

LQC: Past, Present, and Future

My first “real” job taught me two things [1]. I learned a lot about building quantum

computers. And I learned that the most important thing you can do in any position is find your successor. I am now the former director of the LPS Qubit Collaboratory. I want to use this last blog post to remind everyone how and why the LQC got started, celebrate what it has achieved so far, and convey why I believe these successes are just the beginning. And of course, I want to thank all my fellow collaboratory-ers.

Even before the National Quantum Initiative (NQI) became law, representatives from the agencies that fund quantum R&D in the U.S. began writing a national quantum strategy. At the time I was Executive Secretary of the Subcommittee on Quantum Information Science where this work happened [2]. Concurrently, LPS began thinking about how we could contribute to the NQI. From this the LQC and programs like the Qubit Foundry were born.

LPS, working with the Army Research Office (ARO), has been a consistent funder of quantum computing research for 30 years, providing support to groups all over the world. LPS deserves a lot of credit for this. Most, if not all, of the scientists you know who create and control qubits can trace their work or career back to an LPS/ARO grant. This includes me! I got started in silicon QC in 2000 as a first-year grad student in a team just then funded by LPS and ARO. While I was starting in Wisconsin, LPS began an internal research program in QC.

LPS is a real lab that does real things, so this was not unusual. But it was still prescient. Because that decision built a foundation of expertise that would later allow LPS to manage an extremely complex and varied set of technologies, from silicon to neutral atoms to quantum characterization, and advise the government on truth from fiction in quantum computing.

Things change. QIS became a new field of science [3]. New corporate entrants like Google hired entire academic groups outright. Startups got venture capital funding. New NQI programs, born out of the House Science and Senate Commerce Committees, were started at NSF, DOE, and NIST. These brought the Department of Energy into QIS in a big way, starting with five $25M/year centers. Hiring people into the government (hiring people anywhere) got harder. The national effort clearly needed LPS to step up its game. While the bimodal approach LPS had taken of broad sponsored research programs and a strong, but much smaller internal research team had worked well for 20 years, LPS [4] decided a third way was needed. That pitch included doubling the labs and science at LPS, developing a workforce development pipeline into the government, and pursuing joint disruptive quantum research. The latter would be based on hard, “impossible” problems—fundamental research problems—chosen based on LPS’ decades of expertise. This manifested in the case for LPS launching a national quantum information science research center for the Intelligence Community, which became the LQC.

To achieve what was promised, LPS needed to break down the wall: enable government

staff, universities, national labs, and companies to work together on targeted problems.

And here's the abbreviated masterclass version of what we did. We called ARO and said we need something called a collaborative agreement. Typically, the government gives grants or contracts to research groups at universities or companies. Program managers create a Broad Agency Announcement - a "call" - which sets target research objectives. The BAA lays out the problem with some target goal (e.g., "a 4 qubit processor with three nines fidelity gates") and asks responders to propose a solution: how you will get there, who is your team, what are the milestones to track progress, and how much will it cost. There is a clear separation between the evaluators, the program managers, and the performers, or people doing the work [5]. A collaborative agreement, on the other hand, allows government scientists and those outside of government to solve problems, or develop intellectual property, together.

But the LQC BAA goes beyond that, somewhat radically. It basically says this: LPS DOESN'T WANT YOUR IDEAS. LPS wants your interest in the problem, your experience and capability to tackle it, and your willingness to do so together. In many ways this was an expansion of pilot projects like MATISSE, which was a collaboration between Princeton, HRL, MIT, Chicago, and LPS to tackle the mega question (at the time) of whether coupling a spin quantum dot qubit to a microwave resonator could really work. (It can.)

The core of the LQC are the research thrusts. But the first thing you do when starting a new organization is write down its mission. The mission of the LQC is threefold:

1. **Pursue disruptive fundamental research** and enabling technologies with a focus on qubit development for quantum computing and other applications (such as sensing);

2. **Build a quantum workforce** through research experiences and innovative training in government at LPS and at LQC partners; and

3. **Grow deep, collaborative partnerships** to tackle the most difficult and relevant long-term problems for quantum information science and technology.

And this mission has core values:

- Maintain our scientific integrity in everything we do;
- Create a research environment of trust, respect, and open communication;
- Choose the hard problems over the easy ones and pursue the technical challenges that others put off;
- Work hard and be kind.

The core values (and evaluation processes set up behind them) are important. LPS both sponsors external research and conducts research internally. The processes we developed

to propose and evaluate LQC proposals must maintain the professional and scientific integrity of LPS' staff (even though a hard wall is not needed: remember, LPS IS A LAB THAT DOES STUFF, not a funding agency).

But most important—and the core of the LQC—are the research problems. These are the problems that at the time we thought would, if solved, disrupt QC in a good way. Notice that they are hard problems, often requiring deep and patient investment in, for example, materials science.

Here's a table of those initial thrusts - and my interpretation of why the time was right to work on them.

Spin qubits, fast.	*Working spin qubits are hard to fabricate and require significant infrastructure and workforce investments. How can we make them faster? How can we characterize them faster?*
More epitaxy, better qubits?	*Are epitaxial devices really better for quantum computing? We need improvements in computational methods and understanding of surfaces/interfaces.*
Voltage controllable superconducting qubits.	*Can we make superconducting devices compatible with voltage-based control electronics? Can we maintain compatibility with existing wafer growth facilities at LPS and LQC partners?*
Going hot and not looking back.	*Can we design qubits and quantum processors to operate in the range of 350 mK to 2 K?*
Beyond Moore, Before Shor.	*Can these increasingly well-controlled quantum devices and systems for classical computing and enabling device applications?*
Accelerated Learning of Quantum Information Concepts.	*Can we leverage classroom and laboratory experiences to train a*

> *talented quantum workforce of the future faster?*

The LQC was launched right before COVID hit. And that was a hit on getting labs built, etc. I don't have time or space to list all that was accomplished but I want to give some highlights that are special to me:

- The Qubits for Computing Foundry program was launched with Lincoln Labs for superconducting qubit. Recently Intel and HRL were added for spin qubits. https://www.qubitcollaboratory.org/foundry/ Dozens of groups around the country can now do qubit experiments now.
- All new multi-PI labs including the super-semi lab, a new spin qubit testbed, and a superconducting qubit multiprocessor lab were stood up. We also completed radical upgrades to LPS' fab that support this and other work, including two new e-beam writers and new growth and deposition tools.
- LPS hosted a Hot Qubit Workshop which inspired some new experiments. Sometimes just asking scientist to consider a problem results in progress.
- The LQC super-germanium (Super-Ge) collaboration has resulted in some major contributions to our understanding of voltage tunable superconducting-semiconductor qubits, including the decoherence of Andreev spin qubits, understanding the physics of super-semi weak links, and the design 3D super-semi quantum computer architectures.
- LPS has supported research into accelerated quantum learning, including major workshops, a virtual summer quantum short course, and new quantum masters programs at UCLA and Wisconsin, support for the Q-12 education partnership.

Which brings me to goodbye. Fortunately for LPS and the LQC, the "we" throughout this blog post mostly didn't mean me. Remember lesson number 2 above. First and foremost, "we" meant Chris Richardson, who having served as deputy director of the LQC and led most of this transformation, will be replacing me as director of the LPS Qubit Collaboratory. So, more great stuff to come, guaranteed.

(Note that I also highlighted the LQC in my last blog post at OSTP.)

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The qubit processor lab at LPS: One of the new multi-PI labs funded by the LQC at LPS, almost ready for christening.

[1] I worked in DARPA's Microsystems Technology Office as a SETA. SETA's are contracted (I worked for Booz Allen Hamilton) technical consultants who support the term-limited government program managers at DARPA.

[2] The National Science and Technology Council is an office within the Executive Office of the President.

[3] The best example of this is the growth of the Division of Quantum Information in the American Physical Society.

[4] I was managing the intramural QIS program at the time and Technical Director of LPS.

[5] Technical program manager's contribute significantly to the success of sponsored research program, which is why LPS typically has very technically deep PMs.