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# QIS Research at Sandia National Laboratories

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Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.



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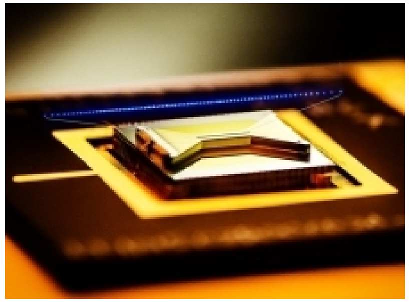
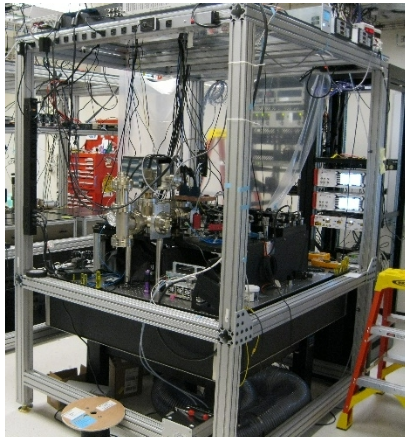
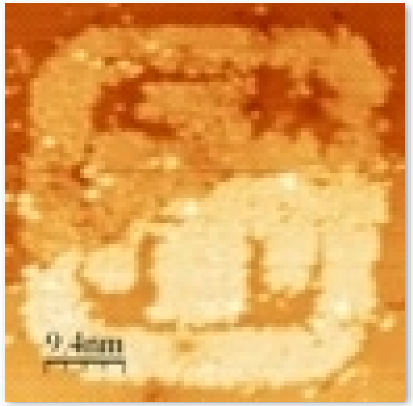
# Overview of Sandia QIS Portfolio

- Sandia has a multiplatform, multiapplication quantum information science program. Notable elements of the program are
  - Working quantum devices in multiple technologies
  - Applications to quantum computation, sensing, and communications/networking
  - Expertise in characterizing quantum devices and estimating required quantum resources for high impact quantum applications
- The QIS program is built leveraging Sandia's strengths in microelectronics fabrication, nanotechnology, and computational modeling, and complements and strengthens Sandia's overall mission.
- Sandia is currently working to mature and explore quantum technologies under DOE and other governmental agency funding.

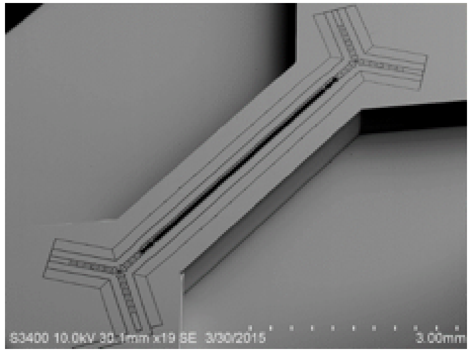




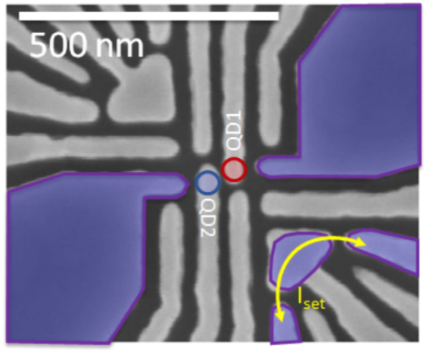


# Sandia has produced a number of unique products

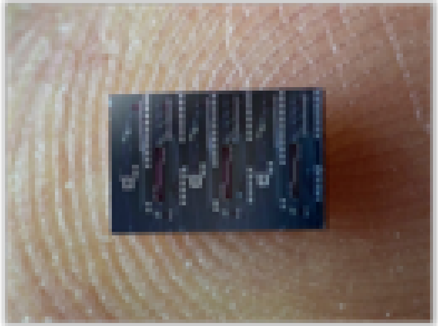
Pioneer of surface ion traps



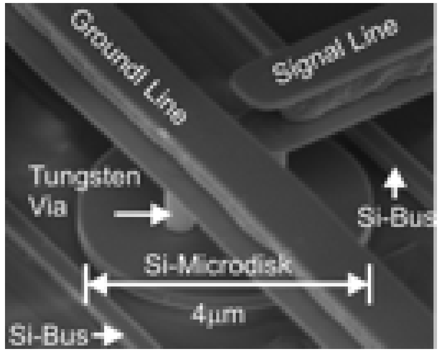

First Si donor-dot qubits



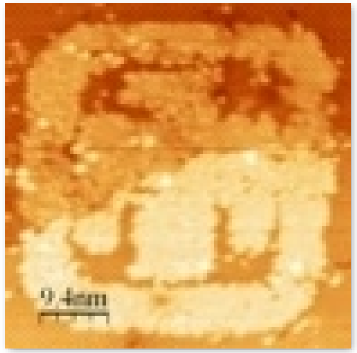

First chip-scale quantum transceiver



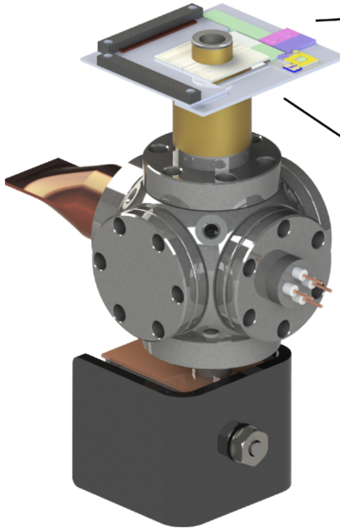
Si photonics optical modulator/filter



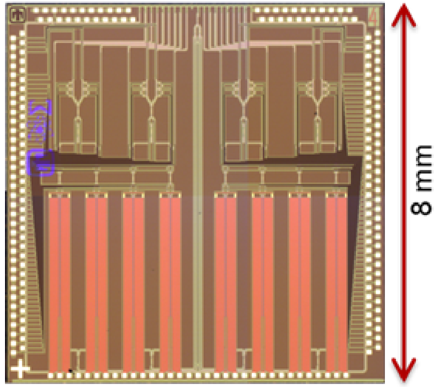

Sandia logo using atomically precise advanced manufacturing



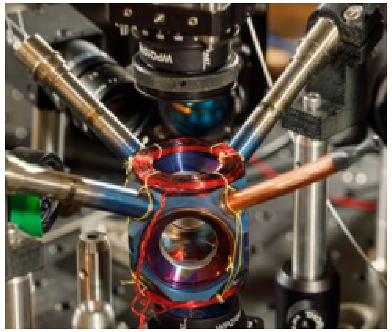
Integrated photonics and trapping ion clock



First atom interferometer using a PIC for Raman lasers




First passively pumped vacuum package for atoms

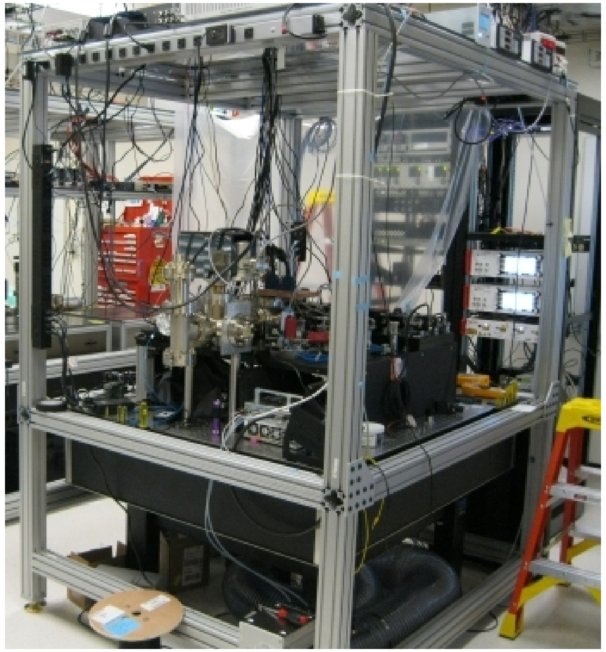


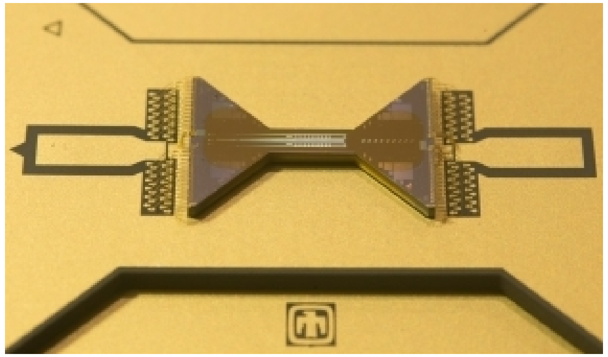
# Quantum Scientific Computing Open User Testbed

PI: Susan Clark

- DOE/ASCR quantum testbed to understand promise of quantum computing platforms for DOE science problems.
- 3 Qubit chain, moving toward 11 qubits shortly
  - Qubit coherence time ≈ 14s
  - Parallel single qubit gates on all qubits, target fidelity 99.5%
  - Serial two-qubit gates between any pair of qubits, target fidelity 98%
- Jaqal Quantum Assembly Language
  - Enable full control of gate scheduling and execution
  - Enable low-level access
  - Extensible set of native gates
- Initial Testbed Offering
  - Iterate on experiments to understand results and improve performance
  - Provide an understanding of low-level implementations and their consequences
  - Access to pulse level programming and custom native gate implementations
- QSCOUT System 1.0 Up and Running
  - 5 projects for first round (2021) , 5 projects for second (2022)

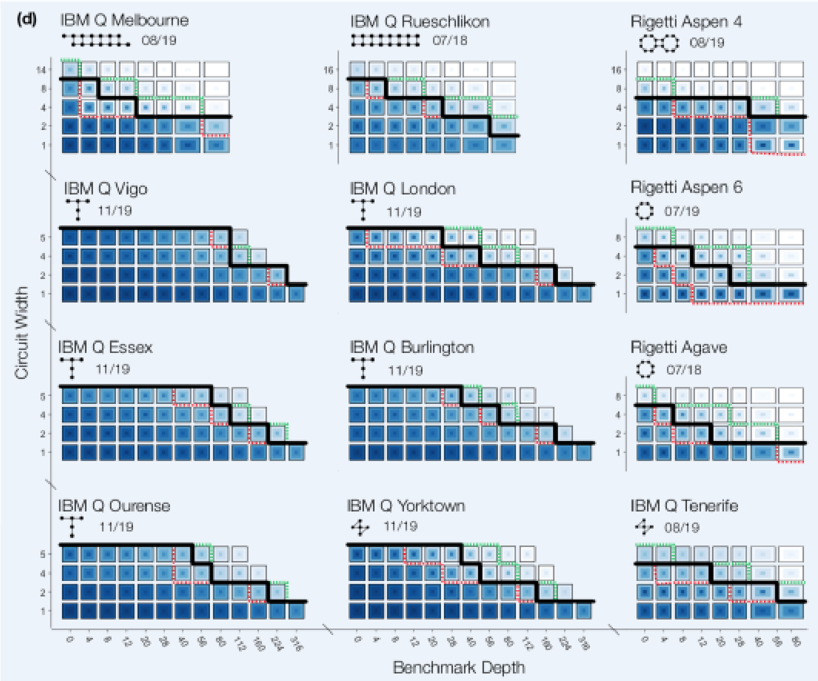
2021 R&D 100 WINNER



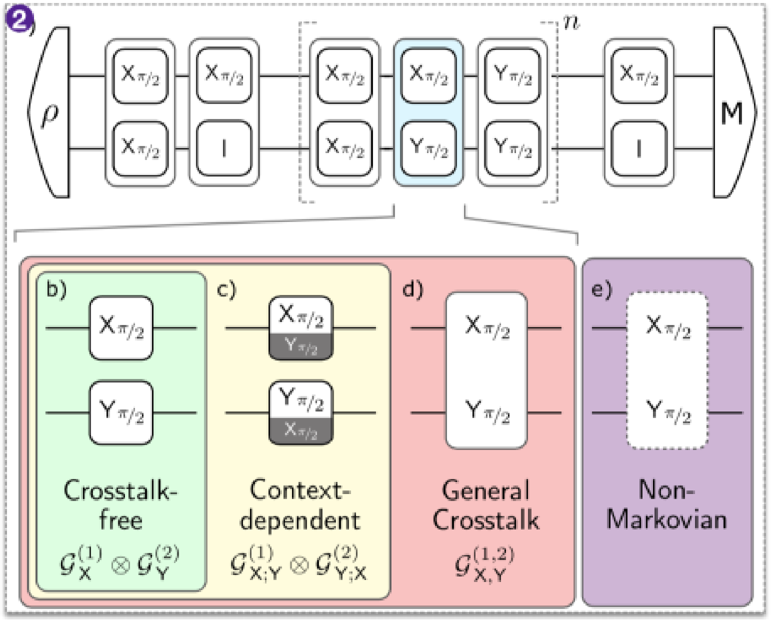


Peregrine Trap

# Quantum Performance Laboratory: Characterizing Quantum Processes and Processors







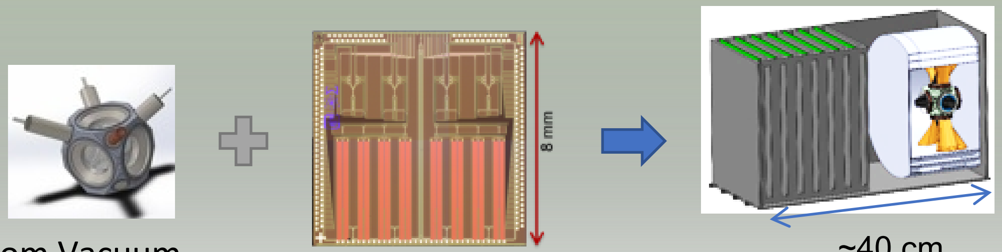

Volumetric benchmarking provides a new paradigm for benchmarking quantum processors

- What succeeds/fails. What model suggests *should* succeed but fails.
- Mirror circuits allow simulation of complicated programs whose answer is knowable (cf. Google supremacy).
- Applied to many different hardware platforms

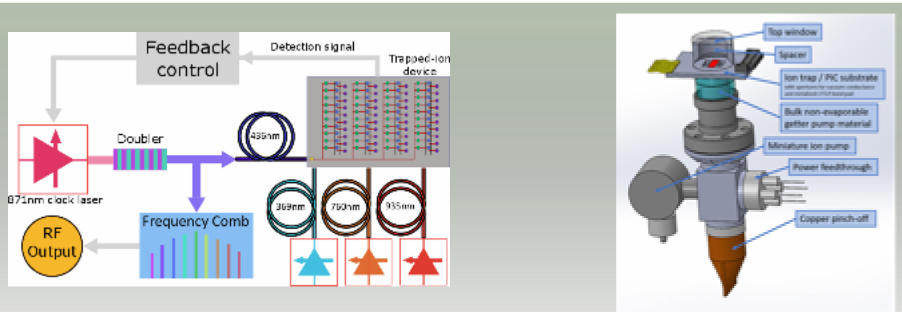
Recent work involves deeper investigation into nature of errors on quantum processors:

- Characterize increasingly sophisticated noise processes to understand why processes fail.
- Dig deeper into errors: what would happen if we could totally eliminate crosstalk, e.g.
- Separates context, crosstalk, and non-Markovian noise, both conceptually and in terms of process matrices.

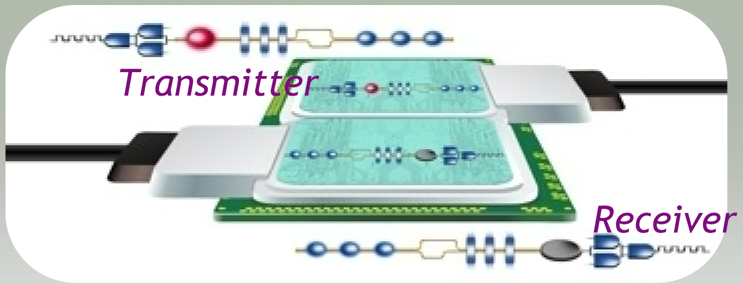
# Quantum Integrated Photonics, Clocks, Sensors



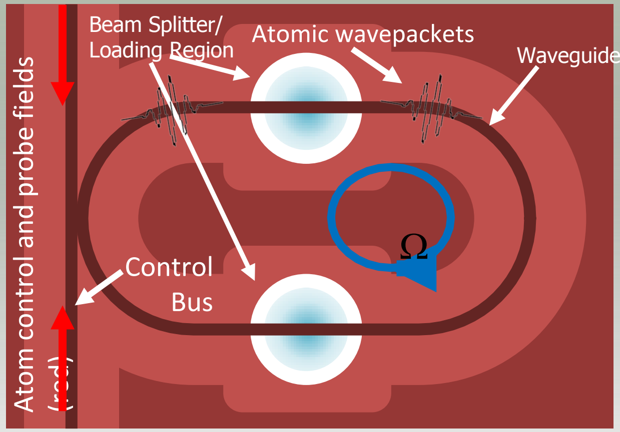

**Strategic Inertial Guidance with Matter waves (SIGMA) Grand Challenge LDRD**
(Strategic-grade Accelerometer – sub-100 ng)




**DARPA A-PHI - Atomic Clock**
(Trapped Ion Clock using Technology-On-Chip - TICTOC)

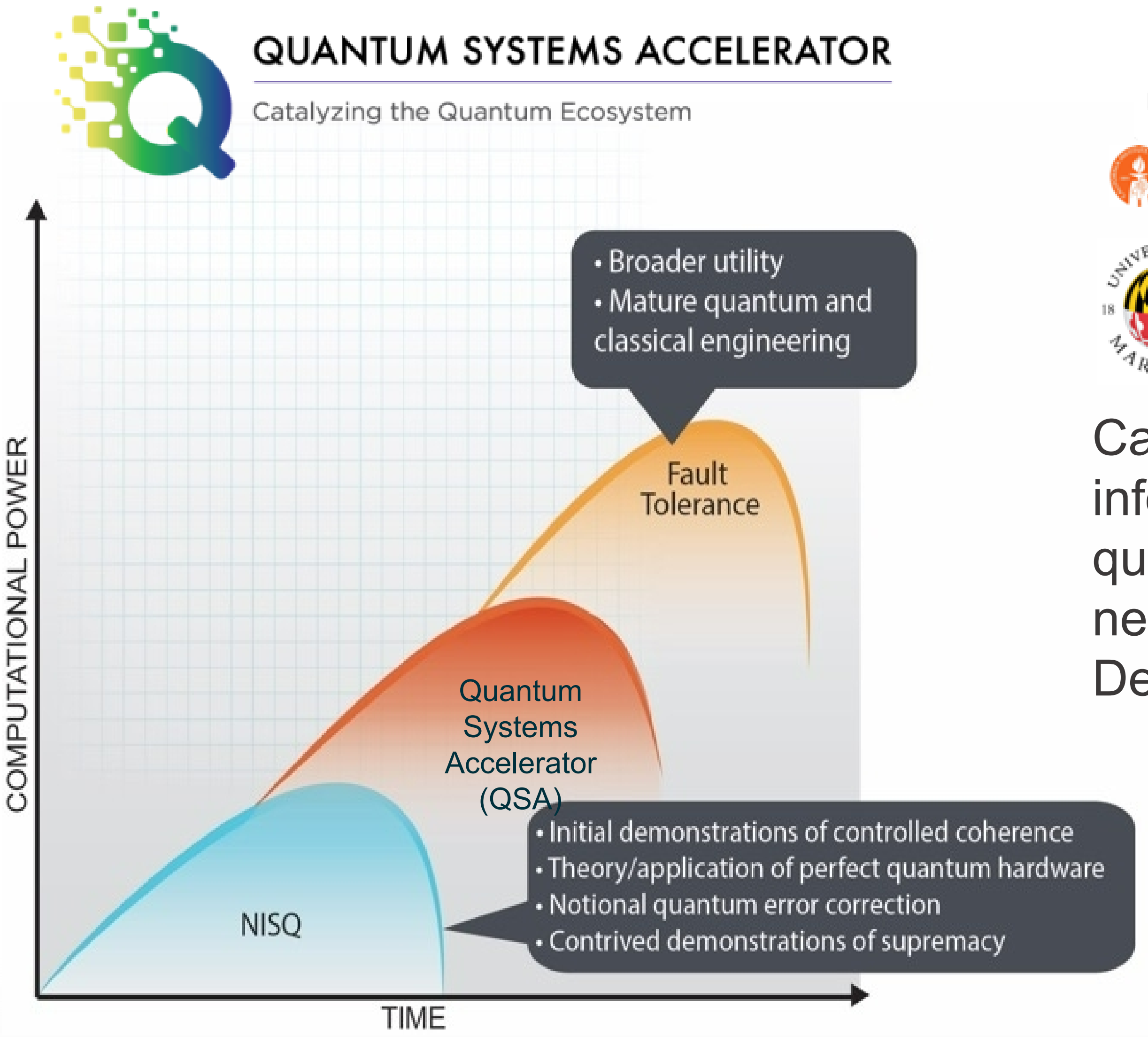



**CV QKD Communication LDRD**
(evaluation of next-gen. Continuous Variable Quantum Key Distribution transceivers)




**DARPA A-PHI - Atomic Gyroscope**
(Matter wave Sagnac interferometer using nanoscale optical waveguides)

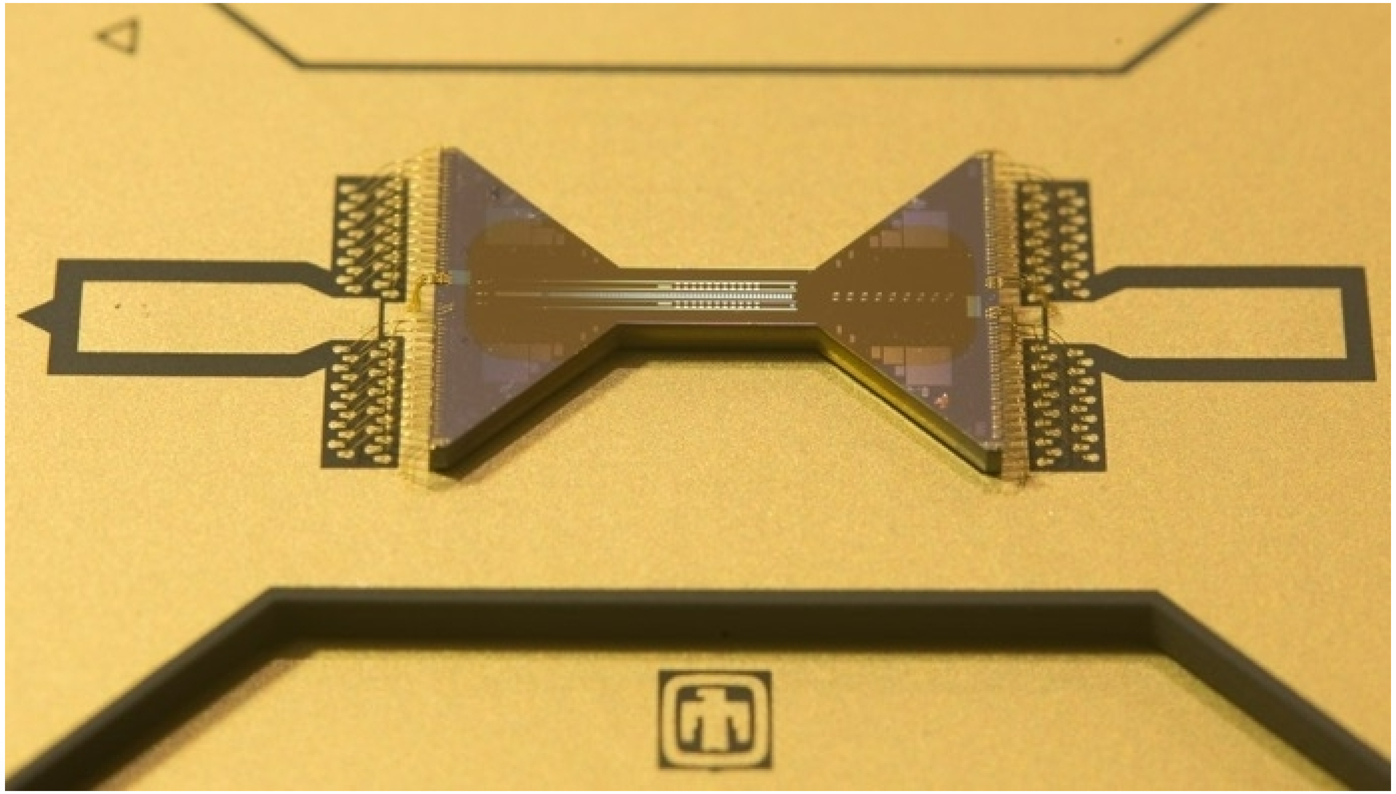
# QSA Addresses the Scientific Foundations for Quantum Computation




Catalyzing **national leadership** in quantum information science to co-design the algorithms, quantum devices, and engineering solutions needed to deliver certified quantum advantage in Department of Energy scientific applications.

# How to work with Sandia QIS — QSCOUT

- Call for proposals (multiple calls per year, next one expected in Spring 2022)
- 2 page proposal (more instructions on website)
- Technical and feasibility evaluation
- Individually meet with teams to discuss implementation and share data



QSCOUT JAQAL

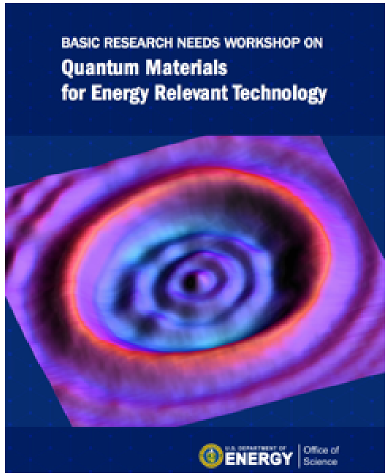
We look forward to hearing from you!

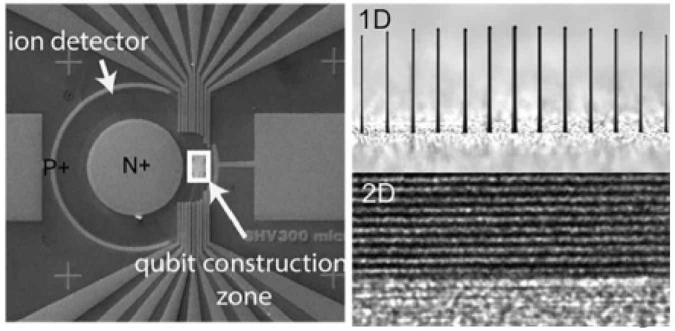
https://qscout.sandia.gov

qscout@sandia.gov

# How to work with Sandia QIS — CINT

- Center for Integrated Nanotechnologies
  - DOE funded nanoscience research facility.
  - Next user call opens March 1, 2022.
- Quantum Materials Systems Thrust at CINT
  - Mike Lilly, Thrust leader
  - Vision: synthesize materials with new properties, understand quantum phenomena, and integrate nanoscale systems with quantum behavior to address fundamental science challenges in quantum materials and quantum information sciences.
  - Good coordination between CINT and other Quantum activities at Sandia
- Key integration Science Challenges
  - Exploring interactions between quantum systems and the environment
  - Preparing quantum materials and qubits in a controllable manner
  - Discovering emergent phenomena in quantum materials
  - Integrating quantum materials in solid-state architectures for applications at the macroscale



# How to work with Sandia QIS — LDRD

## Sandia Academic Alliance, LDRD, and Virtual QIS Call

**Quantum Sensing**

- Development of improved quantum sensors and application of quantum sensing to near-term mission problems (ND, NSP)
- Investigation of networked quantum sensors for enhanced sensitivity for Sandia mission applications (ND, NSP, NI)

**Quantum Devices and Networking**

- Development of approaches to transduce quantum information to integrate different quantum technologies and/or for distributed quantum computing. (CIS, NSP)
- Hybrid quantum processors/systems for connecting different qubit modalities to capitalize on the advantages of different qubit systems. (NM, NI)
- New devices or experimental approaches to qubit and gate design that advance the state-of-the-art in physical qubit reliability and connectivity across functional processing regions in any of the core QIS device technologies: trapped ions, spins, neutral atoms, superconducting, and optomechanics. (NM, NI)

**Materials for QIS**

- Investigation of materials with properties leading to low-noise quantum sensing or information processing devices, including both those related to existing systems, as well as the development of novel materials less susceptible to noise, defects, and decoherence. (MS, NM)

**Quantum Applications and Algorithms**

- Development of algorithms and applications for quantum computers informed by both near-term and long-term mission needs in areas of digital and analog quantum simulation, edge soft computing and visualization, optimization, and linear algebra. (CIS, NSP)
- Development of protocols and methods for benchmarking the performance of, calibrating, characterizing, and predicting the behavior of quantum information and sensing devices at different scales and complexities. (CIS, NSP)
- Development of novel control and composite gating approaches, including those making use of machine learning, to minimize operations error, increase gate fidelity, and reduce the gap to realization of small applications in near-devices, including mitigating errors at the application scale. (CIS, NSP)
- Development of algorithms, analyses, simulation tools, and programming methods for modeling of quantum processors, operations layout execution and scheduling, efficient solutions for quantum/classical feedback, and integration across multiple layers of classical computing and classical control that may also enable hybridization of quantum processors. (CIS, NSP)
- Exploration, development, and rigorous analysis of quantum or quantum-inspired classical algorithms for which quantum resources may offer advantage over or inform classical counterparts. (CIS, NSP)