The Quantum Colaboratory

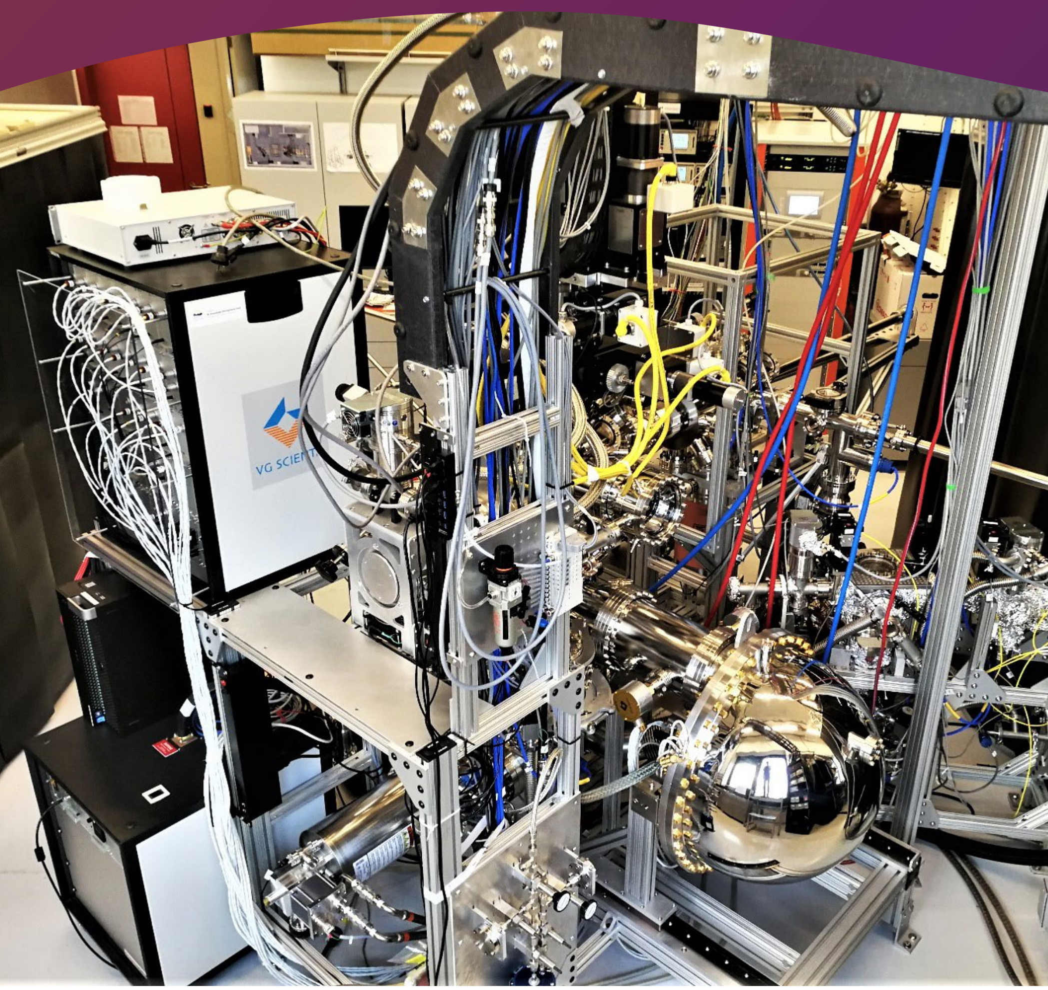
Bringing Quantum Technologies to Life

The Quantum Colaboratory's
Strategic Plan 2021 – 2026

University of Waterloo · Université de Sherbrooke · The University of British Columbia

Main Focuses

- → Implement the quantum innovation cycle as a shared resource for all researchers
- → Connect quantum technologies to societal problems and science exploration
- → Develop and share unique tools that increase the speed of adoption for quantum technologies



Time- and Angle-Resolved Photoemission Spectroscopy (ARPES)

This state-of-the-art spectrometer maps the electronic structure of materials, giving unique insights into the out-of-equilibrium dynamics in many-body systems. It is a unique tool for characterizing quantum matter, and one that is rarely available through shared facilities. This is housed and was developed at UBC.

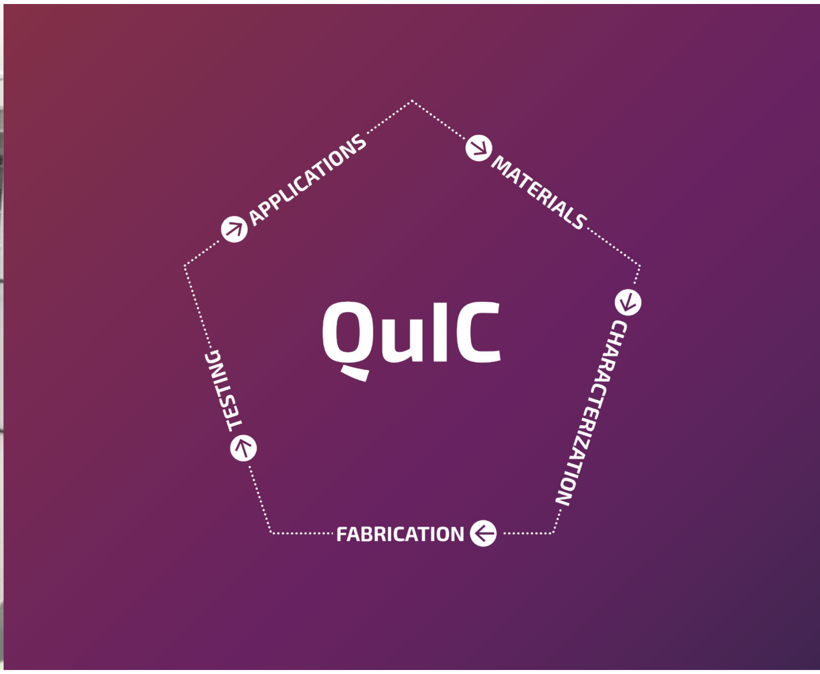
Quantum Technologies Brought to Life

Looking ahead to the next five years, the aims of the Quantum Colaboratory (Quantum Colab) are to strengthen Canada's global leadership in quantum technology, connect quantum technologies to breakthrough applications, train quantum workers and researchers on the uses and applications of quantum technology, and connect new science and engineering to the development of advanced quantum tools.

This expanding initiative will strengthen connections between the three physical centers and increase partnerships with international and national labs over the strategic plan's lifetime. Already the Quantum Colab is an attractor for quantum research and development in Canada.The plan will engage our diverse team of scientists and engineers to position Canada's quantum technology innovations as some of the most impactful in the world.

The Quantum Colab was established in 2019 by combining the tools and expertise of three quantum-focused Canada First Research Excellence Fund programs: the Stewart Blusson Quantum Matter Institute (Blusson QMI) at the University of British Columbia (UBC), Institut quantique (IQ) at the Université de Sherbrooke (UdeS) and Transformative Quantum Technologies (TQT) at the University of Waterloo. Through the Quantum Colab, each center makes available unique expertise and tools that all users can access. The three centers have coordinated their operations to streamline the flow of processes between them, ensuring every user benefits from advances at all sites.

The Quantum Colab is organized around a Quantum Innovation Cycle (QuIC) that provides a rubric for the continued development of the tools and processes necessary to advance the young field of quantum technologies.



QuIC is defined by five essential capabilities for advancing quantum science and technology:

- **Materials growth** – including superconducting and quantum materials, in particular, often requires dedicated systems to control defects, interfaces and film quality.
- **Materials characterization** – learning how to measure and controlling sources of decoherence, and to explore signatures of many-body physics.
- **Device fabrication** – and integration of efficient, low noise circuits and packaging, especially that are suitable for complex systems.
- **Device control and testing*** – preserving coherence through device design and coherent control methods, including quantum error correction.
- **Applications*** – Quantum simulation is the application that closes the innovation cycle. It is a tool for researchers to discover and optimize both materials and control methods. Quantum sensing brings new efficiencies to health, medicine and physics exploration.

Quantum often demands that we preserve and control coherence and that entanglement can be achieved. This brings new requirements for each of the five QuIC capabilities. Through the Quantum Colab, users benefit from access and are provided with the expertise required to use these unique resources successfully.

The Quantum Colab has developed strong partnerships with national labs in Canada and the United States. This has paved the way to building quantum tools connected to large-scale resources, including the synchrotron at the Canadian Light Source and the research reactor at the National Institute for Science and Technology.

Performance measurement strategy

Selected key performance indicators of the impact of the Quantum Colab:

340 ANNUAL USERS
84% academic, 9% industry, 2% not-for-profit, and 5% public

GEOGRAPHIC DISTRIBUTION OF USERS
94% in Canada, 4% in US, and 2% international

331 PAPERS
Since 2019

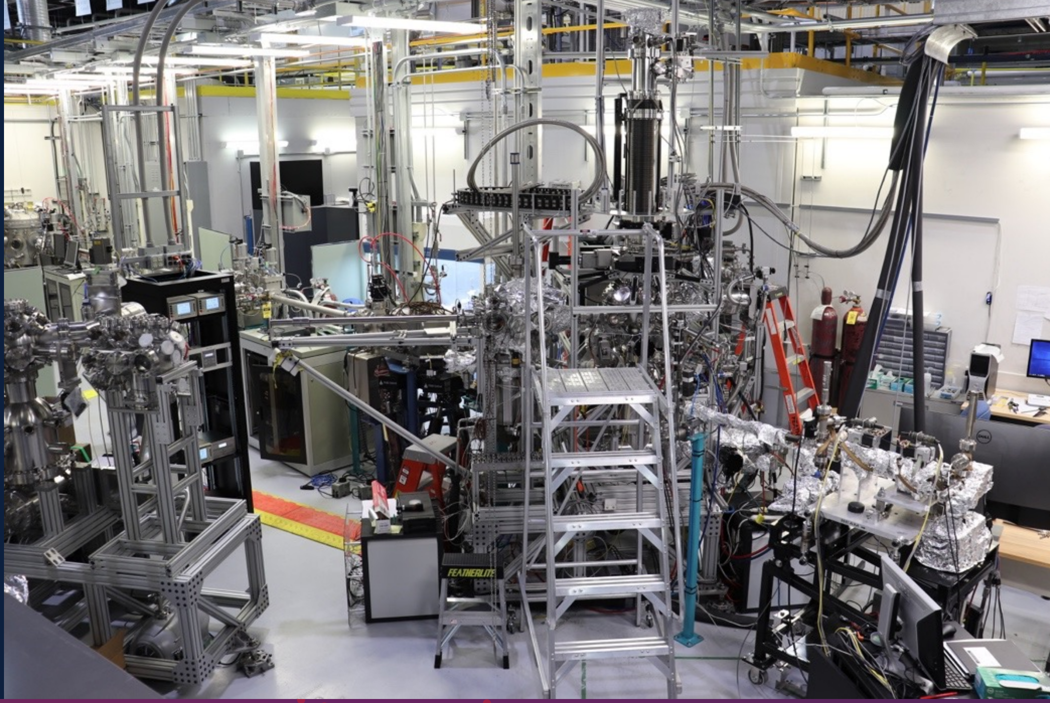
66 PATENTS AND LICENSES
Since 2019

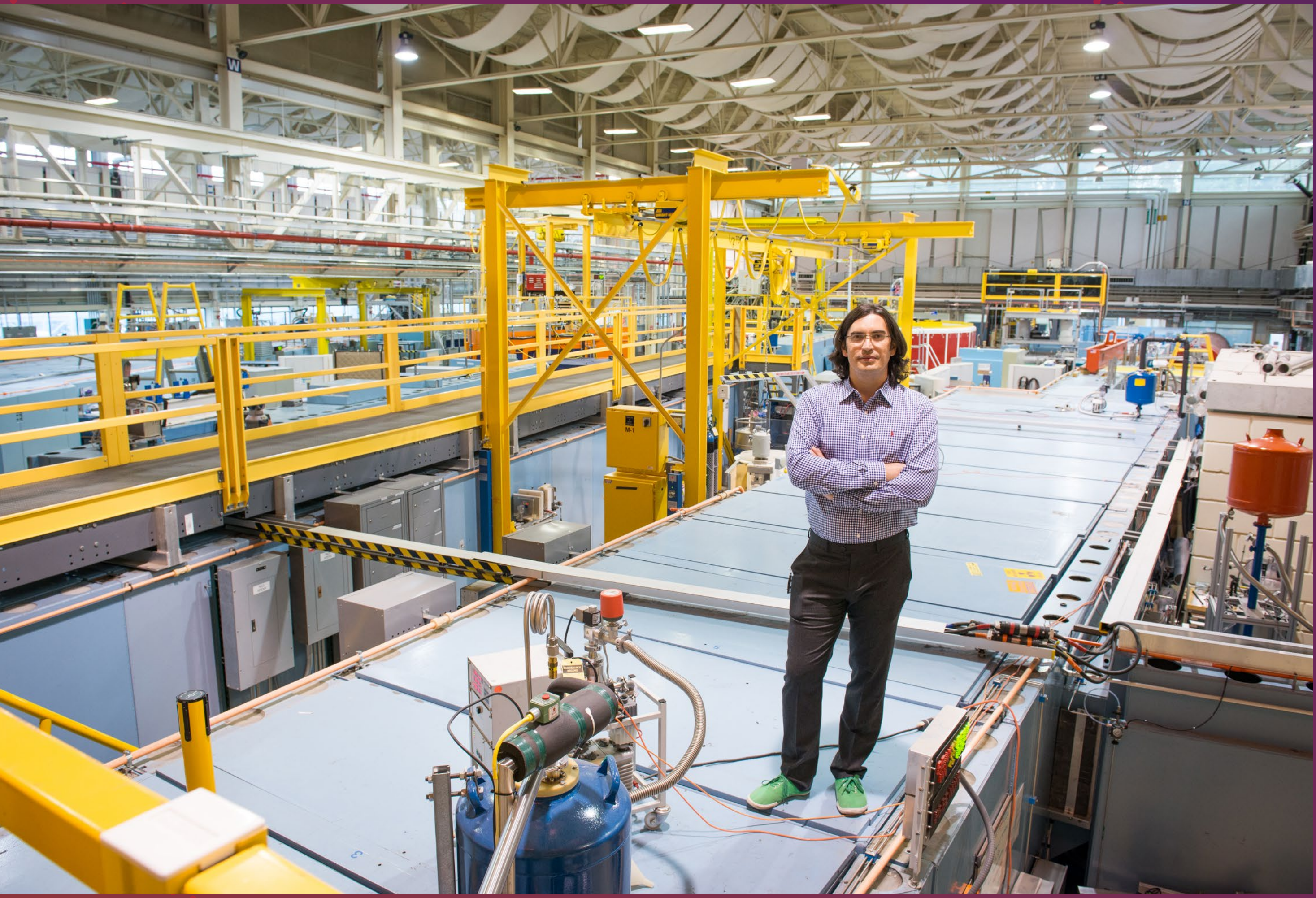
55 TECHNICAL STAFF

52 USERS FROM STARTUPS AND SMES, 4 INTERNATIONAL
Since April 2019

* Capabilities are rarely part of any shared resource, being generally limited to specialists' labs.

UBC ARPES beamline at the CLS. The ARPES endstation shown on the right is fully operational, the Spin-ARPES endstation on the left is waiting to be installed.





Dr. Pushin at NIST where the Quantum Colab has developed neutron interferometry instruments.

Strategic goals

The Quantum Colab's Strategic Plan, "Bringing Quantum Technologies to Life," calls for the following actions:

Provide resources to enable quantum technology development

- For existing tools, develop efficient maintenance and staffing plans commensurate with tool use via consultation with the International Science Advisory Committee (ISAC) and user community
- Target tool additions via consultation with the ISAC and user community
- Partner with industry to bring new capabilities to the Quantum Colab

Open tool suite to the broad community, including those pursuing applications

- Invest in facilities that link quantum technology to applications. Some examples include:
  - Low-temperature systems for transport measurements
  - Dilution refrigerator for quantum electronics testing
  - Optics lab for exploring quantum solutions for eye health
  - Diamond NV lab for exploring quantum sensing
  - Single photon lab

Continue to develop new capabilities in-house and support their transition to user facilities

- Select targets for new tool developments with the ISAC and users
  - MRFM
  - Spin resolved ARPES
- Advance quantum simulators and their range of applications
  - Condensed matter, 2-D on torus
  - Quantum material discovery
- Partner with companies that have emerging capabilities

Train users and serve as an attractor for the quantum industry in Canada

- Continue to develop Quantum Explorations and similar spaces
  - Workforce training, MS in Quantum Technology, Quantum Engineering
  - Undergraduate School on Experimental Quantum Information Processing introduction to quantum lab experiences for undergraduates
- Seek industry partnerships to make training relevant

Ensure the Quantum Colab is sustainable through a diverse portfolio of support

- Seek operational support for sustained operations
- Seek innovation and commercialization funding to expand industry engagement
- Expand industry base through tool selection and performance

Deriving new operations and staff support is an essential element of the plan to maintain Canada's position as a world leader in delivering quantum solutions.

2022 Quantum Colab Upgrades

The Quantum Colab is developing and bringing on-line new capabilities to help discover and characterize new quantum materials and advance quantum technologies.

Quantum Materials Electron Microscopy

Two new state-of-the-art multi-user electron microscopy facilities will come on line.

At UBC, the facility will house a Nion Scanning Transmission Electron Microscope (STEM) and a high-resolution Focused Ion Beam (FIB). The FIB has full 8” wafer capability. The customized STEM has ~10meV energy resolution, and ~ 0.1 Å^{-1} momentum resolved Electron Energy Loss Spectroscopy, EELS.

At UW, the TEM facility is being upgraded with a JEOL JEM-F200 STEM including EELS. The imaging magnification is 0.136nm. The analytical capabilities include EDS, energy filtered TEM and EELS.

These capabilities are critically important for being able to reliably fabricate high-quality quantum materials and the facility will meet the needs of academic researchers as well as the demands of industry partners.

Design, fabrication, and testing of quantum electronic devices and qubits

The laboratory will provide infrastructure and expertise for the design, fabrication, and testing of a wide range of quantum electronic devices. Device measurement infrastructure includes several dilution refrigerators, low-noise low-frequency electronics for transport and thermodynamic measurements, and qubit control systems.

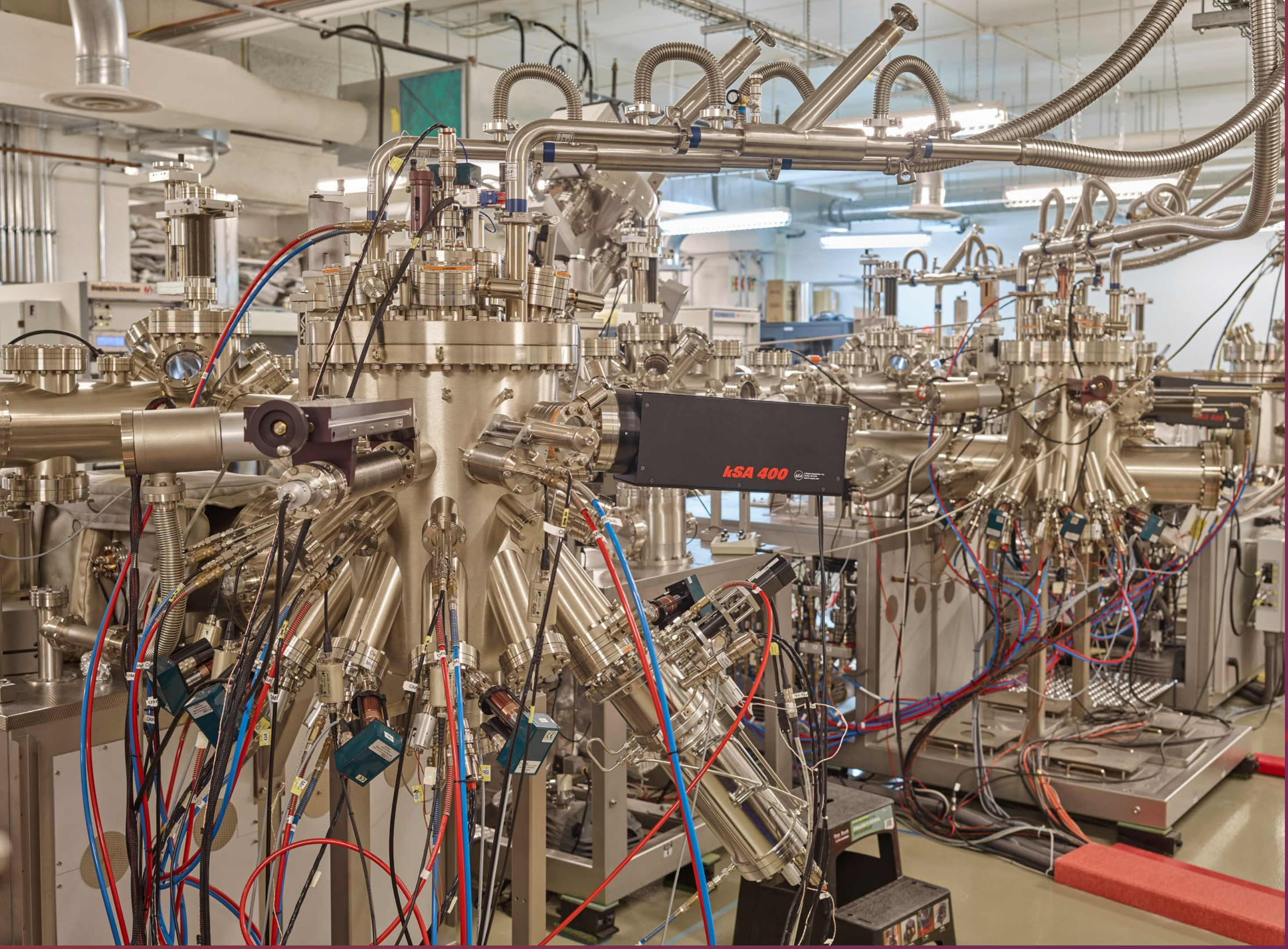
Nanospectroscopy Laboratory for Polaritonic Materials Discovery

Polaritonic materials display many fascinating and useful properties such as the ability to trap and manipulate light at the nanoscale. The exquisite sensitivity of polaritonic materials to their dielectric environment creates an opportunity to control, and ultimately design, nanophotonic devices by integrating them with quantum materials that can have tunable and nanoscale structure in their dielectric properties.

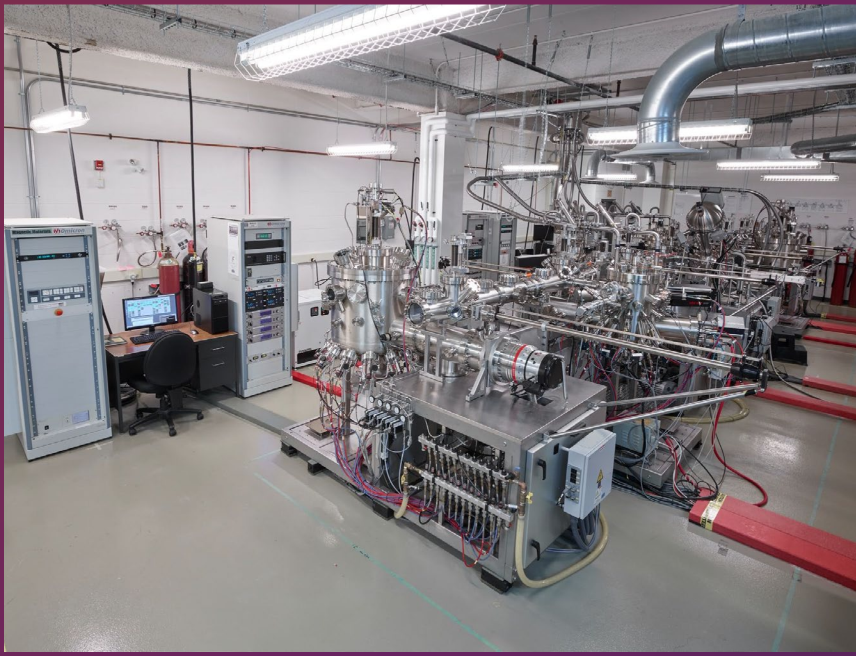
The Quantum Colab's Competitive Advantage

Key capabilities of the Quantum Colab

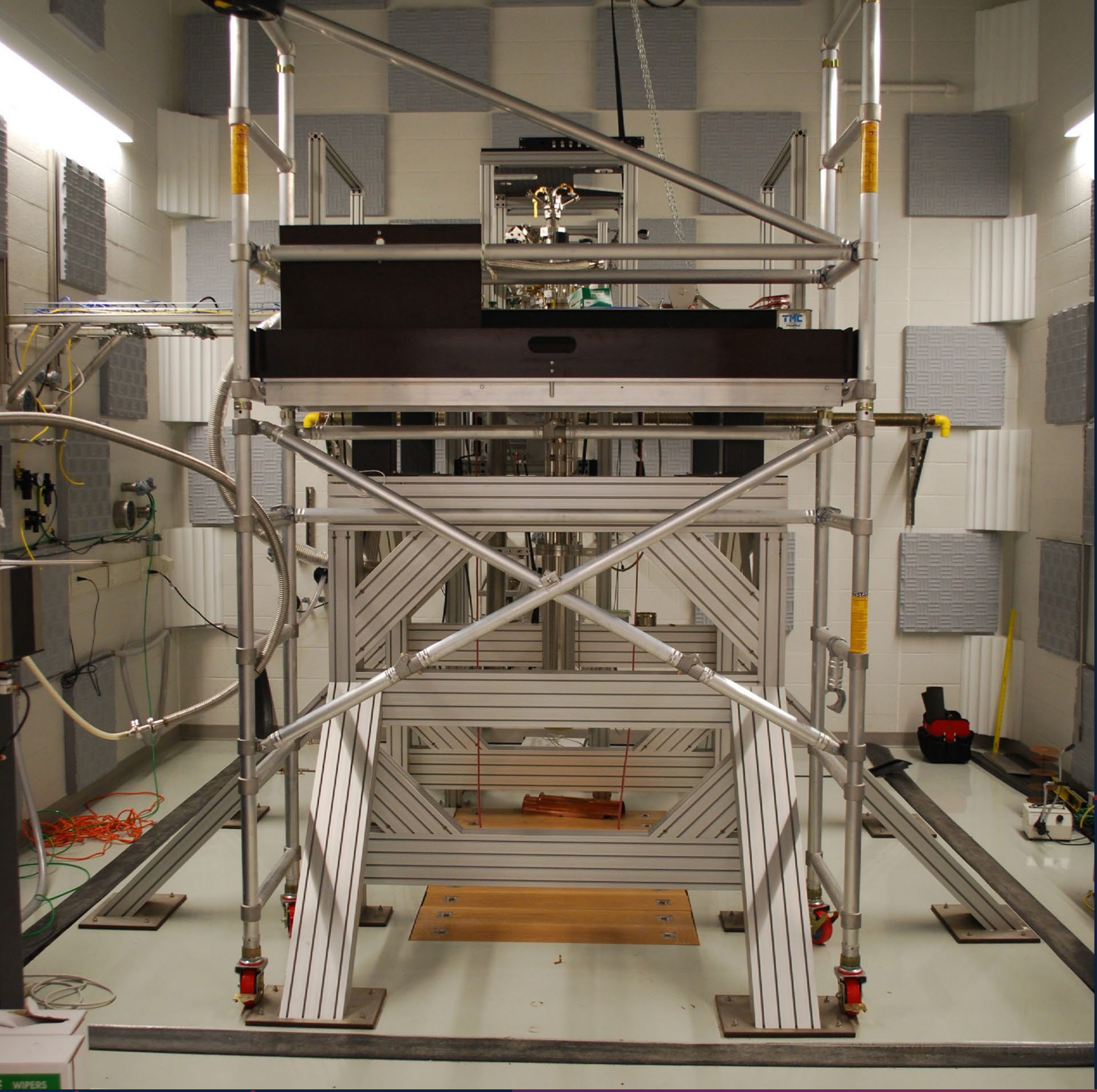
	CONVENTIONAL TOOLS	SPECIALIZED QUANTUM TOOLS *(THE **BOLD** AREAS ARE WHERE THE QUANTUM COLAB HAS A VERY UNIQUE STRENGTH)*
MATERIALS GROWTH TERMAL, E-BEAM EVAPORATORS	Sputtering, HV	**UHV MBE**, dedicated UHV evaporators, SC JJ, dedicated CVD, graphene, CNT, diamond Si, ALD
MATERIALS CHARACTERIZATION	SEM, AFM, XRD, ellipsometry, PPMS, MPMS	LT STM, **ARPES**, TEM, LT high field >15T, **neutron interferometry, subsurface chem and defects, MRFM, ESR**, optics, excitonics
DEVICE FABRICATION AND ASSEMBLY	E-beam lithography, photolithography (direct write, mask aligner), RIE, chip bonding	Maskless aligners, **inert atmosphere fab and assembly**, design tools, µw design, 3D and packaging, photonic design and fab, fiber splicer, **Vanguard Sonata Photonic Wire Bonder**
DEVICE CONTROL AND TESTING	Typically very few are available as shared resources, e.g. probe station	Cryo probe station, **LT systems for testing**, µw and FPGA, **single photon sources and detectors**, controls benchmarking and error correction
APPLICATIONS AS SHARED RESOURCES	Not typically available	**Low vibrations space, quantum simulators**, platforms for sensor development, platforms for communication development, tools to **enable searches for exotic quantum materials**



The 7-chamber UHV MBE system (images taken from two different angles). This uniquely configured, seven-chamber system enables growth of a broad spectrum of quantum materials, including high Tc and other superconductors, topological materials, spintronics and building blocks of Majorana fermions. It is rare for such a tool to be run as a shared resource. Available at UW.



The development of extraordinarily “quiet” space to enable quantum measurements. Low vibration space at UBC.



Magnetic Resonance Force Microscopy (MRFM). This tool allows the spatial characterization of chemistry and electronic structure at atomic resolution and near sub-surface. It is developed in-house and placed in an extremely low vibration/ low noise lab. It is being tested, and once fully on-line, will be a unique capability that is only available through the Quantum Colaboratory at the University of Waterloo.

Glossary

AFM
Atomic Force Microscope

ALD
Atomic Layer Deposition

ARPES
Angle-Resolved Photoemission Spectroscopy

CNT
Carbon Nanotube

CVD
Chemical Vapour Deposition

Diamond Si
Diamond Silicon

ESR
Electron Spin Resonance

Fab
Fabrication

FPGA
Field Programmable Gate Array

HV
High Vacuum

ISAC
International Scientific Advisory Committee

LT
Low Temperature

MBE
Molecular Beam Epitaxy

MRFM
Magnetic Resonance Force Microscopy

MPMS
Magnetic Property Measurement System

NV
Nitrogen Vacancy

PPMS
Physical Property Measurement System

QuIC
Quantum Innovation Cycle

RIE
Reactive Ion Etch

SC JJ
Superconducting Josephson Junction

SEM
Scanning Electron Microscope

STM
Scanning Tunneling Microscope

Tc
Critical Temperature

TEM
Transmission Electron Microscopy

UHV
Ultra-High Vacuum

μw
Microwave

XRD
X-ray Diffractometer

To learn more about the Quantum Colab, including its governance, management and how to become a user, visit quantumcolab.ca.