Quantum Testbed Stakeholder Workshop

Hosted by the
Advanced Scientific Computing Research Program

SLAC

Quantum Computing Capabilities and Interests

February 14 – 16, 2016

U.S. DEPARTMENT OF ENERGY | Office of Science

SLAC

SLAC Capabilities and Interests Summary Slide

Primary Expertise & Interest Areas

- World-leading expertise on superconducting quantum sensors
- Strong RF and microwave engineering support capability
- Interest in quantum sensors for BES, HEP, and QIS applications

Most Differentiating Factor

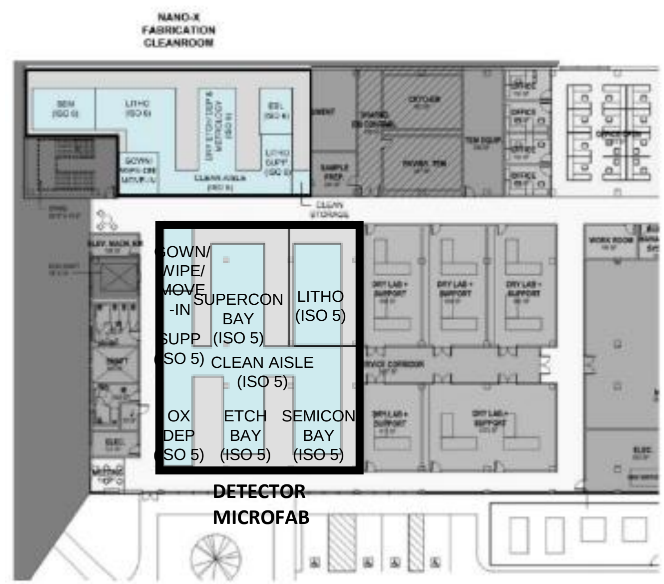
SLAC is strongly investing in superconducting device micro- and nano-fabrication, designed to serve BES, HEP, and QIS applications

Main Contribution/Role

- Fabrication of superconducting quantum devices (sensors, qubits)
- Potential to host quantum test facilities in partnership with universities and other laboratories. Strong expertise in microwave, cryogenic, and quantum circuits to support facilities.
- Facilities to host diverse user community.

Fabrication and Characterization Capabilities

- SLAC is constructing extensive dedicated clean-room facilities optimized for the fabrication of superconducting quantum sensors and qubits.
- 8000 square feet of clean space and fabrication toolsets that bridge fabrication at the micro- and nano-scales for integrated superconducting device fabrication capabilities.
- Full suite of tools for lithography (optical and e-beam), film deposition and patterning, micromachining.
- Hybrid of project-oriented and user facility. Managed for process control and yield.



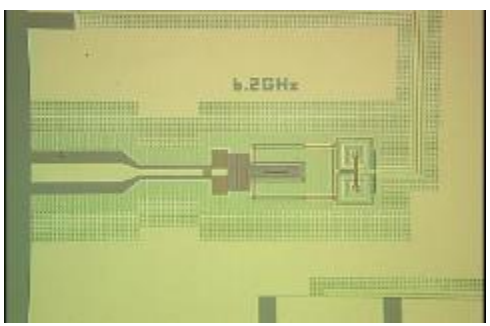
Quantum Computing Hardware Capabilities

SLAC staff have extensive history in quantum sensor / amplifier and qubit device design, fabrication and testing. Building up facilities at SLAC.

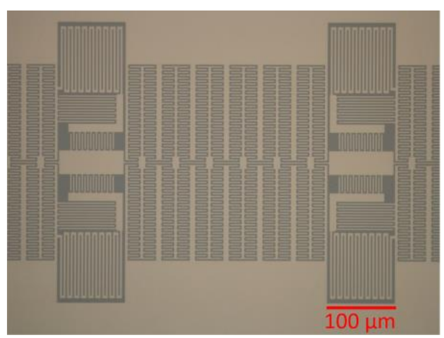
Hsiao-Mei Cho

Dale Li

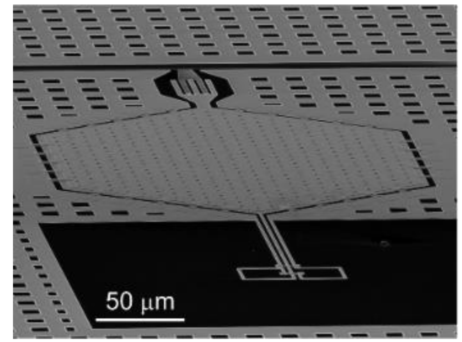
Kent Irwin



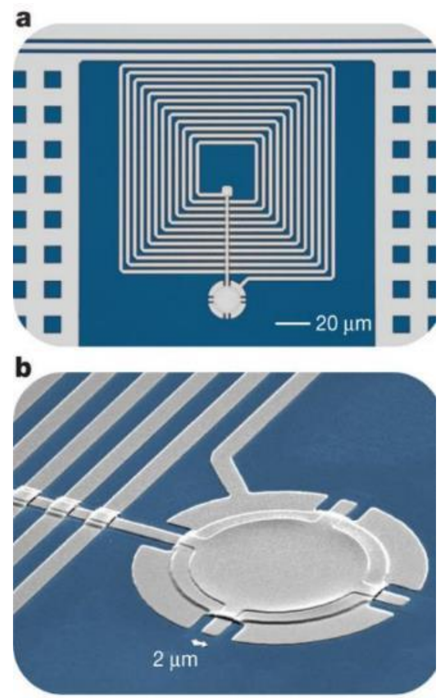
Josephson para-amp (with Lehnert, JILA)



Kinetic inductance para-amp (with NIST)



Qubits, quantum information processing



Mechanical circuits in the quantum ground state

JD Teufel et al. Nature 475, 359 (2011), with NIST

Quantum Computer Science Capabilities

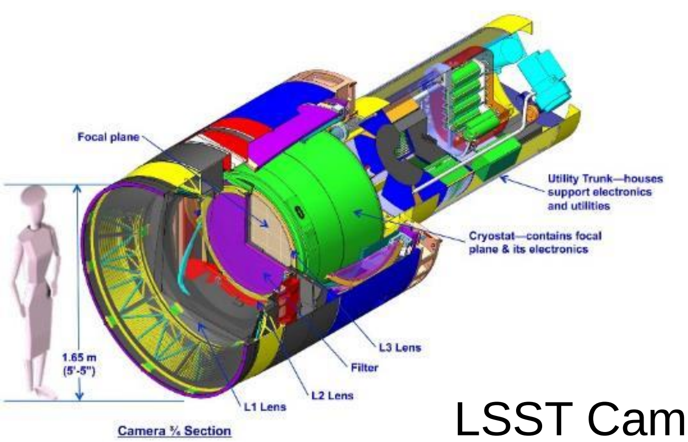
Growing connection to Stanford campus CS through SLAC computer science division. Exploring quantum CS connections including:

- Qubit storage in continuous degrees of freedom (e.g. microwave cavity and mechanical modes). Multi-mode quantum error correction codes (**Patrick Hayden**, Stanford Professor of Quantum Physics)
- Theoretical exploration of problems demonstrating quantum supremacy. (**Patrick Hayden**)
- Post-quantum cryptography: secure communication when the adversary has a quantum computer. (**Dan Boneh, CS/EE**)
- Classical software abstractions for controlling quantum computers (**Dan Boneh**)
- Quantum algorithms

Alex Aiken, director of SLAC Computer Science Division, and chair of Computer Science department at Stanford

Capabilities in Engineering and Supporting Technology

- Extensive systems engineering capabilities in microwave and rf technology and electronics.
- Systems engineering for major user facilities: LCLS, world's first x-ray laser. SSRL synchrotron.
- World's largest digital camera for LSST.
- Superconducting devices: invented TES and SQUID sensors in all presently deployed CMB experiments and CDMS/Super-CDMS, superconducting x-ray detectors for BES.
- Extensive cryogenics experience, including mK devices: CDMS, BICEP-3, x-ray detectors at SSRL.



LSST Camera

LCLS

Facility Management Experience

- Large international user's community for light sources and user facilities
  - Linac Coherent Light Source (LCLS)
  - Stanford Synchrotron Radiation Laboratory (SSRL)
  - FACET, NLCTA, ESTB & ASTA
- On-site housing for user community at Stanford Guest House located at SLAC
- Micro- and Nano-fabrication facilities (under development)
  - Hybrid of project-oriented facility and user facility
  - Intended to optimize yield and process control, while serving multiple process-compatible applications.
  - More flexible than a foundry, more process control than a user facility.

Applications to Domain Science

- Quantum computing devices have strong application to quantum sensing (qubits, sensors, squeezed states, etc.) for HEP and BES
    - Quantum sensors and amplifiers for ultra-light dark matter (Dark Matter Radio)
    - Superconducting sensors and amplifiers for WIMP searches: CDMS and SuperCDMS
    - Superconducting x-ray detectors for high-efficiency x-ray spectroscopy
    - Superconducting CMB detectors and quantum-limited multiplexed readout technology
- Quantum simulation has strong application in chemistry, biology, and quantum materials programs in SLAC Photon Science
- Quantum computing capabilities would directly impact Computer Science Division at SLAC

Investments in Quantum Computing Technology

- Extensive investment in relevant quantum sensor technology (*but not yet qubit technology)*
- Motivation and priorities:
  - Basic Energy Sciences applications (x-ray spectroscopy)
  - High Energy Physics applications (e.g. light-field dark matter, CMB)
  - Partnership in Stanford Quantum Science and Engineering long-range planning process
  - Broad interest in precision measurement science
- LDRD and related investments
  - BICEP-3: 2560-pixel CMB detector operating at the South Pole: currently most sensitive instrument for inflationary B modes (completed LDRD).
  - 240-channel superconducting x-ray spectrometer successfully doing biospectroscopy at SSRL (completed LDRD).
  - Dark Matter Radio: quantum sensors for ultra-light-field dark matter – axions and hidden photons. (in second year of LDRD).
  - Large investment in quantum sensor and amplifier program (program development).

External Partnerships

- Partnerships with Stanford Campus
  - Strong connection on Stanford campus on CMB, dark matter, x-ray spectroscopy (Cabrera, Irwin, Kuo, Church, Graham, Dimopoulos…)
  - Exploring partnership with Stanford campus on quantum algorithms (Hayden, Boneh)
  - Growing connections to campus on superconducting qubit / QED / micromechanical circuits (Safavi-Naeini)
- Partnership on superconducting sensors with Berkeley, Caltech, UPenn, Princeton, Harvard, UMn, UMich, Cornell, Colorado, …
- Partnership with NASA on quantum sensors for x-ray (Athena), CMB (inflation probe satellite, balloons)
- Strong connections to NIST on all quantum sensor applications
- Geographical location in silicon valley opens up opportunities for collaboration with local quantum companies. Early collaborative connections *on campus* to Rigetti computing and Google quantum A.I. (Martinis)
- Experience working with industry on sensors, RF technology, electronics