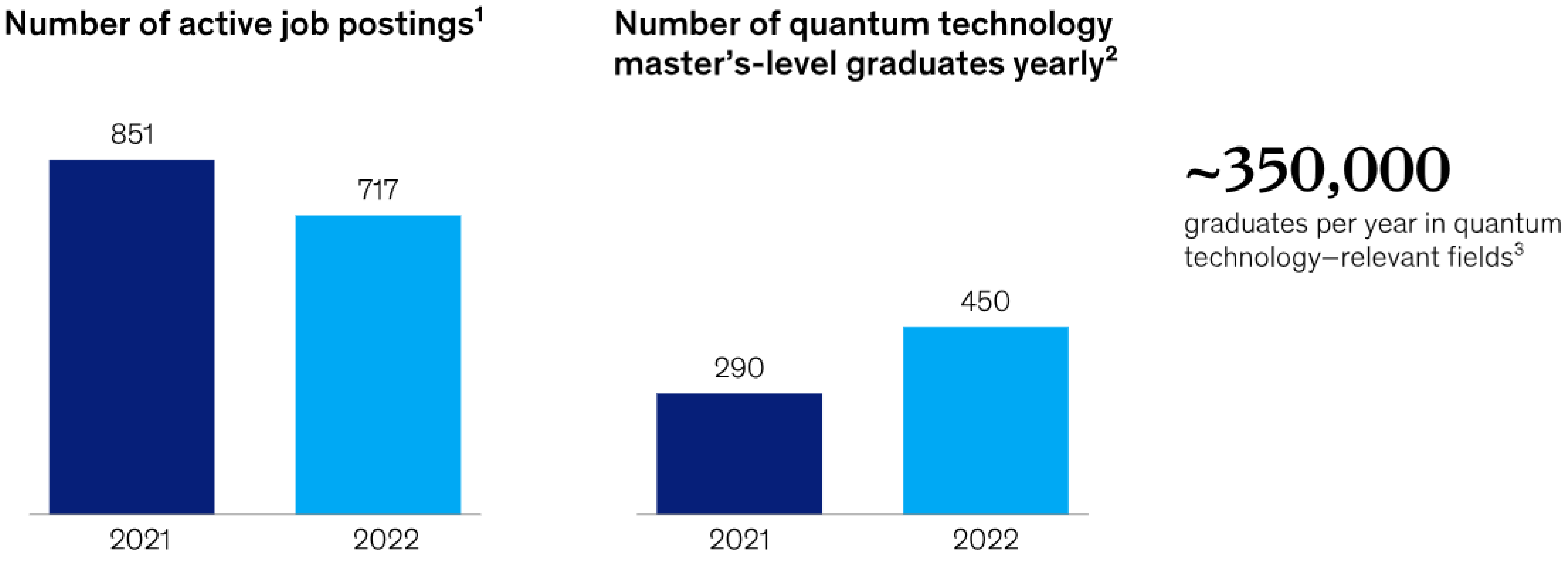


Exhibit 2

'For 2021, number of active job postings as of December 2021, and for 2022, monthly average number of active job postings.
Estimate based on the number of universities with such programs and how many students graduate per year.
**Graduates of master's level or equivalent in biochemistry, chemistry, electronics and chemical engineering, information and communications technology, mathematics and statistics, and physics.*
Source: OECD; Quantum Computing Report; QURECA

This progress occurred even though the number of job openings in quantum technologies increased by 19 percent from 2021 to 2022. Going forward, the gap could narrow further, in part because more academic institutions are integrating quantum into their curriculums and because universities produced 55 percent more master's-level graduates in quantum technologies. According to our research, the number of universities with formal master's programs in quantum technologies shot up from 29 in 2021 to 50 in 2022.

This analysis shows that the remaining jobs could be filled by graduates from fields that are related to quantum technologies, which produce approximately 350,000 master's-level graduates per year worldwide. Talent in these fields—biochemistry, chemistry, electronics and chemical engineering, information and communications technology, mathematics and statistics, and physics—is most plentiful and concentrated in the European Union. In 2020, 303 out of every million EU residents were newly minted master's-level graduates in a field that is relevant to quantum technology (Exhibit 3).

The European Union has the highest number and concentration of quantum technology talent.

Absolute number of graduates in quantum technology–relevant fields, 2020[1]

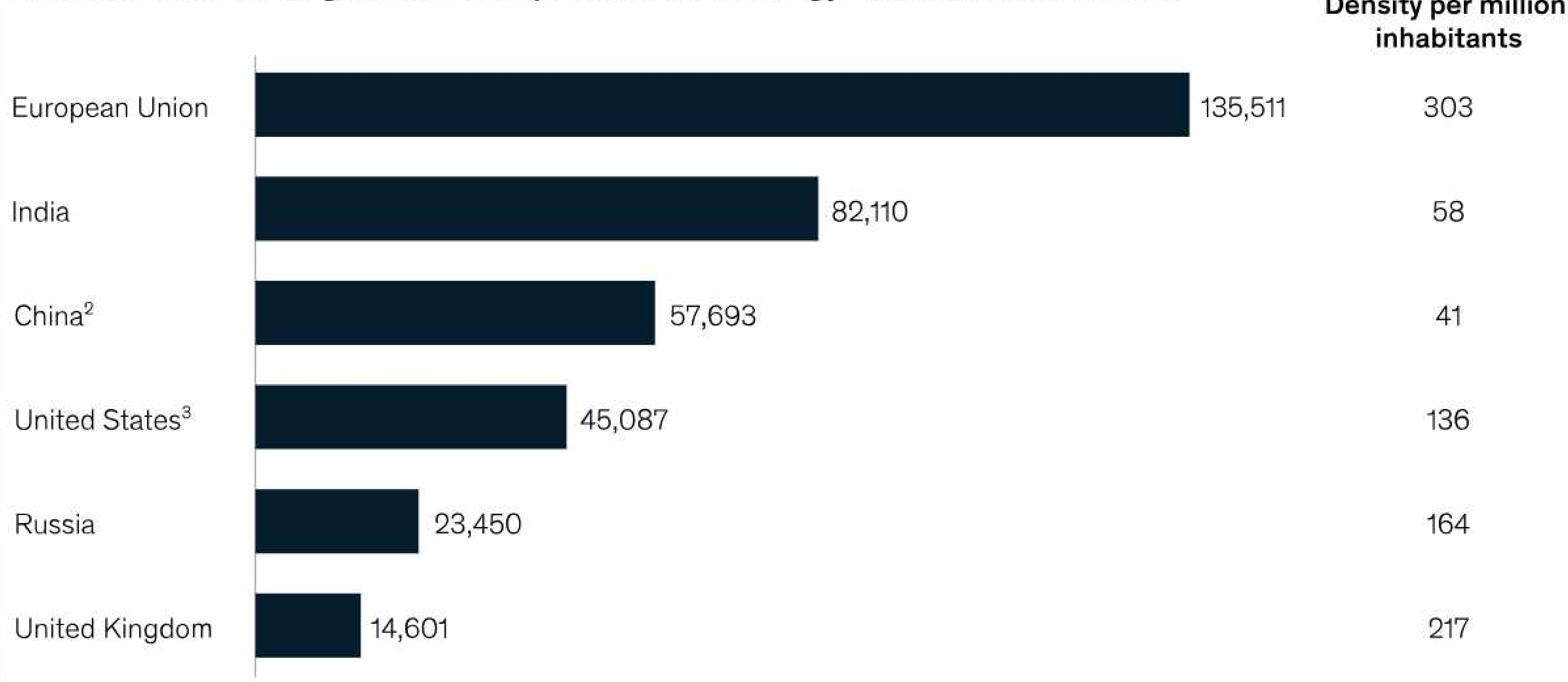


Exhibit 3

'1 Graduates of master's level or equivalent in 2019 in biochemistry, chemistry, electronics and chemical engineering, information and communications technology, mathematics and statistics, and physics.

2 High-level estimates

3 The actual talent pool for the United States may be larger, as bachelor's programs are longer and master's programs are less common.

Source: National government websites; OECD

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The quantum technology ecosystem in 2023

50 QT master's degree programs

180 universities with QT research groups

1,589 QT-related patents granted in 2022

44,155 QT-related publications in 2022

$106B
potential quantum technology market size by 2040

350
start-ups in the ecosystem

A more established ecosystem attracted record investment, but the pace of start-up creation slowed

Worldwide investments in quantum technology start-ups reached their highest levels in 2022, at $2.35 billion, a modest 1 percent increase from 2021. About 68 percent of all start-up investments in quantum technology since 2001 have streamed into the industry over the past two years, an indication of investor confidence in the technologies' future commercial potential.

But the rate of new-company creation has not kept pace with investments. Only 19 quantum technology start-ups were founded in 2022, compared with 41 in 2021, bringing the total number of start-ups in the quantum technology ecosystem to 350. This suggests that more investments are going to established start-ups than to new companies.

Read the full report

Quantum computing

$9B–$93B estimated market size by 2040
$5.4B invested as of Dec 2022

223 start-ups as of Dec 2022

Quantum communications

$1B–$7B estimated market size by 2040
$1.0B invested as of Dec 2022

72 start-ups as of Dec 2022

Quantum sensing

$1B–$6B estimated market size by 2040
$0.4B invested as of Dec 2022

23 start-upsas of Dec 2022

Potential economic value from

Quantum Computing

$620B–$1,270B

across four industries by 2035:

- chemicals
- life sciences
- finance
- automotive

Source: Quantum technology monitor (April-2023) Mckinsey - **Read the full report**

Quantum sensor for a future navigation system tested aboard Royal Navy ship

Hayley Dunning
Imperial College London

A prototype quantum sensor built at Imperial, with potential application in GPS-free navigation, has been tested in collaboration with the Royal Navy.

The test marks an important step in bringing new quantum technologies out of the lab and into real-world settings.

Many navigation systems today rely on global navigation satellite systems (GNSS), such as GPS, which uses signals from satellites orbiting the Earth. However, GPS navigation is not always accessible, obstacles like tall buildings can easily block the satellite signals, and they are also susceptible to jamming, imitation, or denial, thereby preventing accurate navigation. It has been estimated that a single day of satellite service denial would incur a cost of £1 billion to the UK.

Self-contained satellite-free navigation systems do exist; however, current technologies drift over time, meaning they lose accuracy unless regularly calibrated with satellites. The quantum sensor has the potential to remove this drift, significantly improving the accuracy over long timescales.

The Imperial College London team unveiled their first ‘quantum compass’ prototype in 2018, and have since been refining the technology to the point where it can now be tested in the field.

Real-world environments

The latest Imperial quantum sensor was integrated into a Qinetiq NavyPOD – an interchangeable rapid prototyping platform, before setting sail to London aboard a new Royal Navy research ship the XV Patrick Blackett.

The experiment is the first step towards understanding the application and exploitation of quantum-enabled navigation, which could provide significant navigational advantages when operating in satellite-denied areas.

Dr Joseph Cotter, lead scientist on the quantum sensor from the Department of Physics at Imperial, said: “Access to the Patrick Blackett provides us with a unique opportunity to take quantum sensors out of the lab and into the real-world environments, where they are needed.”

Access to the Patrick Blackett provides us with a unique opportunity to take quantum sensors out of the lab and into the real-world environments, where they are needed.

Dr Joseph Cotter

Commander Michael Hutchinson, Commanding Officer of XV Patrick Blackett, said: “Working with Imperial College London on this project has been an exciting and interesting opportunity for all of us. So far, the testing has gone well but the technology is still in its very early stages. It’s great to be a part of Royal Navy history.”

Exploiting ultracold atoms

The Imperial quantum sensor is a new type of accelerometer. Accelerometers measure how an object’s velocity changes over time. By combining this information with rotation measurements and the initial position of the object, the current location can be calculated.

The quantum accelerometer uses ultracold atoms to make highly accurate measurements. When cooled to extremely low temperatures the atoms start to display their 'quantum' nature, resulting in wave-like properties. As the atoms move through the sensor, an 'optical ruler' is formed by using a series of laser pulses. This allows the acceleration of the atoms to be precisely measured.

Quantum legacy

These new tests build on a legacy of quantum research at Imperial. Imperial has formed the Centre for Centre for Quantum Engineering, Science and Technology (QuEST) to translate discoveries in quantum science into transformative quantum technologies.

Professor Peter Haynes, Director of QuEST at Imperial, says: "The quantum accelerometer is a pioneering technology at the forefront of quantum innovation. It has the potential to transform navigation by making it more accurate and secure.

"This work represents the latest advance in Imperial's long track record of world-leading research in quantum science and technology. With deep expertise in basic science, engineering and translation, we are focused on making quantum technologies - and the benefits they hold - a reality."

The XV Patrick Blackett ship also has another Imperial connection. The 1948 Nobel Prize winner Professor Lord Blackett was head of the Imperial College Department of Physics from 1953 to 1963 and the main building on the South Kensington campus still bears his name.

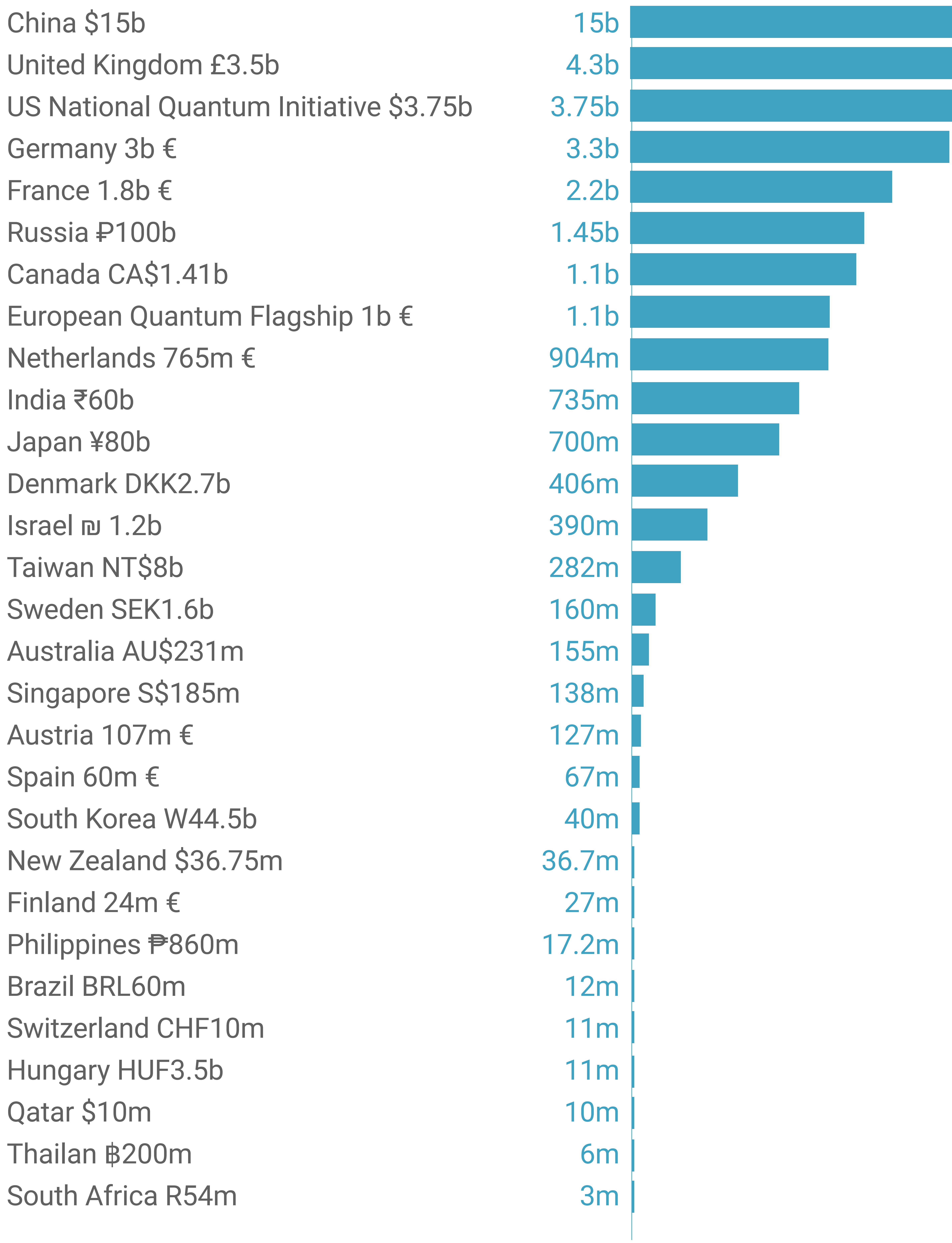
S. Korea to Invest 5 trillion Won in R&D for 12 Strategic Technologies in 2024

South Korea is primed to inject 5 trillion won (around US$3.8 billion) into research and development (R&D) endeavors in the upcoming year, advancing 12 strategic technologies. This substantial allocation underscores South Korea's aspiration to seize global leadership in cutting-edge fields. The Ministry of Science and ICT disclosed this initiative, highlighting its integral role in the nation's long-term growth strategy.

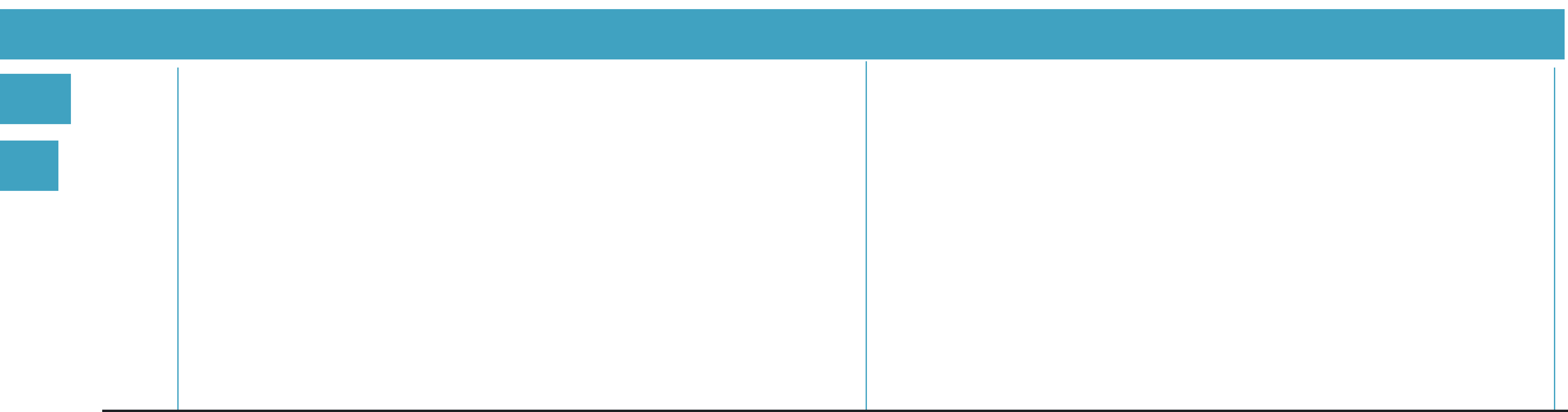
This R&D budget for 2024 reflects a noteworthy increase of 6.4 percent from the previous year's 4.7 trillion won. The augmented investment aims to fortify sectors of substantial influence and promising emergence. These sectors encompass semiconductors and displays, secondary batteries, advanced mobility, next-generation nuclear power, advanced biology, aerospace, ocean engineering, hydrogen, cybersecurity, artificial intelligence (AI), next-generation communications, advanced robotics, and quantum technology.

Concurrently, the Ministry revealed a roadmap bolstering three pivotal sectors: secondary batteries, semiconductors and displays, and advanced mobility, which are all arenas of intense global competition. The government is committed to fostering core material acquisition and developing high-performance batteries within the secondary battery sector. Additionally, the focus on high-performance, energy-efficient semiconductors is crucial for maintaining South Korea's edge in global chipmaking. The initiative also emphasizes innovative screen development in the display sector and positioning local entities at the forefront of advanced mobility in response to evolving regulations.

World Quantum Initiatives



2023



Global Quantum Effort 2023 $36b (estimate)

The global quantum effort leading to research and innovation in quantum science and technology is continually rising with current worldwide investments exceeding $36 billion. Overall, the global quantum technology market is projected to reach $106 billion by 2040

(Source QURECA 2023)

Read the full report

The first quantum-accelerated nanophotonics vibrometer

Unlock the future of non-contact material detection with our Quantum Photonic Vibrometer. This revolutionary device, proven to the US Department of Defense, leverages quantum mechanics to detect and inspect highly obscured objects at greater distances and opens new frontiers in remote sensing and beyond.

QCi has developed the first quantum long-range vibrometer, taking advantage of the profound benefits quantum technology enables. Every material has a unique fingerprint of natural frequency. We use quantum photonic detection to recognize and isolate those materials at greater speed and fidelity than any non-quantum alternatives can achieve, and with minimal power.

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