CHICAGO QUANTUM EXCHANGE

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

ANNUAL REPORT 2022

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 of Physics, the University of Illinois 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 workforce development, the CQE drives quantum jobs, companies, and technologies in Chicago, in Illinois, and across the U.S.

2021 SPOTLIGHTS

Chicago Quantum Exchange member institutions made significant strides in 2021. New institutes drove research and trained the quantum workforce of the future. Partnerships spanned universities and the private sector. The fourth annual Chicago Quantum Summit connected quantum experts from across the globe, virtually and in person.

30+

CORPORATE PARTNERS, including **11 new in 2021**

450+

CHICAGO QUANTUM SUMMIT attendees from **23 countries**

$134M

FEDERAL FUNDING to CQE members in 2021

3 international partners + **2** nonprofit partners + **1** regional academic partner

40%

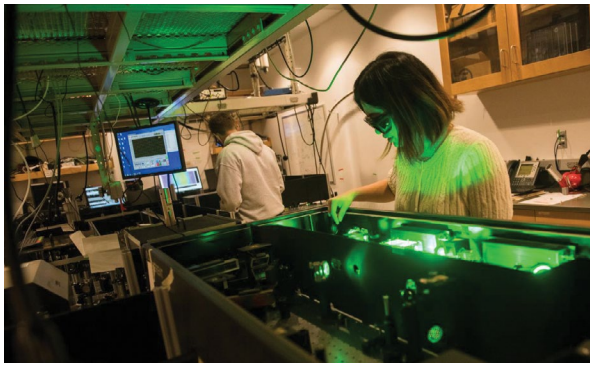
of NQI Act–funded centers awarded in Illinois

IBM-Illinois institute will accelerate discovery and education

A new collaboration drawing on the strengths of academia and the industrial sector is set to spur breakthroughs in emerging areas of technology. IBM and the Grainger College of Engineering at the University of Illinois Urbana-Champaign launched the IBM-Illinois Discovery Accelerator Institute. The large-scale collaboration is backed by a $200 million investment designed to increase access to technology education and skill development. Programming will focus on the rapidly growing areas of hybrid cloud and AI, quantum information science and technology, accelerated materials discovery, and sustainability.

Leaders of global quantum ecosystem gather at Chicago Quantum Summit

Experts from government, industry, and academia assembled at the fourth annual Chicago Quantum Summit on November 4, 2021, to consider the future of quantum information science and engineering. Twenty-five panelists from around the world discussed how to strengthen the field and expand the quantum ecosystem on local and global scales. Twenty-three countries were represented by more than 450 participants who attended either virtually or in person on the UChicago campus.



NSF establishes $25M quantum biology institute in Chicago

As part of a nationwide initiative to boost research in quantum science, the National Science Foundation established a $25 million institute headquartered at the University of Chicago, funding it for five years. The Quantum Leap Challenge Institute for Quantum Sensing for Biophysics and Bioengineering (QuBBE) is working to pioneer uses of quantum sensing for biology and to train the quantum workforce through STEM education and outreach. The new institute is a partnership between UChicago, Chicago State University, the University of Illinois Chicago, and Harvard University.

The CQE grows its network of industry and institutional partners

Two world-leading research institutions and 11 companies that help build and scale quantum technologies joined the CQE's growing network of partners in 2021. The Weizmann Institute of Science and the Ohio State University are at the forefront of quantum information science and engineering. New corporate partners advance the technologies behind quantum computing and communications, among other applications, and include Ally Financial, Classiq, Corning Incorporated, Lake Shore Cryotronics, Oxford Instruments, Toshiba Corporation, and companies participating in the Duality quantum startup accelerator. Read more about Duality on page 11.

RESEARCH & DISCOVERY

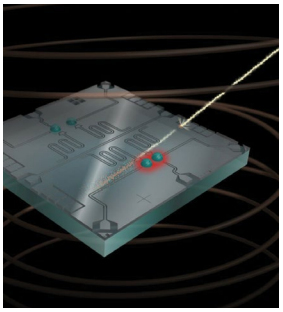
Members of the Chicago Quantum Exchange are advancing the fundamental and applied research that propels discoveries with far-reaching applications. Their initiatives bring us closer to fully understanding and controlling objects at the smallest scales.

150+
RESEARCHERS across member institutions

40
HONORS to CQE researchers in 2021

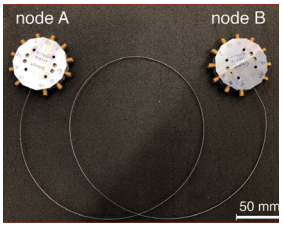
10
WORKSHOPS on emerging research

> *"Research and its translation requires a whole ecosystem approach. It needs true co-design and development between federal and state governments, industry, and researchers. We must remember that success will not be defined by the actions of just one institution, one state, or one person."*
>
> **CATHY FOLEY, Chief Scientist of Australia,** at the 2021 Chicago Quantum Summit



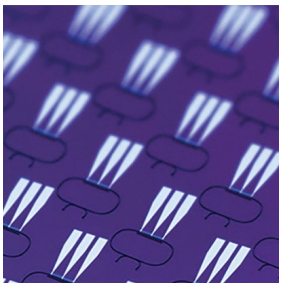
Correlated errors in quantum computers emphasize need for design changes

Quantum computers could outperform classical computers at many tasks, but only if the errors that are an inevitable part of computational tasks are isolated rather than widespread events. Researchers at the University of Wisconsin–Madison, led by physicist Robert McDermott, found evidence that errors are correlated across an entire superconducting quantum computing chip. This finding highlights a problem that must be addressed in the quest for fault-tolerant quantum computers. The study, done in collaboration with Fermilab and others, was published in the journal *Nature*. The researchers' work also points to mitigation strategies.



For first time, researchers send entangled qubit states through a communication channel

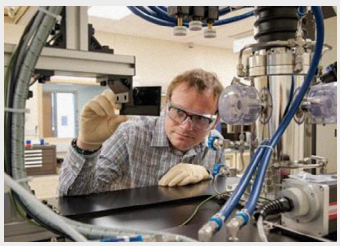
In a breakthrough for quantum computing, researchers sent entangled qubit states through a communication cable linking one quantum network node to a second node. The University of Chicago researchers, led by Andrew Cleland, also amplified an entangled state via the same cable. They first used the cable to entangle two qubits in each of two nodes, then entangled these qubits further with other qubits in the nodes. The results, published in *Nature*, could help make quantum computing more feasible and lay the groundwork for future quantum communication networks.



New photonic chip for isolating light may be key to miniaturizing quantum devices

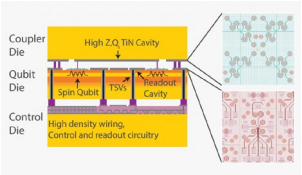
University of Illinois Urbana-Champaign and Illinois Quantum Information Science and Technology Center member Gaurav Bahl and his research group have designed a simple, compact photonic circuit that uses sound waves to rein in light. The new study, published in the journal *Nature Photonics*, demonstrates a powerful way to isolate, or control the directionality of light. The team's measurements show that their approach to isolation currently outperforms all previous on-chip alternatives and is optimized for compatibility with atom-based sensors.

CHICAGO QUANTUM PROFILE



Joe Heremans | Argonne National Laboratory

Joe Heremans is a staff scientist at Argonne, where he works on wide bandgap solid-state materials systems with individual atomic defects. These defects "trap" an electron whose quantum (spin) state can be manipulated with lasers, electric and strain fields, and microwaves. These systems have promising applications in quantum communication and nanoscale quantum sensing.

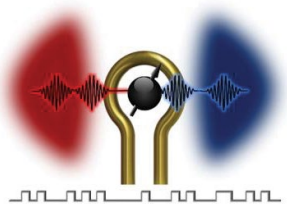


New 3D integrated semiconductor qubit saves space, maintains performance

Semiconducting qubits are a promising area of research on the road to a fully functional quantum computer. Less than one square micron in size, thousands of these qubits could fit into the space taken up by one of the current industry-leading superconducting qubit platforms. Wiring the smaller qubits has proven difficult, but researcher Nathan Holman at HRL Laboratories has solved this issue. Holman graduated from the University of Wisconsin–Madison physicist Mark Eriksson's group with a PhD in 2020. In a study published in *NPJ Quantum Information*, Holman and colleagues applied flip chip bonding to 3D integrate superconducting resonators with semiconducting qubits for the first time, freeing up space for the control wires in the process. The new chip performs as well as non-integrated ones do.

Researchers develop new tool for analyzing large superconducting circuits

The next generation of computing and information processing lies in quantum mechanics. Quantum computers are expected to be capable of solving large, extremely complex problems that are beyond the capacity of today's most powerful supercomputers. New research tools are needed to advance the field. Northwestern University scientists in the research group of Jens Koch developed and tested a theoretical tool for analyzing large superconducting circuits. Circuit size is important since protection from detrimental noise tends to come at the cost of increased circuit complexity. Currently, there are few tools that tackle the modeling of large circuits, making this method an important contribution to the research community.



Opening the gate to the next generation of information processing

Argonne National Laboratory and UChicago scientists have devised a unique means of achieving effective gate operation with a form of information processing called electromagnonics. Their pivotal discovery allows real-time control of information transfer between microwave photons and magnons. It could result in a new generation of classical electronic and quantum signal devices that can be used in various applications such as signal switching, low-power computing, and quantum networking. The new technology paves the way for improved information transfer in both classical and quantum regimes. The study, conducted by nanoscientists led by Xufeng Zhang, was reported in *Physical Review Letters*.

TRAINING & EDUCATION

Chicago Quantum Exchange members and partners educate the next generation of the quantum workforce, and equip those already working in science and engineering to transition to quantum careers. These efforts will support a trained workforce able to apply new discoveries to industries such as computing, healthcare, energy, and finance.

79

STUDENTS supported through QISE-NET since 2018

17

MEMBERS AND PARTNERS providing internships

240+

PARTICIPANTS in quantum recruiting events

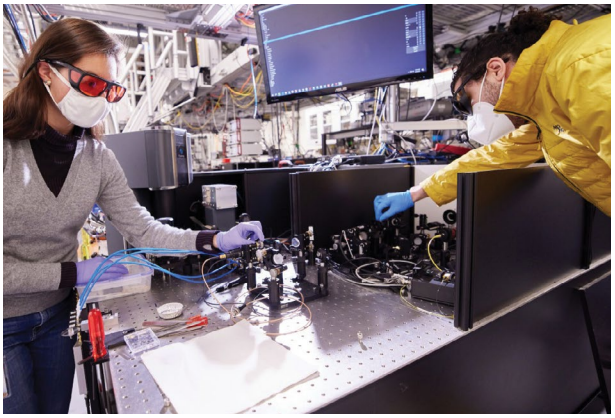
$5M

FUNDING in 2021 for QuSTEAM to develop quantum workforce

9

QUANTUM COMPANIES engaged in trainee recruiting events

UNDERGRADUATE EDUCATION



New undergraduate research fellowship champions inclusive quantum community

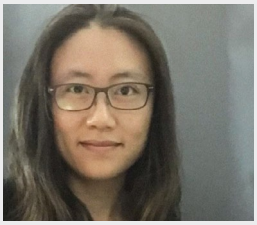
The Open Quantum Initiative (OQI) — a working group of students, researchers, educators, and leaders across the CQE — launched the OQI Undergraduate Fellowship to advocate for and contribute to the development of a diverse and inclusive quantum workforce. The fellowship program will welcome participants in summer 2022. For 10 weeks, fellows will live and work at a CQE member or partner institution, completing a research project in quantum information science and engineering under the guidance of a mentor.

QuSTEAM initiative awarded $5M to advance quantum science education

NSF's Convergence Accelerator awarded QuSTEAM $5 million to build transformative, modular quantum science degree and certification programs. The grant marks QuSTEAM's next step to develop a diverse, effective, and contemporary quantum-ready workforce by creating more equitable pathways to quantum science education. The multidisciplinary program QuSTEAM: Convergence Undergraduate Education in Quantum Science, Technology, Engineering, Arts, and Mathematics is headed by five Midwestern universities: the Ohio State University, the University of Chicago, the University of Michigan, Michigan State University, and the University of Illinois Urbana-Champaign. In Chicago, this includes a partnership to build a quantum curriculum with faculty at City Colleges of Chicago.

> *"For quantum science and engineering to achieve its full potential, it must be accessible to all. The OQI Undergraduate Fellowship provides explicit support for historically marginalized communities, which is crucial to increasing quantum engagement in a way that creates a more diverse and equitable field."*
>
> **KAYLA LEE, Academic Alliance Lead at IBM Quantum,** keynote speaker of the OQI workshop

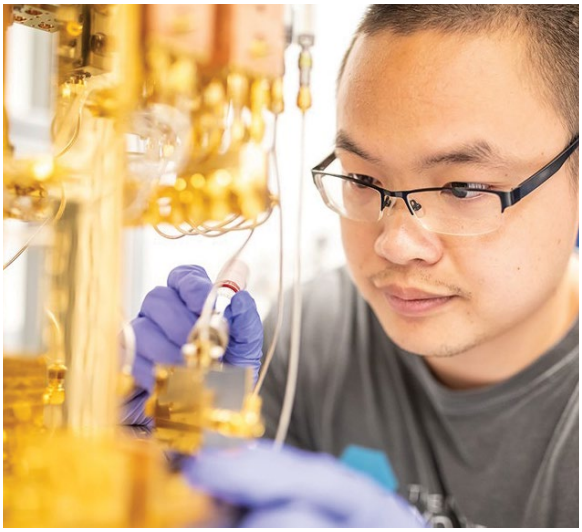
CHICAGO QUANTUM PROFILE



Jennifer Choy | The University of Wisconsin–Madison

Jennifer Choy is an assistant professor of engineering physics at the University of Wisconsin–Madison who studies quantum sensing and nanophotonics. She aspires to be a great mentor to undergraduate and graduate students and encourages students to study quantum science, even if they don't plan to go into the field professionally.

GRADUATE EDUCATION



Quantum PhD program will ready next-generation scientists

UChicago's Pritzker School of Molecular Engineering granted its first PhDs in quantum science and engineering. The new degree provides students with the skills needed to create, manipulate, and apply quantum phenomena toward developing radical new technologies. A cornerstone of PME's educational offerings is training a specialized workforce educated in aspects of applied physics, chemistry, computer science, electrical engineering, and materials science. The degree builds on this foundation, preparing graduates to help realize quantum technology's potential to transform industries including information security, healthcare, sustainability, and finance.

POSTDOCTORAL PROGRAM

Fermilab announces Carolyn B. Parker Fellowship for Black postdocs

Fermilab's Superconducting Quantum Materials and Systems Center (SQMS) announced a new fellowship opportunity for Black and African American postdoctoral scholars: the Carolyn B. Parker Fellowship, named for the first African American woman to earn a postgraduate degree in physics. The fellowship is sponsored by the DOE Office of Science and offers a three-year appointment at SQMS with a possible two-year extension. The chosen fellow will conduct research both domestically and internationally with SQMS partners.

OUTREACH TO K-12 AND BEYOND

New summer programs immerse students, teachers in quantum labs and industry

In summer 2021, the NSF Quantum Leap Challenge Institute for Hybrid Quantum Architectures and Networks (HQAN) launched a series of education and outreach opportunities. High school teachers and advanced students gained hands-on experiences in quantum science and engineering. TeachQuantum placed high school teachers in quantum research labs and prepared them to teach quantum-focused STEM concepts in their classrooms. Chicago State University students gained research experiences to address quantum science topics. And HQAN students interned in the quantum industry, at Qubitekk and ColdQuanta.

CHICAGO QUANTUM PROFILE

Eric Chitambar | The University of Illinois Urbana-Champaign

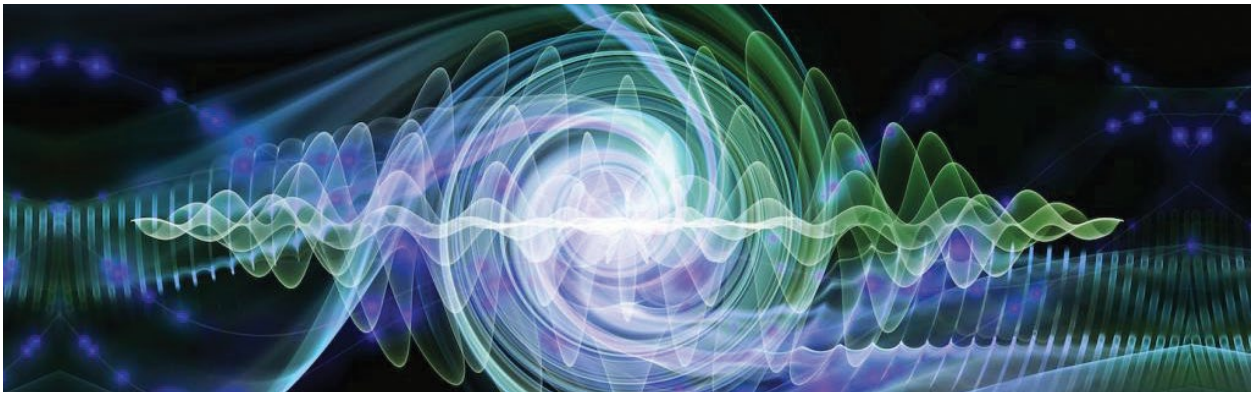
Eric Chitambar is an associate professor of electrical and computer engineering at the University of Illinois Urbana-Champaign, where he studies quantum information theory. He's interested in understanding different ways that fundamental nonclassical features of quantum systems, such as entanglement and coherence, can be used to enhance communication. To students thinking about a career in quantum information science, he says, "Do it!"

BUILDING THE QUANTUM ECONOMY

By convening leading academic researchers, top scientific facilities, and innovative industry partners, the Chicago Quantum Exchange is unlocking the region's potential to be the center of the quantum economy by fueling world-changing discoveries, empowering a robust quantum workforce, and creating quantum jobs across the U.S.

> *"The sheer potential of quantum to transform the way so many sectors operate has been matched at only a few points in human history, and Illinois' advantages in the quantum revolution have already centered our state as a leader."*
>
> **J.B. PRITZKER, Governor of Illinois,** in the announcement for Duality

> *"Through the launch of Duality, Chicago is showing the world that it has the critical elements needed to incubate and launch these types of ventures."*
>
> **VANESSA CHAN, Chief Commercialization Officer at DOE and Director of DOE's Office of Technology Transitions,** in the announcement for Duality



Duality quantum startup incubator-accelerator launches, welcomes first startup cohort

In 2021, the CQE and the University of Chicago Polsky Center for Entrepreneurship and Innovation launched Duality, the first accelerator program in the nation exclusively dedicated to startup companies focused on quantum and enabling technologies. Duality provides technical and business resources to help quantum startups bridge the gap between the laboratory and the marketplace that is a critical barrier to success for emerging technologies. Duality is reinforced by its founding partners, the University of Illinois Urbana-Champaign, Argonne National Laboratory, and P33.

DUALITY SELECTED SIX COMPANIES TO JOIN ITS FIRST COHORT OF QUANTUM STARTUPS:

Axion Technologies, a Tallahassee, Florida–based company led by Carol Scarlett. The startup is developing a quantum random number generator for high-performance computing systems.

Great Lakes Crystal Technologies, an East Lansing, Michigan–based company led by Keith Evans. The startup is developing a commercial manufacturing process for semiconductor-grade diamond materials for photonics, electronics, and quantum technology applications.

qBraid, a Hanover, New Hampshire–based company led by Kanav Setia. The startup is developing a cloud-based platform for managed access to other quantum computing software and hardware.

QuantCAD, an Iowa City, Iowa–based company led by Michael Flatté. The startup is developing simulation software for modeling noise and current in quantum devices such as high-resolution quantum sensors.

Quantopticon, a Guildford, United Kingdom–based company led by Mirella Koleva. The startup is developing simulation software for designing and optimizing quantum optical devices.

Super.tech, a Chicago, Illinois–based company led by Pranav Gokhale. The startup is developing software that accelerates quantum computing applications by optimizing across the system stack from algorithms to control pulses.

Duality startups work out of the offices of the Chicago Quantum Exchange, where they gain from and strengthen an immersive ecosystem. The startups benefit from entrepreneurial training, mentorship, exposure to industry, access to state-of-the-art facilities, funding, and connections with investors and strategic partners.

CQE PARTNERS

Industry

Ally

Applied Materials

ASM

Atom Computing

Boeing

Classiq

ColdQuanta

Corning

Discover

EeroQ

Hamamatsu

HRL Laboratories

IBM

Intel

JPMorgan Chase

Lake Shore Cryotronics

Microsoft

Oxford Instruments

Protiviti

Quantum Design

Quantum Machines

Quantum Opus

Qubitekk

Rigetti Computing

Super.tech

TOPTICA Photonics

Toshiba

Verizon

Zurich Instruments

Duality Startups

Axion Technologies

Great Lakes Crystal Technologies

QuantCAD

qBraid

Quantopticon

Super.tech

International

QuTech

CQC²T

Weizmann Institute of Science

Nonprofit

P33

Quantum Economic Development Corporation (QED-C)

Regional

The Ohio State University

QUANTUM CONVERSATIONS

"We are talking to people in industry and academia about what aspects of quantum information are most critical, what skills are needed, what workforce training looks like today and what they expect it to look like a couple years from now."

EZEKIEL JOHNSTON-HALPERIN, QuSTEAM lead investigator, Professor, Department of Physics, The Ohio State University, in the QuSTEAM announcement

"Instead of relying on the materials we know exist, we should continue to try to make new ones, make them better — develop qubits based on what we want, not what we have."

ELIZABETH GOLDSCHMIDT, Assistant Professor in Atomic, Molecular, and Optical Physics at the University of Illinois Urbana-Champaign; member of the Illinois Quantum Information Science and Technology Center (IQUIST), Hybrid Quantum Architectures and Networks (HQAN), and Q-NEXT, in a profile for Argonne National Laboratory

"I think it's very clear now that quantum information science is a foundational change in information science and technology. That has to have dramatic impacts on our economy, national security, and future prosperity. We know some of those, and we have a lot to learn about how those impacts will manifest themselves in the next 10 or 20 years."

CHARLES TAHAN, Assistant Director for Quantum Information Science and Director, National Quantum Coordination Office, White House Office of Science and Technology Policy, at the 2021 Chicago Quantum Summit

SELECT CQE PATENTS

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

Title: Silicon-Germanium Alloy-Based Quantum Dots with Increased Alloy Disorder and Enhanced Valley Splitting

Owner: The University of Wisconsin–Madison

Inventors: Mark Friesen, Merritt Losert, and Susan Coppersmith

US Patent 63/214,957, filed on June 26, 2021

Contact: Emily Bauer, emily@warf.org

Title: Silicon-Germanium Heterostructures with Quantum Wells Having Oscillatory Germanium Concentration Profiles for Increased Valley Splitting

Owner: The University of Wisconsin–Madison

Inventors: Robert Joynt, Mark Friesen, Mark Eriksson, Susan Coppersmith, and Donald Savage

US Patent 11,133,388

Contact: Emily Bauer, emily@warf.org

Title: Physical Layer of a Quantum Communication Network

Owner: Northwestern University, Purdue Research Foundation

Inventors: Mahdi Hosseini, Gregory Kanter, Prem Kumar

US Patent 63/137,673

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

Title: Quantum Repeaters with Concatenated Quantum Error Correction

Owner: The University of Chicago

Inventors: Liang Jiang, Filip Rozpedek, Kyungjoo Noh

International Patent App. No. PCT/US21/35940

Relevant publication: npj Quantum Inf 7, 102 (2021). **https://doi.org/10.1038/s41534-021-00438-7**

Contact: Mario Riojas, riojasm@uchicago.edu

Title: Biocompatible Surface Functionalization Architecture for a Diamond Quantum Sensor

Owner: The University of Chicago

Inventors: Peter Maurer, Mouzhe Xie

US Patent App. No.: 63/203,315

Relevant publication: **https://arxiv.org/abs/2108.04843**

Contact: Ben Cox, blcox@uchicago.edu

Title: Universal Coherence Protection in a Quantum Three-Level System

Owner: The University of Chicago

Inventors: David Awschalom, Kevin Miao

International Patent App. No.: PCT/US21/31569

Relevant publication: Science 369(6510):1493-1497 (2020), **https://www.science.org/doi/10.1126/science.abc5186**

Contact: Ben Cox, blcox@uchicago.edu

Title: Method for Precision Quantum-Interference Based Non-local Contactless Measurement

Owner: The University of Illinois Urbana-Champaign

Inventors: Paul Kwiat, Colin Lualdi, Spencer Johnson, Kristina Meier

US Patent 63/249,256

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

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

Owner: The University of Illinois Urbana-Champaign

Inventors: Gaurav Bahl, Donggyu Benjamin Sohn

US Patent 10,690,856

Contact: Jeffrey Wallace, jrwallac@illinois.edu

CHICAGO QUANTUM EXCHANGE

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