CHICAGO QUANTUM EXCHANGE

An intellectual hub for advancing the science and engineering of quantum information

ANNUAL REPORT 2021

The Chicago Quantum Exchange connects leading academic talent, top scientific facilities, and prominent corporate and nonprofit partners to advance the science and engineering of quantum information, train the quantum workforce of tomorrow, and drive the local and national quantum economy.

CHICAGO QUANTUM EXCHANGE MEMBERS

THE UNIVERSITY OF CHICAGO

Argonne NATIONAL LABORATORY

Fermilab

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Northwestern University

CHICAGO QUANTUM EXCHANGE STEERING COMMITTEE

David Awschalom
Liew Family Professor of Molecular Engineering, UChicago; Director of the Chicago Quantum Exchange; Director of Q-NEXT, a Department of Energy National Quantum Information Science Research Center led by Argonne

Supratik Guha
Senior Scientist/Senior Advisor to Argonne Physical Sciences & Engineering; Professor of Molecular Engineering, UChicago

Joe Lykken
Fermilab Deputy Director of Research, Head of the Fermilab Quantum Institute

Dale Van Harlingen
Donald Biggar Willett Professor, College of Engineering, University of Illinois at Urbana-Champaign

OUR WORK

With world-class researchers, acclaimed science and engineering programs, uniquely capable research facilities, and leading industry, nonprofit, and international partners, the Chicago Quantum Exchange is one of the largest collaborative teams working on quantum information science in the world.

BRIDGING ACADEMIA, INDUSTRY, AND GOVERNMENT

The CQE facilitates collaboration, joint projects, and information exchange among private and public universities, national laboratories, and corporate and nonprofit partners.

ADVANCING RESEARCH, DISCOVERY, AND IMPACT

The CQE's research, focused on quantum communications, computing, and sensing, is shaping the future of quantum science and engineering and its impact on the world.

TRAINING QUANTUM SCIENTISTS AND ENGINEERS

The CQE is developing the next generation of the quantum workforce and equipping those already working in science and engineering to transition to quantum careers.

DRIVING THE LOCAL AND NATIONAL QUANTUM ECONOMY

As a hub for cross-sector collaboration, research and discovery, and workforce development, the CQE drives quantum jobs and technology in Chicago, in Illinois, and across the U.S.

20
corporate partners, including **14 added** in 2020

2 international partners + **2** nonprofit partners

$260M+
federal funding to CQE member institutions in 2020

1,000
Chicago Quantum Summit attendees from **42 countries**

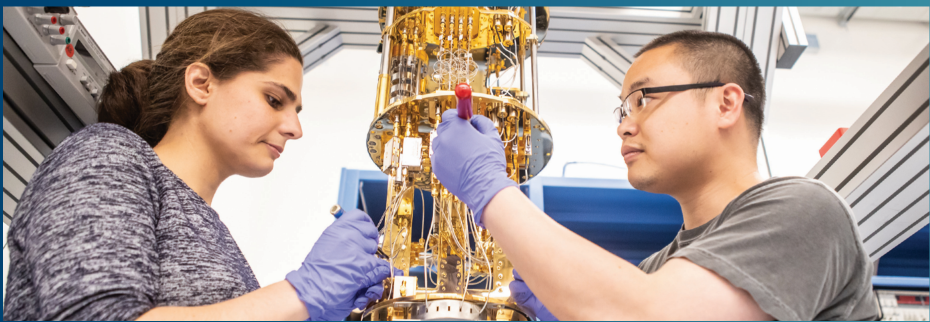
130+
researchers from **6 member** institutions

20+
honors given to researchers at CQE member institutions in 2020

2020 HIGHLIGHTS

The Chicago Quantum Exchange members and partners share knowledge and resources to advance technology that can change the world. In 2020, CQE member institutions welcomed several new federal centers and institutes, advancements in quantum science, and innovative programs to prepare a quantum workforce.

CQE members awarded $255M in federal funding for National Quantum Centers



In summer 2020, the White House Office of Science and Technology Policy announced $700M in funding to quantum information science centers through the Department of Energy (DOE) and quantum information science institutes through the National Science Foundation (NSF). Of the eight new centers, three were established at Chicago Quantum Exchange member institutions. Each of these Illinois-based federal centers engages dozens of researchers and students across CQE universities, national laboratories, and industry partners.

Two DOE Quantum Information Science Research Centers are each funded at $115M over five years:

Q-NEXT

Argonne National Laboratory leads Q-NEXT, which brings together nearly 100 researchers from national labs, universities, and leading U.S. quantum technology companies with the goal of developing the science and technology to control and distribute quantum information. This public-private partnership is essential to creating a domestic supply chain of new quantum materials and technologies for a robust quantum economy.

SUPERCONDUCTING QUANTUM MATERIALS AND SYSTEMS CENTER (SQMS)

SQMS is a Fermilab-led center that aims to significantly increase the coherence of quantum systems and to build and deploy a beyond-state-of-the-art quantum computer based on superconducting technologies. The center will also develop new quantum sensors, which could lead to discovering the nature of dark matter and other elusive subatomic particles.

The NSF established a new Quantum Leap Challenge Institute with a $25M, five-year award:

HYBRID QUANTUM ARCHITECTURES AND NETWORKS (HQAN)

Led by the University of Illinois at Urbana-Champaign, and including University of Chicago and University of Wisconsin–Madison, HQAN will create hybrid quantum platforms that discover and refine designs for locally distributed quantum processors and networks by leveraging the strengths of multiple types of quantum hardware, including atomic and superconducting systems.

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"We're going to see a renewed Chicago, a bold and continued rising Second City, and an essential hub and home for America's leadership in quantum innovations and technologies."

Paul Dabbar, Former Under Secretary for Science, U.S. Department of Energy

Dabbar contributed the op-ed "America's quantum future runs through Chicago" to Crain's Chicago Business.

"In Wisconsin we have been working for several decades to develop diverse approaches to high performance qubits for computation. The HQAN institute will enable a community of researchers to pool their knowledge and connect the different approaches to synthesize new solutions for distributed quantum information processing."

Mark Saffman, Co-PI at HQAN; Physics Professor, University of Wisconsin–Madison; and Chief Scientist, ColdQuanta

Saffman commenting on the formation of HQAN.

With QuSTEAM, CQE members, collaborators aim to create skilled quantum workforce

Scientists from three CQE member institutions and three other universities across the Midwest are collaborating to redesign quantum science education and develop a diverse and effective workforce that will lead the growing U.S. quantum economy. The new program is called QuSTEAM: Convergent Undergraduate Education in Quantum Science, Technology, Engineering, Arts, and Mathematics. QuSTEAM will develop a modular curriculum built around single concepts that can feed many educational paths. Funded by the NSF Convergence Accelerator, QuSTEAM collaborators include CQE members and partners UChicago, Argonne, University of Illinois at Urbana-Champaign, Applied Materials, HRL Laboratories, and IBM, as well as Ohio State, Michigan State, and Chicago State universities.

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DOE quantum internet blueprint centers on national labs including CQE members

At a July 2020 press conference at UChicago, DOE unveiled a report outlining a blueprint strategy to develop a national quantum internet, bringing the United States to the forefront of the global quantum race and ushering in a new era of communications. The blueprint strategy reflects insights from DOE national laboratories, universities, and industry and lays out essential research, engineering barriers, and near-term goals. DOE's 17 national laboratories will serve as the backbone of the coming quantum internet, including CQE member institutions Fermilab and Argonne, where this year scientists accomplished a 52-mile quantum loop.

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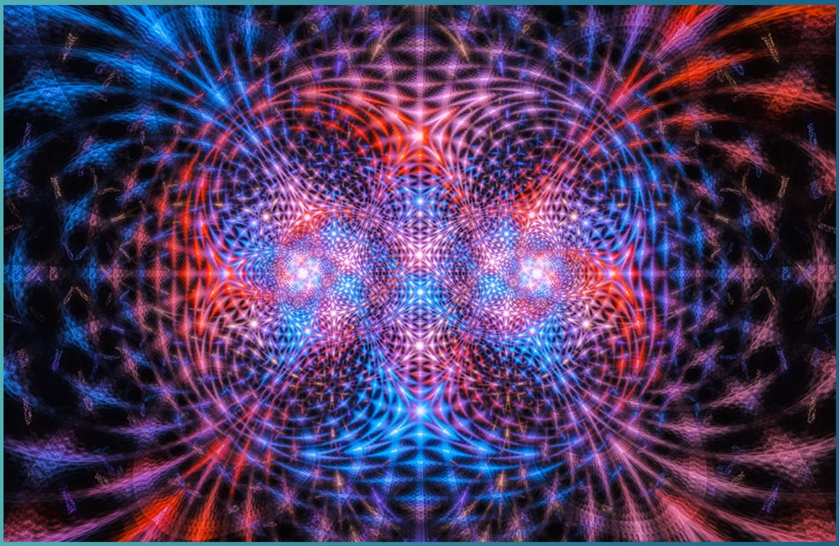

Quantum loop accomplishes important step in 'unhackable communication,' developing national quantum internet

Scientists from Argonne and UChicago successfully entangled photons across a 52-mile network in the Chicago suburbs, an important step in developing a national quantum internet. A quantum internet could catalyze technologies that greatly accelerate today's internet, significantly improve communications security, and support dramatic computing and sensing advances. Headquartered at Argonne, the quantum loop is among the longest land-based quantum networks in the nation. The experiment was led by Argonne senior scientist and UChicago professor David Awschalom and funded by DOE. Argonne and Fermilab have plans to scale the quantum loop to develop a two-way quantum link network together.

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"Today, with its share of innovation economy and its STEM workforce, Chicago is poised to become what Brookings calls a growth center, with a high-tech innovation sector that produces significant technology gains and wealth."

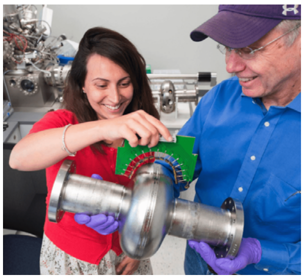
Penny Pritzker, Founder and Chairman of PSP Partners, Pritzker Realty Group, PSP Capital, and PSP Growth, and former U.S. Secretary of Commerce

Pritzker spoke at the Chicago Quantum Summit in 2020.

RESEARCH & DISCOVERY

Fundamental and applied research are the gateway to fully understanding and controlling objects at the smallest scales and driving discoveries with far-reaching applications. The future impact of quantum science and engineering relies on the research and discoveries happening at institutions today, including these by members of the Chicago Quantum Exchange.

Investigating matter's fundamental nature



Northwestern physicist Jim Sauls' research in quantum liquids and "quantized vortices" could lead to advanced technologies based on superfluids, superconductors, and more. Sauls leads a joint team of researchers at Northwestern and Fermilab who are among those pushing the boundaries of accelerator research. His investigations into the fundamental properties of matter and radiation, published in *Physical Review* and *Nature Physics*, are uncovering new phenomena that may contribute to new materials such as superconducting technologies, mainly focused on qubits. Their applications could include, for example, advancements in particle accelerators based on superconducting radio-frequency (SRF) cavities. SRF technology generates electromagnetic forces that accelerate subatomic particles with speeds near the ultimate speed of light.

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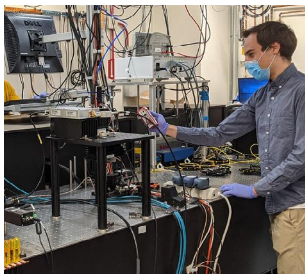
Tailor-made qubits could boost computing and sensing



An interdisciplinary team of physicists and chemists led by David Awschalom at the University of Chicago and Danna Freedman at Northwestern University has developed a new method to create qubits. The team chemically synthesized molecules that encode quantum information into their spin states, which they could control with light and microwaves. "This is a proof-of-concept of a powerful and scalable quantum technology," said Awschalom. "We can harness the techniques of molecular design to create new atomic-scale systems for quantum information science." The research was published in *Science*.

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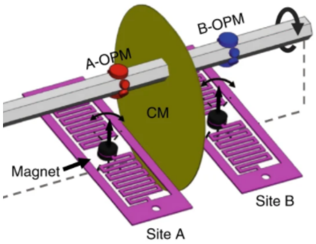
A new way to transport energy



University of Illinois at Urbana-Champaign researchers Inbar Grinberg, Gaurav Bahl, and Taylor Hughes have experimentally demonstrated a new way to transport energy even through wave-guides that are defective, and even if the disorder is a transient phenomenon in time. The researchers built a topological pump, a system that produces on-demand robust transport of mechanical energy when it is periodically driven in time. After each pumping cycle, a single particle enters a chain of atoms on one end, and a single particle exits the chain on the other end. This reliably occurs even if the chain has disorder. Their findings, published in *Nature Communications*, could lead to much more robust communications devices that continue to operate despite damage.

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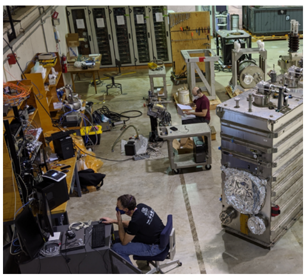
Expanding quantum computing use cases in physics and engineering



A quantum algorithm known to be useful in studying and solving problems in quantum physics can be applied to problems in classical physics, according to a new study from Jeff Parker at the University of Wisconsin–Madison, published in *Physical Review A*. Generalized eigenvalue problems broadly describe trying to find the fundamental frequencies or modes of a system. The quantum algorithm that Parker studied, known as quantum phase estimation, had been previously applied to standard eigenvalue problems. Generalized eigenvalue problems introduce a second matrix, creating more mathematical complexity. Solving them is critical to understanding common physics and engineering questions, such as nuclear fusion reactors' efficiency.

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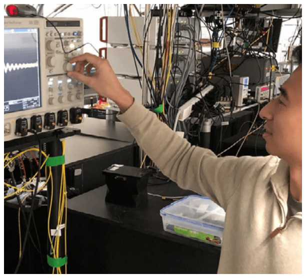
Extending quantum states to last 10,000 times longer



A team of University of Chicago scientists led by David Awschalom discovered a simple modification that allows quantum systems to stay coherent 10,000 times longer than before. Rather than physically isolating a system from the noisy surroundings that lead to decoherence, the team worked with the usual electromagnetic pulses used to control quantum systems, applying an additional continuous alternating magnetic field. This allowed the system to stay coherent up to 22 milliseconds and almost completely tune out some forms of temperature fluctuations, physical vibrations, and electromagnetic noise, all of which usually destroy quantum coherence. The discovery, published in *Science*, should enable more complex quantum computing operations and allow quantum information to travel longer distances.

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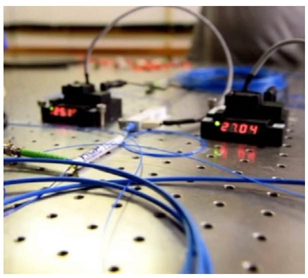
Researchers mark progress in developing a quantum internet



For the first time, scientists have demonstrated a sustained, long-distance teleportation of qubits of photons with fidelity above 90 percent. The qubits were teleported over a fiber-optic network of 44 kilometers using single-photon detectors. Fermilab scientist Panagiotis Spentzouris co-authored the study, published in *PRX Quantum*, which makes headway in realizing a quantum internet. The achievement follows a recent U.S. Department of Energy press conference in Chicago, where they unveiled a blueprint for developing a national quantum internet that would usher in a new era of communications.

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TRAINING & EDUCATION

As our understanding of quantum information science grows, so does the need for scientists and engineers able to apply these discoveries in everyday areas like computing, health care, energy, and finance. The Chicago Quantum Exchange trains the next generation of the quantum workforce and equips those already working in science and engineering to transition to quantum science careers.

60 students supported through QISE-NET since 2018

10+ CQE corporate partners providing internships

3 CQE IBM postdocs in 2020

$1.5M funding for QuSTEAM and Q2Work in 2020 to develop the quantum workforce

5 quantum companies engaged in trainee recruiting events

CONTINUING EDUCATION

Certificate programs empower established scientists to join the quantum economy

The University of Chicago has introduced a Quantum Engineering and Technology certificates program to retrain scientists and engineers in quantum technology and its applications. It empowers scientists — particularly those educated in classical physics, computer science, and other science and engineering fields — with the training to pursue a career in the growing quantum industries. The program addresses a gap in skilled quantum information science professionals highlighted by an industry survey from the Quantum Economic Development Consortium (QED-C). The program launched in September 2020 and is a collaboration between CQE and UChicago's Pritzker School of Molecular Engineering. It is the latest effort by the two organizations to develop the quantum workforce of the future.

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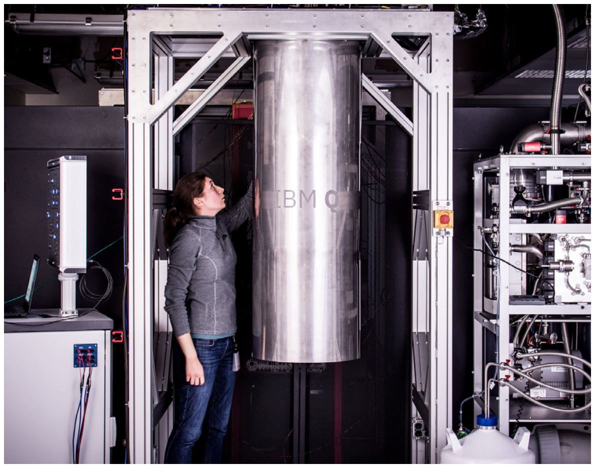
"It's the first program to transition quantum science into the hands of engineers and other professionals living outside academia in the commercial sector. It allowed me to participate in a meaningful way in this oncoming shift towards quantum technologies."

Jonathan Trousdale, Chief Technology Officer, OrthoSensor

Trousdale participated in the Quantum Engineering and Technology certificates program.



GRADUATE EDUCATION

Third cohort joins nationwide quantum training program

In 2020, the second and third cohorts of graduate students joined the Quantum Information Science and Engineering Network (QISE-NET), bringing the total number of students supported to 60. The only program of its kind, QISE-NET helps students develop pathways to industry careers by pairing graduate students with both an academic adviser and a collaborator from a leading technology company or national laboratory. Students and their two mentors pursue a pressing research question for up to three years. Managed by CQE, QISE-NET is a partnership between UChicago and Harvard University with support from a $2.5M National Science Foundation award.

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POSTDOCTORAL PROGRAM

CQE IBM postdoc program bridges academia and industry

The CQE IBM Postdoctoral Trainees program welcomed its first cohort this year. The program provides postdocs with opportunities and mentorship across all CQE member institutions and the IBM Quantum Network. By bridging academia and industry, the program is a unique platform for selected postdocs, who receive annual discretionary funds to investigate materials, fabrication techniques, algorithms, and software and hardware development to fully realize and scale quantum computers.

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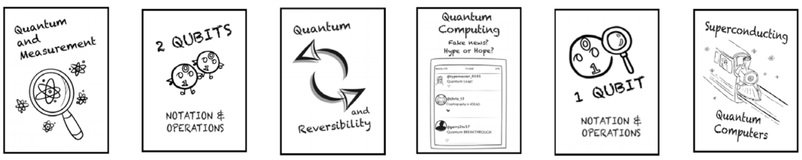
OUTREACH TO K-12 AND BEYOND

Supporting the development of QIS learning experiences and curriculum for the next generation of quantum leaders



The University of Illinois at Urbana-Champaign and University of Chicago, in collaboration with the University of Pittsburgh, are leading an ambitious national program to support the growth of a diverse and equitable quantum workforce. Q2Work is supported by a three-year, $750,000 award from the National Science Foundation and is the academic lead on the National Q-12 Education Partnership. Q2Work will collaborate with the quantum education community to build a portal for quantum education materials for all ages. In addition, the program will organize content and programming focused on key concepts in quantum information science in order to prepare these ideas for future integration into K-12.

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"The people engaged in the quantum field and making Illinois already a leader in this are just the tremendously talented individuals that we're going to rely upon for the future."

J.B. Pritzker, Governor of Illinois

Pritzker spoke at the Chicago Quantum Summit in 2020.

CQE PARTNERS

Industry

Applied Materials
Boeing
ColdQuanta
Discover
Hamamatsu Photonics
HRL Laboratories
IBM
Intel
JPMorgan Chase
Microsoft
Protiviti
Quantum Design
Quantum Machines
Quantum Opus
Qubitekk
Rigetti Computing
Super.tech
TOPTICA Photonics
Verizon
Zurich Instruments

International

QuTech
CQC^2T

Nonprofit

P33
Quantum Economic Development Consortium (QED-C)

"We're focusing our research on new qubit technologies and addressing key bottlenecks in their control and connectivity as quantum systems get larger. Our collaborations with members of the Chicago Quantum Exchange will help us harness our collective areas of expertise to contribute to meaningful advances in these areas."

Jim Clarke, Director of Quantum Hardware at Intel

Clarke on Intel partnering with the CQE to achieve quantum practicality.

"Collaborating with the Chicago Quantum Exchange will help us to be among the first to develop cutting-edge quantum algorithms for financial use cases, and experiment with the power of quantum computers on relevant problems, such as portfolio optimization and option pricing."

Marco Pistoia, Managing Director, Head of Applied Research and Engineering at JPMorgan Chase

Pistoia on how JPMorgan Chase partnering with the CQE will enable the use of quantum computing algorithms and software for secure transactions and high-speed trading.

29
CQE-hosted events

10
research seminars on recently published work

261
participants in quantum recruiting events

4
workshops on emerging research opportunities

SELECT CQE PATENTS

The following technologies from CQE-affiliated faculty members are available for licensing.

Title: SeQUeNCe - Simulator of Quantum Network Communication

Owner: Argonne, available by open-source license

Relevant publication: https://github.com/sequence-toolbox/SeQUeNCe

Contact: Paulina Rychenkova, prychenkova@anl.gov

Title: Borophenes, boron layer allotropes and methods of preparation

Owner: Northwestern University

Inventors: Andrew Mannix, Joshua Wood , Brian Kiraly, Brandon Fisher, Nathan Guisinger, Mark Hersam

U.S. Patents 10,829,381 and 10,703,637

Relevant publication: Nature Nanotech 13, 444–450 (2018). https://doi.org/10.1038/s41565-018-0157-4

Contact: Arjan Quist, arjan.quist@northwestern.edu

Title: Methods for preparation of concentrated graphene ink compositions and related composite materials

Owner: Northwestern University

Inventors: Michael Geier, Mark Hersam, Yu Teng Liang, Pradyumna Prabhumirashi, Kanan Puntambekar, Ethan Secor

U.S. Patent 10,800,939

Relevant publication: J. Phys. Chem. Lett., 4, 1347 (2013). https://doi.org/10.1021/jz400644c

Contact: Arjan Quist, arjan.quist@northwestern.edu

Title: Reconfigurable Free-Space Quantum Cryptography System

Owner: University of Illinois at Urbana-Champaign, Duke University

Inventors: Paul Kwiat, Daniel Gauthier

U.S. Patent 10,652,013

Contact: Svetlana Sowers, Ph.D., svsowers@illinois.edu

Title: Nanoscale High-Performance Topological Inductor

Owner: University of Illinois at Urbana-Champaign, U.S. Government

Inventors: Matthew Gilbert, Timothy Philip, Daniel Somerset Green

U.S. Patent 9,837,483

Relevant publication: Sci Rep 7, 6736 (2017). https://doi.org/10.1038/s41598-017-06965-8

Contact: Jeffrey Wallace, jrwallac@illinois.edu

Title: Breaking Time-Reversal Symmetry with Acoustic Pumping of Nanophotonic Circuits

Owner: University of Illinois at Urbana-Champaign

Inventors: Gaurav Bahl, Donggyu Benjamin Sohn

U.S. Patent 10,690,856

Contact: Jeffrey Wallace, jrwallac@illinois.edu

Title: Electrically Tunable Quantum Platform Using Spin Defects in Semiconductor Heterostructures

Owner: University of Chicago

Inventors: David Awschalom, Christopher Anderson, Alexandre Bourassa

International Patent App. No. PCT/US20/22702

Relevant publication: Science 2019, Vol. 366, Issue 6470, pp. 1225-1230. https://doi.org/10.1126/science.aax9406

Contact: Benjamin Cox, blcox@uchicago.edu

Title: Accessing Nonlinearity in Superconducting MM Wave Coplaner Resonators

Owner: University of Chicago

Inventors: David Schuster, Jonathan Simon, Aziza Suleymanzade, Alexander Anferov

International Patent App. No. PCT/US20/20831

Relevant publication: Phys. Rev. Applied (2020) 13, 024056. https://doi.org/10.1103/PhysRevApplied.13.024056

Contact: Benjamin Cox, blcox@uchicago.edu

Title: Semiconductor system with transitional metal impurity for quantum information processing

Owner: University of Chicago

Inventors: David Awschalom, William Franklin Koehl, Samuel James Whiteley, Berk Diler

U.S. Patent App. Nos. 10,372,015 and 10,747,087

Relevant publication: Physical Review B 95, 035207, 2017. https://arxiv.org/abs/1909.08778

Contact: Benjamin Cox, blcox@uchicago.edu

Title: Quantum Error Correction Method

Owner: University of Chicago

Inventors: David Schuster, Srivatsan Chakram

International Patent App. No. PCT/US20/20851

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