

ISSUE 27 | FALL 2015

A NEWSLETTER FROM THE INSTITUTE FOR QUANTUM COMPUTING, UNIVERSITY OF WATERLOO

NEWMBIT

A **big** space
to work with the
very small

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UNIVERSITY OF
WATERLOO



Institute for
Quantum
Computing



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Collaboration with a new department - pure mathematics.

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Two Quantum Frontiers Distinguished Lectures within a month.

ON THE COVER

Plassys Sputter for niobium superconducting films and an assortment of fume hoods in the Quantum NanoFab.

Cover Photo by: IQC

FALL 2015

publisher
IQC COMMUNICATIONS &
STRATEGIC INITIATIVES

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FROM THE EDITOR

Why do we celebrate our visitors at the Institute for Quantum Computing? Why do we encourage our members to visit other institutes and communities? Because an introduction to new people could mean new ideas, and that could mean great collaborations. Sometimes it just leads to the introduction of quantum information and science to a new curious audience.

The spring term was full of visits. Guests from around the world attended workshops, conferences and schools at IQC. Often we take the opportunity to invite these guests to present a talk, a Quantum Frontiers Distinguished Lecture or a public lecture. We were lucky enough to host two Distinguished Lectures featuring **IMMANUEL BLOCH** from the Max Planck Institute of Quantum Optics and **LEO KOUWENHOVEN** from the Delft University of Technology.

Kouwenhoven was part of a Dutch delegation visiting Canada with the **KING AND QUEEN OF THE NETHERLANDS**. It was a great honour to roll out the orange carpet for the royals who were at IQC to witness the signing of MOUs and the presentation of the first Liberation Scholarships to Canadian students.

Canadian students, as well as students from around their world, joined us at IQC for three schools this summer. QCSYS and USEQIP introduce a new generation of researchers to quantum mechanics, while QKD provides graduate students and young postdoctoral fellows with relevant approaches and techniques to their research.

Our researchers also hit the road to talk about IQC and the research we do here. Not only do they speak at scientific conferences, but they speak with some "new" audiences that are curious about the quantum world. **RAYMOND LAFLAMME** had the opportunity to head to Ottawa with the Kitchener-Waterloo Symphony to perform *Quantum Music at the Frontier of Science*, as well as a visit to Stratford to speak as part of the Stratford Festival's Forum series.

Whether we host visitors or we visit others, if we host researchers or curious high school students, we teach, we share and we learn. Every visit brings new opportunities.

JODI SZIMANSKI, Senior Communications Manager

A scholarship and a **royal** handshake

Their Majesties King Willem-Alexander and Queen Máxima visited Waterloo to attend a presentation of scholarships in celebration of the 70th anniversary of the liberation of the Netherlands during the Second World War.



- » The Liberation Scholarship winners including IQC's **MADELAINE LIDDY** (third from the right) with the Royal Couple (centre).
- » **FERIDUN HAMDULLAHPUR**, University President & Vice-Chancellor welcomes their Majesties.

MADELAINE LIDDY, a master's student in electrical and computer engineering with a specialization in quantum information, was among the first of 70 Canadians who received the Liberation Scholarship. Studying under **DAVID CORY**, Canada Excellence Research Chair in Quantum Information Processing, Liddy is researching Nitrogen-Vacancy (NV) chemical sensors.

NV centres are defects in diamond that can be used as extremely precise quantum processors. Liddy's work involves modifying the diamond surfaces to optically control shallowly

implanted NV centres. Once modified, biological and chemical species such as proteins or DNA can be attached to the surface and detected through changes in the local magnetic field of the NV centre in diamond.

Liddy will spend a term at Delft Technical University to continue her research on Nitrogen-Vacancy (NV) chemical sensors with Professor **RONALD HANSON**.

"I am incredibly honoured to receive this scholarship and to keep the connection between the Netherlands and Canada alive and strong," said Liddy.

With uncles, cousins, a brother-in-law and a grandfather who served in the Canadian military, Liddy is proud to share stories of their service during the Second World War, the Korean War and in Afghanistan. In addition, Liddy has an aunt whose Dutch parents survived the German occupation of the Netherlands. "After surviving the loss of family members, malnutrition and forced labour, Canada became a beacon of hope for them," she said. ■



A **big** space to work with the very small



ULTRA-CLEAN
CLASS-100 CLEANROOM WITH

less than **100 particles** per cubic
foot of air



TEMPERATURE
FLUCTUATION:

+/- 0.1°C



Researchers in the Quantum NanoFab are working with films as thin as three to four nanometers (nm) – for perspective, the width of DNA molecules is approximately 2.5 nm.

Nanofabrication is an extremely complex and challenging task; in part because of the size of the devices that researchers are attempting to build. According to **VITO LOGIUDICE**, Director of Operations, Quantum NanoFab, it's also extremely gratifying when you can get something to work in a repeatable fashion.

Since our last story in our Winter 2014 issue, the Quantum NanoFab has now opened and devices are being built in the 8,000 square foot facility. Over 120 registered users are trained to use state-of-the-art equipment to further the research of both the Institute for Quantum Computing (IQC) and the Waterloo Institute for Nanotechnology (WIN).

Powerful tools for the very small

When building devices, researchers use three broad categories of fabrication processes:

- » **Deposition, or growth, of different types of materials**
- » **Patterning materials**
- » **Etching to selectively remove materials as a function of a pattern.**

One of the nine deposition tools in the Quantum NanoFab is the AJA Twin Chamber Sputter System. As the name suggests, it has two chambers connected by a load lock, which is basically a vacuum chamber. The load lock allows researchers to introduce samples, called substrates, without bringing the process chambers to atmosphere, keeping their environment ultraclean. One process chamber is for materials that conduct electricity while the other is for non-conducting, or insulating films.

Researchers also have access to the Rapid Thermal Processor that can heat up to 1,000 Celsius in seconds. There is also a large furnace that can deposit polysilicon films that are doped n-type "in-situ". N-type polysilicon films have phosphorous atoms incorporated in them as needed to make a semiconductor such as silicon electrically active.

Once the materials are deposited onto their substrates, researchers typically need to pattern these thin films using lithography techniques. In addition to ovens, a mask aligner and spin coaters for this purpose, the Quantum NanoFab also has a 30kV Electron-Beam (E-Beam) Lithography System. In March 2016, a new 100kV E-Beam Lithography System will also become available. This new machine will extend the current capabilities for patterning structures from 40 nm down to 8 nm (approximately 80 atoms wide) and could be used to build structures to corral a single electron for example.

HUMIDITY RANGE:

45%

[**+/-3%**]

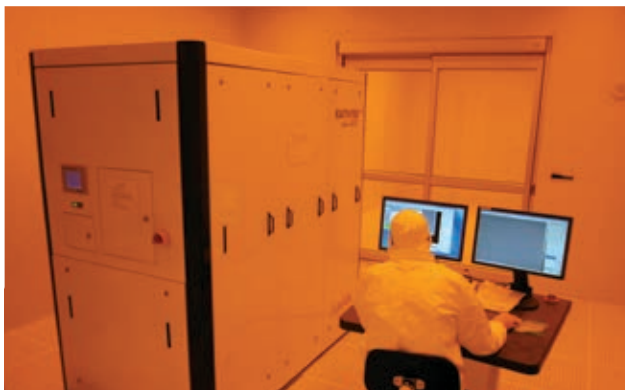
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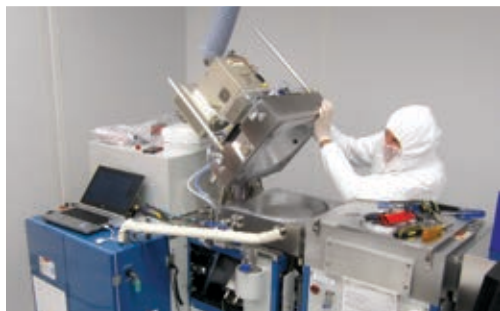
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« AJA Twin Chamber Sputter System



« Raith E-beam
Lithography system



» ALD Chamber undergoing annual PM

Some of the current projects include:

- » Semiconductor quantum dot devices
- » Superconducting quantum devices for quantum information and other applications
- » Spintronic components
- » Fabrication of Al Josephson junctions and resonator-based qubits for quantum computing
- » Terahertz silicon waveguides
- » Low-temperature scanning NV-centre magnetometry

After the patterning is complete, there is often a need to selectively remove, or etch, some of the exposed material. A flexible etching tool in the Quantum NanoFab is the Ion Mill. This machine can etch almost anything including gold and ceramic – both known for their durability and stability which makes them difficult to etch precisely. The process is similar to sandblasting, but instead of using sand, it uses ionized argon atoms to etch at the atomic scale.

Before a device is ready for use, characterization equipment is used to test various parameters. The four-point probe can measure how conductive a surface is, while the Film Stress Measurement tool measures the stresses of the layers of film to ensure they won't peel apart or degrade over time.

Measurement at the atomic scale is also sometimes required. One piece of equipment – the ellipsometer – can measure the thicknesses of films down to 3-4 nm as well as other film properties. One of the two ellipsometers in the Quantum NanoFab is integrated into the Atomic Layer Deposition (ALD) System so that it can take measurements under vacuum without the film leaving the chamber and thus risking contamination.

Building a community one layer at a time

Logiudice's team works hard to respond to and enable the nanofabrication needs of researchers at IQC and WIN. That includes ensuring that the equipment is working at its best, as well as providing training so that every researcher entering the lab starts with a base level of knowledge of the equipment operating and safety procedures.

Once trained on the specific equipment needed for their individual projects, researchers are encouraged to share their learnings. "When everyone shares their knowledge and experiences, it helps all researchers to build quality, reliable devices that will perform as designed," said Logiudice. "Anyone wanting to achieve success in such a complex field must share information."

A collaborative community with great facilities attracts great researchers. It impresses potential new faculty on tours and it's attracting industry partners and some University of Waterloo startups. With over 120 users, and more being added after training sessions held every couple of months, the possibilities to be developed in the Quantum NanoFab are endless. ■



SCIENCE HIGHLIGHTS

IQC faculty, postdoctoral fellows and students continue to conduct internationally recognized quantum information science research. Here is a sampling of their cutting-edge research published in academic journals over the past term.



» New professor, new department for collaboration

In July, IQC welcomed new faculty member **VERN PAULSEN**, and added a seventh department at the University of Waterloo – pure mathematics – to our collaborators. Paulsen's group will study the theoretical limits on the amount of information that can be communicated over a noisy channel; explore the differences between random quantum strategies and random classical strategies; and develop algorithms for finding combinatorial games that have winning quantum strategies.

While a faculty member at the University of Houston, Paulsen's work concentrated on operator theory, operator algebras, frame theory, C^* -algebras and quantum information theory. He has also been involved in the Quantum Information Technology (QIT) programs at Sweden's Mittag-Leffler Institute and Cambridge's Isaac Newton Institute, as well as a Visiting Fellow and Professor at several other universities. ■

» ANOTHER WATERLOO ALUMNUS RETURNS



WILLIAM SLOFSTRA returns to Waterloo where he completed his BMath in Pure Mathematics and Combinatorics & Optimization. After completing his PhD in Mathematics at the University of California, Berkeley, he spent six months as a Research

Associate at UBC before becoming the Kreneger Assistant Professor at the University of California, Davis.

As a Research Assistant Professor at IQC his research aims to apply Lie theory/representation theory, Schubert calculus and connected areas to quantum information, as well as identify new classes of tractable non-local games that might be especially suitable for practical applications. Non-local games give an example of a distributed computational task where entanglement can improve performance. This has applications in other tasks in quantum information including entanglement verification and quantum key distribution. ■

Similarities between a classical and quantum coin-flip

Quantum communication can sometimes offer remarkable security advantages between two parties sharing information. Understanding these advantages is key to designing quantum cryptographic protocols. A team of researchers has found a way to further analyze the security of quantum protocols for a cryptographic task known as coin-flipping, where two parties who do not trust each other generate a truly random bit.

IQC alumnus **JAMIE SIKORA**, now at the Centre for Quantum Technologies (CQT), National University of Singapore, along with faculty member **ASHWIN NAYAK** and **LEVENT TUNÇEL**, Department of

Combinatorics and Optimization at the University of Waterloo presented deep mathematical connections between quantum and classical coin-flipping protocols, and as a result, are able to rule out a large family of quantum protocols from attaining the best known bound on security. These results could be helpful in finding secure multi-party quantum protocols in the future and lead to further research in quantum cryptography.

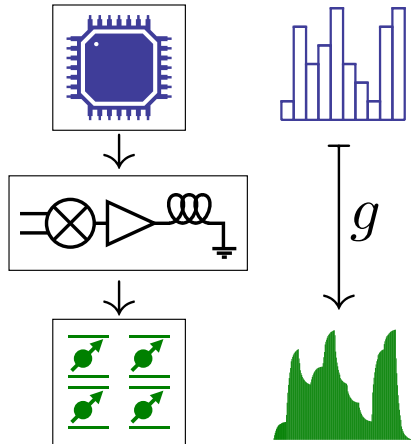
The paper *Quantum and classical coin-flipping protocols based on bit-commitment and their point games* appeared on the arXiv in April.

WEB <http://bit.ly/QuantumCoinFlip> ■

SCIENCE HIGHLIGHTS

CONTROL IN QUANTUM DEVICES

PHYS. REV. APPLIED 4, 024012 (2015)



Design of a quantum device sometimes requires a compromise between the complexity of the control hardware and its overall efficiency of controlling the quantum system. A team of researchers has developed a general framework that will minimize this compromise, leading to faster quantum logic gate times and lower error rates in certain implementations to minimize the impact of the imperfection of the control hardware.

Control hardware is usually designed to minimize distortions that classical electronics introduce to control pulses as they are sent to quantum systems. This can limit the capability and performance of the hardware. The new framework proposes a practical way to account for distortions and still yield precise and robust quantum control – even if the distortions are nonlinear and noninvertible. As an example, they performed a numerical demonstration of the robust control of a qubit with a strongly-driven superconducting resonator. The next step will be to demonstrate that this technique is useful experimentally to create practical robust quantum devices.

The paper, *Controlling Quantum Devices with Nonlinear Hardware* by IQC researchers **IAN HINCKS**, **TROY BORNEMAN** and **DAVID CORY**, and IQC alumnus **CHRISTOPHER GRANADE**, now at the University of Sydney, appeared in *Physical Review Applied* in August.

WEB <http://bit.ly/QuantumDeviceControl> ■

» CONFERENCES

Quantum computing and classical programming languages collide

Few opportunities exist for experts from the fields of quantum computing, programming languages and compiler design to exchange ideas and report on their research progress. The Quantum Programming and Circuits Workshop held at IQC June 8-11 included conversations about building tools for automation and verification of large quantum circuits and corresponding quantum “programs”, the simulation of quantum computers by classical computers and embedded languages versus non-embedded languages.

Some of the presentations by IQC members or alumni included:

- » Postdoctoral fellow **VLAD GHEORGHIU**: *Quantum ++ - A modern C++ quantum computing library*
- » Alumnus **DAVID GOSSET** (Caltech): *Exact synthesis of single-qubit unitaries over Clifford cyclotomic gate sets*

WEB To view the talks from the workshop, go to:
<http://bit.ly/June2015Workshop> ■



» Catching up after a session at the conference



An interdisciplinary community discussing emerging technologies

The 5th Nanoscale Magnetic Resonance Imaging (NanoMRI) Conference brought together an interdisciplinary community of scientists and engineers July 27-31. This year's conference focused on emerging technologies for detecting spins on the nanometer scale, and the application of these technologies to biology, condensed matter systems and quantum information. This year's speakers were a select group from three communities: Magnetic Resonance Force Microscopy (MRFM), Optically-Detected Magnetic Resonance (ODMR) using nitrogen vacancy (NV) centers and quantum nano mechanics. Postdoctoral fellow **TROY BORNEMAN** was one of the invited speakers and presented a talk called *High-fidelity Pulsed Electron Spin Resonance with High-Sensitivity Superconducting Resonators*.



WEB To view the talks from the conference, go to: <http://bit.ly/NanoMRIVideos> ■



TALKS



The social psychology of why women's science grades are lower

IQC sponsored a FemPhys talk by Professor **CHRISTINE LOGEL** from Renison University College. Logel's talk focused on social psychology and the reality of being a woman in STEM.

With a "choose your own adventure" format, Logel covered topics of the audience's choice. The selections included the theory and evidence of why women's science grades may be lower than they deserve and the huge intervention that she is helping lead. The intervention consists of working to reconstrue experiences with different treatments so that stigmatized groups could score higher on tests, such as telling test subjects that all genders perform well on a test.

WEB Watch the recorded talk: <http://bit.ly/ChristineLogel> ■

WHAT'S NEXT AFTER MOORE'S LAW?

JOHN MARTINIS, a professor at the University of California, Santa Barbara (UCSB) and a research scientist in the Google Quantum Artificial Lab visited IQC on August 10 and presented *What's next after Moore's law: quantum computing?* Martinis discussed his recent research at UCSB on superconducting quantum bits as well as his work at Google to build a quantum computer that will solve machine-learning problems. ■

» IQC OUTREACH

» TALKS & TOURS

» Double Distinguished Lectures

During the spring term, we hosted two Quantum Frontiers Distinguished Lectures. First, **LEO KOUWENHOVEN** presented *Majorana Fermions: Particle Physics on a Chip* on May 28. A professor of physics at Delft University of Technology, Kouwenhoven accompanied the delegation from the Netherlands for their visit to announce the Liberation Scholarships (see the story on page 3). Sponsored by Microsoft, Kouwenhoven's group has been searching for particles that are equal to their anti-particles – majorana fermions – in semiconductor nanowires. This work has possible applications for robust and fault tolerant quantum information processing and novel opto-electronic devices.



On June 24, **IMMANUEL BLOCH** of the Max Planck Institute of Quantum Optics gave a talk about ultracold atoms. The talk, *From Topological Bloch Bands to Long-Range Interacting Rydberg Gases – New Frontiers for Ultracold Atoms*, focused on how he and his team had realized artificial gauge fields and topological Bloch bands in ultracold atoms. He also discussed recent results on quantum magnetism with ultracold atoms for novel long-range interacting spin models using Rydberg gases to allow the generation of new phases of matter.

WEB See the video of Kouwenhoven's talk: <http://bit.ly/Kouwenhoven> or Bloch's talk: <http://bit.ly/IBloch> ■



THE MYSTERIES OF QUANTUM COMPUTING

KRYSTA SVORE, a Senior Researcher at Microsoft Research delivered a public lecture on June 9 titled *Quantum Computing: Transforming the Digital Age*. The lecture revealed some of the mysteries of quantum computing, but also showcased recent advances in the field. Before this next revolution in computing can occur, Svore explained the requirements and difficulties of building a quantum computer. Svore also highlighted some of the applications of quantum algorithms and computing including quantum security, artificial intelligence, agriculture and materials science.

WEB Watch the public lecture: <http://bit.ly/KrystaSvore> ■



QUANTUM ON THE ARTS SCENE

Quantum: Music at the Frontier of Science was presented as part of the Ontario Scene at The National Arts Centre in Ottawa on May 3. A collaboration between the Kitchener-Waterloo Symphony and IQC, this musical journey explores the parallels between music and science. Invited guests of IQC, University of Waterloo alumni and others had the opportunity to follow a presentation that starts with the early physics of Newton to quantum mechanics while hearing Mozart, Webern and the avant-garde work of Xenakis and Cage. ■



Curiosity in the field of physics

RAYMOND LAFLAMME travelled west to Stratford on June 28 to be part of a Forum discussion at the Stratford Festival's Studio Theatre with CBC host **PAUL KENNEDY**. Laflamme talked about the quantum revolution, the synergies between the arts and science and what role imagination and curiosity play in the field of physics. He compared the curiosity that led to humans learning how to control fire and use it as a tool that eventually led to steam engines to quantum researchers today trying to learn how to control quantum systems in order to develop a quantum computer. "By being curious and harnessing curiosity, we can help society, help each other to do something, help human conditions," he said. ■

» **RAYMOND LAFLAMME** meets with attendees after the Forum discussion.



KEEPING UP WITH MARTIN

Before students left for the summer, **MARTIN LAFOREST** hosted several high school programs including two Centre for Education in Mathematics and Computing (CEMC) programs, the Workshop in Computer Science for Young Women and the Auckland Workshop. He also hosted students from Sir John A. MacDonald and Centre Wellington District high schools.

Laforest and his many outreach volunteers continued their work through the summer with students as well as teachers, including:

- » **The Perimeter Institute's (PI) International Summer School for Young Physicists program**
- » **PI's EinsteinPlus program**
- » **A group from the CEMC Math Teacher's Conference**
- » **A group on Canadian Association of Physicists annual congress teacher's day**

Various other participants attended sessions on quantum information science and technology this summer including:

- » **SHAD**
- » **University of Waterloo's IDEAS Summer Experience**
- » **Catalyst, an initiative of Waterloo's Faculty of Engineering ■**



» CONFERENCES

Eight days of quantum mechanics

This year, 22 female and 23 male high school students attended the **Quantum Cryptography School for Young Students (QCSYS)** from August 7 to 14. For the first time, we extended the program by three days allowing for more group work, more hands-on activities, and more time to assimilate new concepts, including an in-depth overview of quantum computing and a mentoring session with IQC faculty members, postdoctoral fellows and graduate students. The students from Canada, US, Pakistan, Turkey, UK, Brazil, Zimbabwe, South Africa and the United Arab Emirates, also enjoyed some down time with a visit to Niagara Falls, laser tag and a campfire. ■

» Undergraduate students focused on quantum information science

The Undergraduate School on Experimental Quantum Information Processing (USEQIP) program welcomed 24 undergraduate students to IQC from May 25-June 5. Students in engineering, physics, chemistry, mathematics and computer science, all with an interest in quantum information, got the chance to hear from leading theoretical and experimental researchers and participate in over 30 hours of hands-on activities in the labs. USEQIP students travelled from Canada, US, Brazil, Germany, Denmark, Spain, Republic of Cyprus, Turkey, Iran, Bulgaria, India and South Korea to participate in the program. ■



BUILDING A SOLID FOUNDATION IN QUANTUM COMMUNICATION

From August 17 to 21, 60 students joined us from five continents for the **Quantum Key Distribution (QKD) Summer School**. The five-day program concentrated on theoretical and experimental aspects of quantum communication with a focus on quantum cryptography. Held every two years, it provides graduate students and young postdoctoral researchers with a solid foundation in relevant approaches and techniques to enable them to perform their own independent research. ■

» UPCOMING CONFERENCE

» 7th Relativistic Quantum Information – North

June 21-24, 2016

IQC, University of Waterloo,
Waterloo, Ontario

WEB uwaterloo.ca/rqi-n ■

» Around the INSTITUTE

» student PROFILE: MIKE MAZUREK

Light and contextuality

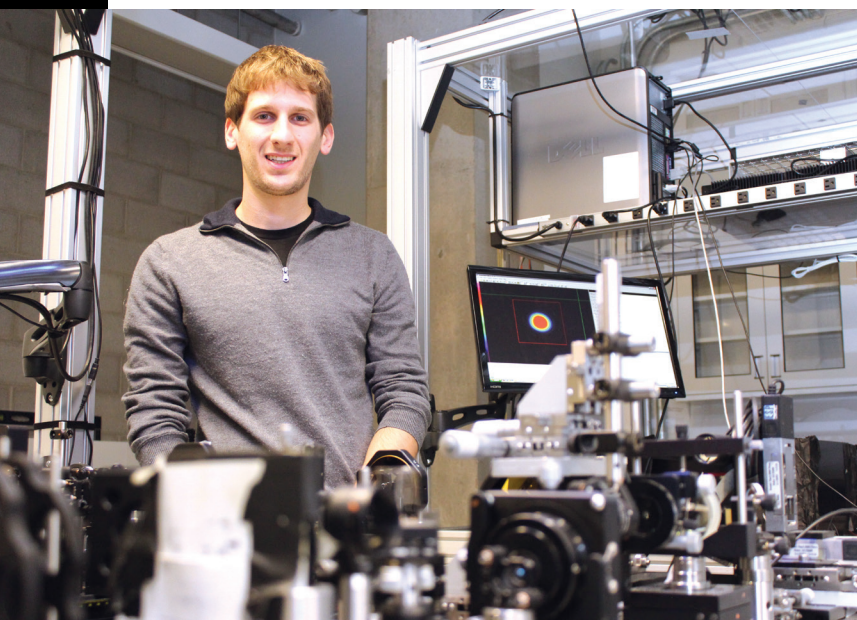
Waterloo's reputation and co-op program drew **MIKE MAZUREK** to the university, but once he took a quantum information processing course and learned about IQC, he realized his future.

Mazurek's PhD research focuses on quantum and nonlinear optics. He uses nonlinear crystals to create a pair of photons, and when one photon is detected, he immediately knows the precise location and characteristics of the other single photon to be used in experiments.

In his latest experiments Mazurek is testing the notion of noncontextuality with his supervisor, Canada Research Chair in Optical Quantum Technologies **KEVIN RESCH** and IQC affiliate and PI faculty member **ROB SPEKKENS**.

Spekkens proposed a generalized notion of noncontextuality that tries to answer the question: can we know all properties of a quantum particle before it is measured? The experiment has shown that it is impossible to always have this information, and so the universe is contextual. The notion of contextuality in quantum mechanics has been confirmed theoretically as a necessary resource required for achieving the advantages of quantum computation as published in a paper by **JOSEPH EMERSON** and postdoctoral fellows **MARK HOWARD** and **JOEL WALLMAN** last year.

Being exposed to new ideas like contextuality gets Mazurek excited. He hadn't researched the abstract ideas of quantum foundations before his first meeting with Resch and Spekkens, and thought it was a great opportunity to work with collaborators at the Perimeter Institute. Always open to new opportunities, Mazurek also gets involved in outreach activities including the *LIGHT Illuminated* exhibition at THEMUSEUM as well as USEQIP and QCSYS. With his acquired skills and knowledge, Mazurek plans to continue research in optics and see where it takes him once he's completed his PhD. ■



QUANTUM TRANSLATIONS

An artistic twist on the quantum realm

Like others studying quantum information science at the Institute for Quantum Computing (IQC), **LAURA DE DECKER** works through quantum mechanical equations and problems, but with a unique objective. As IQC's Artist in Residence, she is creating images that artistically interpret or use quantum phenomena, such as entanglement, superposition and randomness.

Last year, De Decker was awarded a 2015 Ontario Arts Council Chalmers Arts Fellowship research grant to work with IQC Executive Director **RAYMOND LAFLAMME** at Waterloo. The grant gave her the opportunity to combine her love of both art and science. Her objective: to lay the groundwork to create artistic interpretational images of quantum phenomena as large format prints and video animation.

With only a brief introduction during a university chemistry course, quantum science is new to De Decker.

She meets weekly with Laflamme, reads books about it and actually works through mathematical calculations – except her end goal is to create artistic work.

"I am translating the math of quantum mechanics into colour and form," describes De Decker. "At this point, knowing the computer programming commands is not an issue, the challenge is understanding the math and what it represents and translating it into computer code." Using a small amount of computer code through a process of distillation by making schematic sketches, calculations and intuitive processes she has developed over the past fifteen years, she changes the mathematical variables to create and build images.

De Decker's residency concluded in December. "I hope my excitement about quantum mechanics comes through the art I create," she says. "Being Artist in Residence at IQC

"I am translating the math of quantum mechanics into colour and form."

has been a wonderful opportunity. I'm so lucky to get to work with Professor Laflamme, he's a really interesting person and I am learning a lot from him. I'm also thankful for the support of Ontario Arts Council Chalmers Arts Fellowship research grant."

De Decker's existing work exploring the optical mixing of colour will be on display in the *LIGHT Illuminated* show at THEMUSEUM until March, and new work will be part of an exhibition at the Kitchener-Waterloo Art Gallery next summer. ■



Laura De Decker's work has been presented across the country, including Banff New Media Institute, Toronto's Red Head Gallery, Ed Video Media Arts Centre (Guelph), Factory Media Centre (Hamilton) and with Penderecki String Quartet's Quantum to Cosmos Festival performance at the Perimeter Institute for Theoretical Physics (Waterloo). In 2012 she was the first Christie Digital/Contemporary Art Forum, Kitchener + Area (CAFKA) Artist in Residence. Last year, she exhibited a video animation and presented a paper at the 20th International Symposium on Electronic Art (ISEA 2014) hosted by Zayed University in Dubai. Her work is in the collection of the University of Waterloo Stratford Campus and in private collections across Canada and Europe.

« **RAYMOND LAFLAMME** with Artist in Residence **LAURA DE DECKER**

Around

THE INSTITUTE

» An opportunity for undergrads to experience IQC

This year IQC developed a campaign to encourage undergraduate students to learn about quantum information processing and gain research experience by applying for both an Undergraduate Research Award and the Undergraduate School on Experimental Quantum Information Processing (USEQIP). Almost 20 students from Vietnam, Brazil, Denmark, India, Bulgaria, Cyprus and North America were accepted to attend USEQIP and spend the rest of the summer working with a researcher. Along with University of Waterloo co-op students, another four students from Waterloo, Tsinghua University and Columbia University chose to work with researchers through the Undergraduate Research Award program. ■

» TOURS/VISITS

QKDR prototyping project brings NASA to IQC

In early June, a delegation from NASA, Duke University, and **PAUL KWIAT**'s quantum information group at the University of Illinois at Urbana-Champaign (UIUC) visited IQC and toured the quantum photonics laboratory of **THOMAS JENNEWAIN**. The UIUC group previously collaborated with Jennewein's team in the radiation testing of photon detector devices at Tri-University Meson Facility (TRIUMF) as part of IQC's successful Quantum Key Distribution Receiver (QKDR) prototyping project. ■



» Students in Jennewein's quantum photonics lab.



WATERLOO INNOVATION ECOSYSTEM TOUR

The Honourable **BRAD DUGUID** (Minister of Training, Colleges and Universities at the time) visited IQC on June 8, accompanied by the MPPs of Cambridge and Kitchener-Centre **KATHRYN MCGARRY** and **DAIENE VERNILE**. The visit was part of a Waterloo innovation ecosystem tour that included the Perimeter Institute, IQC and Quantum Valley Investments. ■

» **MIKE LAZARIDIS**, Duguid, McGarry and Vernile listen to **RAYMOND LAFLAMME** describe the ultra high vacuum cluster deposition tool while senior scientist **DELER LANGENBERG** looks on.

SHARING COMMON INTERESTS

On May 5, several members of Defence Research and Development Canada (DRDC) visited IQC to talk about areas of common interest including quantum sensors, quantum materials and quantum communication. Several IQC researchers including Canada Research Chair in Optical Quantum Technologies **KEVIN RESCH**, **CHRIS WILSON**, **KYUNG CHOI**, **JONATHAN BAUGH**, **MICHELE MOSCA**, **THOMAS JENNEWAIN**, **ADRIAN LUPASCU**, **GUOXING MIAO** and Canada Excellence Research Chair **DAVID CORY** presented their related research. ■



⤴ Defence Research and Development Canada members with IQC researchers outside RAC II.

≡ ANNOUNCEMENTS



Our Quantum World launches

On May 5, IQC launched a new blog – *Our quantum world* – written by quantum researchers for quantum researchers and anyone interested in their work. The blog gives IQC students, postdoctoral fellows, faculty and invited guests a platform to share their work and insights in a more technical way. Readers are able to find out more about IQC researchers and their work and how it can impact science and society. The term's topics included:

- » Quantum satellites and general relativity
- » The judgment of research papers based on the journal publishing them
- » The importance of learning business lingo for IQC entrepreneurs
- » The EPR paradox
- » The importance of diversity in a workplace
- » Summaries of conferences

WEB uwaterloo.ca/iqc/blog ■

Around

THE INSTITUTE

Taking Research2Reality

Research2Reality shares the stories of world-class researchers who are at the leading edge in Canada.

RAYMOND LAFLAMME and **MICHELE MOSCA** were both invited as interviewees for their video series.

Laflamme explained that by understanding quantum behaviour, we can not only predict it, but control it to create new technologies. These technologies include quantum computers, but also devices that are more sensitive and precise than ever. Mosca focused on how quantum computers will solve mathematical problems so much faster than today's computers and how that will affect the way we protect our information.

WEB Watch the videos:

<http://bit.ly/Research2Reality> ■

FEATURED ON THE DISCOVERY CHANNEL

Innovations with Ed Begley, Jr., featured IQC on the Discovery Channel on May 25. The episode focused on research happening at IQC; explaining how it harnesses the quantum laws of nature in order to develop powerful new technologies and drive future economies. To help audiences understand how quantum mechanics will lead to a new set of technologies that will become an economic driver for the 21st century, the segment showed researchers exploring the deepest questions about quantum.

The full episode included IQC, GE Lighting and Heliene. "These technologies are truly remarkable," said Robert Sikich, Producer for *Innovations*. "The episode was jam-packed with exciting educational information."

WEB <http://bit.ly/InnovationsTVspot> ■



Inspiring flash fiction

Annually, the Centre for Quantum Technologies (CQT) in Singapore runs a contest for quantum-inspired flash fiction. For 2015, IQC joined several partners to help judge the contest and offer its own mini-contest.

The quantum world offers lots of scope for enthralling characters and mind-blowing plot twists, according to Artur Ekert, CQT's director and co-inventor of quantum cryptography. "A writer has plenty to play with when science allows things to be in two places - or even two universes - at once," he says. "The result might be funny, tense or even confusing. But it certainly won't be boring."

Entries were accepted until 11:59:59 PM US EST on December 1, 2015.

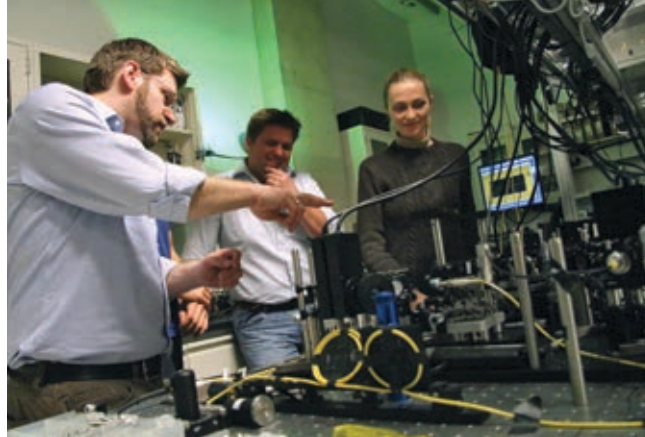
WEB shorts2015.quantumlah.org ■

»» IN THE NEWS

Reporting on the Dutch Royal visit

While several news outlets covered the Dutch Royal visit to Canada, **BRENT DAVIS** of the *Waterloo Region Record* captured the visit to the University of Waterloo. The visit began with **KING WILLEM-ALEXANDER AND QUEEN MÁXIMA** witnessing the signing of two memoranda of understanding: the first, the university and Delft University of Technology, and secondly Waterloo Region and Brainport Eindhoven Region. Afterwards, the Royals were accompanied to a presentation of the six Liberation Scholarships to Canadian students, including IQC Master's student **MADELAINE LIDDY**.

WEB Read the *Waterloo Region Record* article: <http://bit.ly/RoyalVisitCoverage> ■



⤴ **ROB SPEKKENS** and **KATJA RIED** of PI with **KEVIN RESCH** in Resch's Quantum Optics and Quantum Information Lab.

EUREKA! OVER DINNER

After a talk **ROB SPEKKENS** gave at the Convergence conference called *Cause and Effect in a Quantum World*, he and **CHAD ORZEL** had dinner. This discussion inspired a story in *Forbes* magazine on June 29 called *What's the Point of Science Without 'Eureka!' Moments?*

Spekkens described an experiment he completed with Canada Research Chair in Optical Quantum Technologies **KEVIN RESCH** and collaborators at IQC and the Perimeter Institute. He shared with Orzel that he sometimes questioned quantum foundations experiments because so often the experiments prove exactly what the theories predict. After their conversation, Orzel concluded that there are several reasons to continue experiments such as Spekkens': it's not impossible for results to be different than the theory's conclusions; there's value in negative results - good practice for the technology and procedures and may lead to the development of better technology for the labs; and ultimately because we can.

WEB <http://onforb.es/1OWoFQL> ■

FROM THE IQC GSA



The summer in Waterloo was a hot one, and IQC students knew how to take advantage of it. Throughout the summer on most Fridays, a motley crew of IQC members could be found on the patio of the Research Advancement Centre, with two barbecues fired up and burgers being passed out left and right. When the leaves started falling, the barbecues had to be rolled back away, but rest assured that they'll be back the moment the snow melts.

To beat the heat, IQC students found solace in the refreshing air-conditioned chaos of laser tag mid-June. It all came down to the matchup of Team Lasers vs. Team Attenuators, where those who spend their days in the lab with lasers found their hard work pay off as they walked off triumphantly. With the arrival of new students in September, IQC had plans for a bowling night - rolling in for the fourth year in a row, and board games night will make a triumphant return.

Written by John Donohue ■



⤴ Having fun at LaserQuest.

Around

THE INSTITUTE

»» AWARDS AND FELLOWSHIPS

14 NSERC award winners at IQC

Faculty, Research Assistant Professors (RAPs), graduate students and associates of IQC collected a total of 14 awards from the Natural Sciences and Engineering Council of Canada (NSERC) on June 22.

Discovery grant winners:

- »» MICHAL BAJCSY
- »» KYUNG CHOI
- »» THOMAS JENNEWIEIN
- »» EDUARDO MARTIN-MARTINEZ
- »» IQC associates in the University of Waterloo's physics and astronomy department
ROBERT MANN and **JAN KYCIA**

Equipment grant winners:

- »» KYUNG CHOI
- »» ADRIAN LUPASCU
- »» VADIM MAKAROV

Student award winners:

- »» MICHAEL MAZUREK
- »» CHUNHAO WANG
- »» OLIVIA DI MATTEO
- »» JEAN-PHILIPPE MACLEAN ■

New funding from FQXi



On July 21, the Foundational Questions Institute (FQXi) announced that Canada Research Chair in Optical Quantum Technologies, **KEVIN RESCH** and IQC Affiliate **ROB SPEKKENS** were awarded nearly \$100,000 over two years to experimentally test quantum causal relations – one of only 20 of 240 projects selected for funding.

“This funding will help us begin to understand the nature of causation in a quantum world,” said Resch. “It’s anticipated to shed light on foundational problems in quantum theory such as Bell’s theorem, as well as problems in quantum gravity, where space and time must be given a quantum description.” ■

EARLY RESEARCHER AWARD WINNERS



On June 18, faculty member **KYUNG CHOI** and Research Assistant Professor **VADIM MAKAROV** were granted Early Researcher Awards.

Choi is harnessing the interactions of ultracold atoms and single photons to build the foundation for scalable quantum computation and simulation. In the long-term these advancements will lead to the development of quantum processors, networks and simulators. Makarov and his team are developing hack-proof engineering approaches for various quantum cryptosystems, working with industry partners to implement better security in their systems. It’s expected that security certification will be an outcome and a commercializable technology. ■



«« Kyung Choi (top) and Vadim Makarov



Outstanding teaching

A 2014 Outstanding Performance Award was given to **DAVID CORY** for his exceptional contributions to teaching and scholarship at the University of Waterloo. The program recognizes the top 10 per cent of the faculty at the university. ■

Award for causal models research

KATJA RIED was awarded the IQC Achievement Award for her study of casual models in a collaboration between IQC and the Perimeter Institute. In March, Ried and her colleagues published a paper in *Nature Physics*: *A quantum advantage for inferring causal structure*. The paper showed that in quantum mechanics, certain kinds of observations will let you distinguish whether there is a common cause or a cause-effect relation between two variables. Her work in this area continues as they explore the possibility that causal relations themselves may be in some sense in a superposition of two alternatives. In the near term, the results may provide a tool for the analysis of open quantum system dynamics.

The \$5,000 award is given to a graduate student with an outstanding research contribution.

WEB Read about the paper: *A quantum advantage for inferring causal structure*. <http://bit.ly/Correlation-causation> ■



Promoting science comes with awards

Three PhD students were awarded the IQC David Johnston Award for Scientific Research for their dedication to promoting public awareness of quantum information research, general science and IQC.

SARAH KAISER was extensively involved in USEQIP, QCSYS, tours and school visits, developed and delivered workshops for several different groups. She also helped to create and curate the *LIGHT Illuminated* exhibit at THEMUSEUM and has represented IQC at various functions.

A key lecturer at QCSYS, **JUAN MIGUEL ARRAZOLA**'s expertise was very helpful in the development of the QCSYS course notes. He was pivotal in starting the IQC blog, *Our quantum world*, and continues to encourage others to contribute posts. He has also been involved in other special projects.

CAROLYN EARNEST wants to share her joy of science with others. It's why she's involved in IQC outreach initiatives and University of Waterloo initiatives including *Let's Talk Science* and *Engineering Science Quest*. Earnest is also a mentor for the Canadian Association of Girls in Science and a graduate liaison for FemPhys. ■

Around THE INSTITUTE



SPRING COURSES

PHYS 777

Sir Anthony Leggett Lecture Series: Condensed Matter Theory from a Quantum Information Perspective

QIC 890/891

Selected Advanced Topics in Quantum Information

QIC 891

Topics in Quantum-Safe Cryptography

QIC 895

Theory of Quantum Optics ■



ARRIVALS

Faculty

Vern Paulsen
William Slofstra

Postdoctoral fellows

Sandra Gibson
Michele Piscitelli

Staff

Emily Ha

Students

Christopher Chamberland
Hyeran Kong

Visitors

Franklin Cho
Ming Lyu ■

NewBit wins awards

In June, IQC received three awards recognizing achievement of overall communication and effectiveness for *NewBit* including:

- » **An Award for Publication Excellence (APEX) 2015**
Award of Excellence in the category Newsletters -
Writing for the Winter 2014 NewBit
- » **A Gold Council for Advancement and Support of Education (CASE) Circle of Excellence**
Award in the category External Audience
Newsletters (Print)
- » **A Gold Canadian Council for the Advancement of Education (CCAEE) Prix d'Excellence Award**
in the category *Best Brochure, Flyer or Newsletter* ■



LAST YEAR, THE INSTITUTE FOR QUANTUM COMPUTING HAD

» **249** media mentions
FROM
150 publications, including:



THE GLOBE AND MAIL*
POPULAR SCIENCE



nature WIRED

NATIONAL POST Discover

COVERING A RANGE OF TOPICS



IQC PEOPLE
73



EVENTS
26



PROJECTS
76



FUNDING
30



INDUSTRY
44



Teaching Quantum Technology

December 5-6, 2015



A new program for high school teachers

For the first time, IQC offered a free program for high school teachers. They attended lectures and engaged in hands-on activities to help them introduce quantum technology to their students.

Teachers left the workshop with:

- » The ability to teach quantum mechanics beyond the basics and discuss cutting-edge advances in the field
- » Lesson plans and other affordable, ready-to-go activities to take back to the classroom.
- » Discussion points about how quantum mechanics can transform society ■



uwaterloo.ca/iqc/tqt

LIGHT

ILLUMINATED

Celebrating Light & Light-based Technologies



ON UNTIL MARCH 28, 2016



UNIVERSITY OF
WATERLOO



Institute for
Quantum
Computing



INTERNATIONAL
YEAR OF LIGHT
2015



OSA University of Waterloo
Student Chapter



APS
physics

CHKISTIE



TELEDYNE DALSA
Everywhere you look



FiberTech Optics



knowledge
integration
UNIVERSITY OF WATERLOO

Wizard Labs

THEMUSEUM.ca

DOWNTOWN KITCHENER

LOOK FOR THE NEXT ISSUE OF **NewBit** COMING IN THE WINTER!



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Ontario

Canada