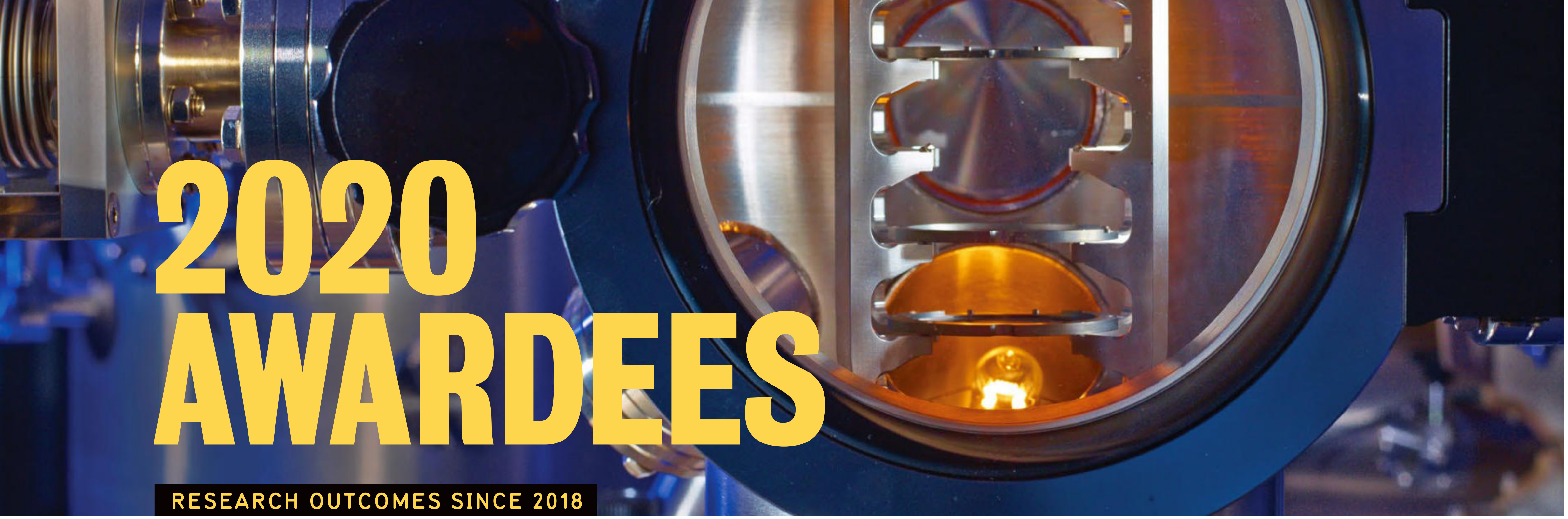


2020 AWARDEES

RESEARCH OUTCOMES SINCE 2018

“MICROWAVE RESONATORS FOR GLOBAL CONTROL OF ELECTRON SPINS QUBITS” PLACED FIRST IN THE CONDENSED

Matter and Materials Physics division and then third in the Best Overall Student Poster Presentation Awards at the annual Canadian Association of Physicists (CAP) meeting in June 2021.

STEPHEN HARRIGAN

QUANTUM RESEARCH

Controlling electron spins in silicon quantum dots – a basic building block for a scalable quantum computer

PhD student Stephen Harrigan’s poster presentation “Microwave resonators for global control of electron spins qubits” placed first in the Condensed Matter and Materials Physics division and then third in the Best Overall Student Poster Presentation Awards at the annual Canadian Association of Physicists (CAP) meeting in June 2021.

The physical world is governed by the laws of quantum mechanics, in which many possible states of a system can coexist prior to a measurement. Conventional computers, in contrast, operate based on the laws of classical physics and can only occupy one particular state at a time. Quantum information processing exploits this ‘sum over possibilities’ to efficiently solve certain computational problems that are out of reach of even the most powerful conventional computers. Problems in this category include exact quantum mechanical simulations of chemical and biological processes at the molecular level, which would revolutionize fields such as drug discovery, medical diagnosis, design of new materials, and nanotechnology.

Surprisingly, there is a viable pathway to adapt conventional silicon CMOS technology to quantum information processing so that the maturity of the modern semiconductor industry can be leveraged. One can transform the conventional MOSFET transistor into a quantum dot, in which a single electron can be confined and manipulated. The spin degree of freedom of the electron represents a bit of quantum information, i.e. a qubit, and can be manipulated via electron spin resonance at microwave frequencies. The aim of our joint project is to develop efficient and optimal control of an array of spin qubits in MOSFET quantum dots.

This begins with a hardware solution for generating a strong, homogeneous microwave magnetic field while minimizing the exposure of the devices to the electric field, which causes undesired effects. The group at Waterloo is adapting a microwave resonator design invented by the group at Technion for spin resonance imaging to solve this problem. Once suitable hardware is in place, we will focus on tailoring microwave pulse sequences using optimal control methods to achieve efficient, selective and high-fidelity qubit transformations. In summary, our project aims to remove significant barriers to building a large-scale quantum computer, a device that would revolutionize computational reach and impact society in myriad ways.

There is potential for impact on industry in the long term. Large companies like Intel (USA), smaller startups like Silicon Quantum Computing (Australia), and several others are leading activities around silicon quantum computing and could benefit from our technology. Societal impact comes in two forms: in the short term, we are training new members of the quantum workforce who will be equipped to join industrial, government or academic R&D efforts. In the longer term, the ability to have exquisite control of quantum degrees of freedom and to build scalable devices will be game changers for future technologies.

The collaboration between Waterloo and Technion is valuable because it requires the complementary expertise of the PIs to solve a challenge that could have a large impact on the development of scalable quantum computing. One of the greatest challenges in this field is to enable fast, global control over the qubits of this quantum computer. In this project we developed unique methodologies to enable such fast control over the silicon qubits using microwave magnetic fields, with minimal interference to their energy levels.

Our approach is novel because it is based on unique surface micro-resonator technology developed in the Blank lab at Technion. This new technology, and the synergetic work with the Canadian partner and their capability to produce unique silicon quantum dots, provide the main edge to this project.

The research showed how small micro-resonators can be used for fast control over silicon-based qubits. We have designed, fabricated and tested these new resonators, as well as verified their confined microwave mode and their capability to provide fast drive of qubits. These developments may ultimately lead to the use of silicon as a basis for future quantum computers, which may solve a variety of computational problems, such as finding the structure of large molecules, optimizing processes, finding new drugs and more, with potential vast benefits to science and

NOTE: These outcomes are from the original funding from the 2014 project “Magnetic resonance and algorithmic cooling-theory and applications of small quantum information processors.” The researchers were provided additional funding in 2020 due to their new research results.

society.
A summary of milestones follows:
Milestone 1: Design (Technion + Waterloo), fabrication (Waterloo) and test (Technion + Waterloo) of 16-17 GHz copper resonators on quartz. This was completed in 2020-2021, and results included in the Master's thesis of Alex Currie (Waterloo) and the poster presentation of Stephen Harrigan at the 2021 Canadian Association of Physicists general meeting.

Milestone 2: Wafer-scale design and fabrication of silicon quantum dot devices (Waterloo; fully in-house via the Quantum Nanofab facility). More than 10 wafers have been processed, and significant progress has been made in optimizing the fabrication recipes and methods. We expect to have fully functional, mass-produced devices by the Fall of 2022.
Milestone 3: Demonstration of magnetic resonance of an electron spin in a quantum dot driven by the global resonator. To expedite this milestone, we have fabricated a new batch of GaAs quantum dot devices, and plan to add Nb bowtie resonators above the device plane in a final fabrication step. We expect this to be completed by August, 2022.

Milestone 4: Integration of Nb resonators with silicon quantum dot devices and demonstration of qubit control. We expect this to be completed by the end of 2022.

Deliverables include scientific dissemination (theses, presentations, reports) as well as physical prototypes.

SINCE 2018

$606,923 Other funding secured

1 Industry connection

1 Student exchange

1 Joint publication

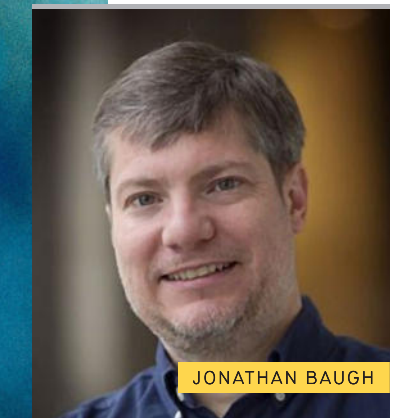
8 Highly qualified personnel (HQP)

5 Conferences and workshops

5 Invited speaker

1 Infrastructure development and commercialization activity

SEE APPENDIX FOR FULL LISTS



JONATHAN BAUGH

AHARON BLANK

QUANTUM RESEARCH

Jonathan Baugh and Aharon Blank

"MY EXPERIENCE AND RESEARCH IN QUANTUM TECHNOLOGY WAS PIVOTAL TO MY CURRENT CAREER AT RAFAEL PHYSICS LABS."

YARON ARTZI (PH D'22)

"THIS PROJECT HAS ALLOWED ME TO PURSUE RESEARCH AT THE FOREFRONT OF QUANTUM TECHNOLOGIES AND GAIN SKILLS RELEVANT IN THIS RAPIDLY GROWING SECTOR."

STEPHEN HARRIGAN (PHD STUDENT)