STATEMENT TO THE
U.S. COMMITTEE ON ENERGY AND COMMERCE
SUBCOMMITTEE ON DIGITAL COMMERCE AND CONSUMER PROTECTION
UNITED STATES HOUSE OF REPRESENTATIVES
Hearing on
Disruptor Series: Quantum Computing
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on behalf of the National Photonics Initiative

Thank you for the opportunity to testify, Mr. Chairman. I am honored to be here before you and the Subcommittee on Digital Commerce and Consumer Protection to offer testimony on the committee's "Disruptor Series: Quantum Computing." I am a quantum physicist and Professor at the University of Maryland, with over two decades specializing in the field of quantum information science. I am also the chief scientist and co-founder of IonQ, Inc., a startup in College Park, MD that will produce universal and reconfigurable quantum computers. Over the past year I have had the opportunity to work with the National Photonics Initiative (NPI), a collaborative alliance among industry, academia and government to raise awareness of and increase investment in the fields of optics and photonics which enables much of quantum technology.

Through the collective efforts of the NPI, I have worked with experts at the University of Chicago, Duke University, Intel Corporation, IBM, Stanford University, AOSense, Inc., Harvard University, Google Inc., Harris Corporation, Massachusetts Institute of Technology, Northrop-Grumman Corporation, California Institute of Technology, University of Oregon, Rigetti Computing and the University of California, Berkeleyto develop a National Quantum Initiative (NQI). I am offering my testimony today on quantum computing and the need for our nation to create and support this NQI.

I appreciate the committee's interest to examine the potential of quantum technology. This is the second time in the past year that I have testified before Congress discussing the importance of an NQI. I was honored to testify before the House Science, Space and Technology Committee in the October 2017 and was later invited to attend the Committee's working group discussion in February on this important topic. I am pleased to keep this conversation going today as part of the Energy & Commerce's "Disruptor Series: Quantum Computing" hearing. I hope the testimony I present today will further this Committee's education about the value and importance of quantum computing and the specifics for implementing an NQI.

About Quantum Information Science

The exponential growth in the power of information technology – Moore's Law – catalyzed US productivity and economic growth over the last 50 years. But, like much of our nation's aging infrastructure, this growth is now ending as scientific breakthroughs from the 1950s and 1960s reach their technological limits. This jeopardizes the safety and security of the American people and threatens what has been the backbone of US economic growth over the past several decades.

There are many complex problems in science and society that will never be solved using conventional computers and information technology. Quantum technology (QT) can store and process otherwise inaccessible amounts of data, owing to the unique principles underlying quantum systems. Unlike the 0s and 1s in conventional computers, *quantum bits* can represent both values 0 and 1 simultaneously, taking on definite values only when observed. The power of a quantum computer doubles with each added quantum bit, leading to many potential applications that are impossible using conventional technology:

- **Optimization over huge data sets**. Quantum computers will be able to sort rapidly through data sets that are too large to ever be stored on conventional devices, such as real-time video of the entire surface of the earth. Quantum programs can potentially store, optimize, or search such databases very rapidly, with potential uses in autonomous vehicle navigation, weather prediction, machine learning, economic market analysis, code-breaking, and logistics including energy and transportation systems.
- **Design of new materials and molecular functions**. Quantum computers can be programmed to simulate the behavior of complex molecules and materials beyond the reach of conventional computers. This will usher the discovery of new substances with exotic electrical/mechanical properties, designer molecules for efficient drug activity, and efficient materials for the conversion of energy between light and electricity.
- **Secure communications.** Quantum bits change when they are observed, meaning it is possible to send information while knowing whether or not it is secret. Quantum communication can also allow secure communication between multiple (possibly untrusted) parties for optimal decision making, and for interconnecting large-scale quantum computers via a quantum internet.

- **Quantum sensing and metrology**. Quantum technologies enable a new generation of atomic clocks and ultra-precise sensors with applications ranging from natural resource exploration and biomedical diagnostics to navigation in a GPS-blind environment.

Nearly all implementations of quantum computers will use photonics in a key role for their operations. A quantum Internet will communicate data between quantum computers using pulses of light traveling on optical fibers. Quantum photonics is already used to operate the most accurate clocks on Earth and the most sensitive probes for biomedical use and geo-exploration.

A Call to Action: Advancing Quantum Technology (QT)

Because of the great promise quantum information science holds for next-generation computing and processing, there are several independent federal and industry efforts underway to advance the research and technology. For example, widespread national interest in quantum information science also coincides with a new perspective on quantum sensors and quantum computing from the Department of Energy (DOE) and recent initiatives launched by the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST).

Perhaps most importantly, the United States is not alone in pursuing quantum research and technology development. In contrast to the decentralized funding structure of quantum information science in the United States, European entities have recently established large, focused, academic/industrial thrusts including the UK Quantum Hub Network ($400 million/five years), the Netherlands QuTech Initiative ($150 million/10 years) and the European Union (EU) Flagship Quantum Program ($1.3 billion/10 years). Outside of Europe, China is aggressive in its commitment to quantum; the country recently launched a satellite devoted to quantum communication protocols, and there is report of a $10 billion investment into a quantum laboratory in Hefei, China. Major initiatives are also underway in Australia and Canada.

This explosion of activity worldwide should be a call for action in the United States. To ensure competitiveness and national security in the field of quantum information science, the United States should dedicate resources to coordinating existing federal and private programs and filling in critical gaps. Especially important are those gaps that exist between academic and government laboratories that lack systems engineering and product development expertise, and within the private industry, which lacks a trained quantum engineering workforce.

Establishing a National Quantum Initiative (NQI)

An NQI will address one of the Grand Challenges of the 21st century – harnessing quantum as a fundamentally new technology to serve national needs in information infrastructure, chemical and biomedical research and development (R&D), cybersecurity and defense capabilities. As quantum information sciences have the potential to touch nearly all areas of science and technology, its development and implementation through the NQI will naturally engage all STEM fields.

QT will also usher great scientific opportunities. Just as the LIGO gravitational wave detector enables scientists to peer into the cosmos with new eyes, QT opens windows into a realm governed by the counterintuitive laws of quantum physics. More than being the basis for new, essential technologies, QT will reveal ever deeper understanding into the nature of the physical world. QT will also advance fundamental science by providing computing power to simulate a host of intractable problems from nuclear physics and neuroscience to other complex interacting systems.

In order to help foster the implementation of an NQI, the NPI drafted an NQI Action Plan and unveiled it in early April. The Action Plan was in fact a major focus of the annual Capitol Hill Day hosted late last month by the NPI that brought NPI representatives from across the country to Capitol Hill to discuss the importance and potential of photonics-enabled quantum technology.

The Action Plan follows the June 2017 white paper, "Call for a National Quantum Initiative" produced by a collective of academics, industry experts and professional societies through the direction of the NPI. The NQI was then supported during the October 2017 hearing by the House Committee on Science, Space and Technology entitled "American Leadership in Quantum Technology," where I presented testimony on behalf of the NPI demonstrating that an NQI will ensure scientific leadership and economic and national security.

NQI Implementation Plan

The operational goals of the NQI are to (a) Engage and produce a world-leading industrial QT workforce, (b) Engineer, industrialize, and automate QT including quantum computers, communication systems and quantum sensors, (c) Provide access to the emerging quantum computer systems, (d) Develop conventional technology and intellectual property (IP) needed to support and enable QT, (e) Produce quantum software and new applications of QT, and (f) Continue the fundamental research needed to support these NQI goals, and arising from the capabilities of QT.

The NQI will be anchored by three to six new facilities called **Quantum Innovation Laboratories** (QILabs), along with a **Quantum Research Network** (QRNet) and a **Quantum Computing Access Program** (QCAP). Each QILab will be located at a central facility in the U.S. and have a distinct and focused research and development mission and may include satellite QILab participants and facilities as appropriate. The QILabs will provide sophisticated, well-engineered experimental platforms for developing and testing QT and performing state-of-the-art scientific studies. The QILabs will supplement existing technology transfer and research programs at government agencies, which will also continue to support fundamental research in quantum science necessary for QT innovation. QRNet will consist of a web of autonomous research groups distributed throughout the country at academic, government, and industrial sites. QCAP will ensure leading American researchers have access to quantum computing capabilities.

Each **QILab** and its satellites will focus on research and development of a particular family of quantum technologies, or a suite of closely related technologies, including supporting technology, control systems, software and user interfaces, and theoretical co-design of applications or algorithms mapped to the technology. For example, QILab thrusts in solid-state superconducting and semiconductor quantum systems would fabricate quantum computers with more than 100 quantum bits, develop and optimize quantum materials, advance cryogenic packaging and fast electronic control systems, and mitigate noise from material defects. QILab activity in isolated atomic systems including trapped ions and neutral atoms would develop quantum computers with more than 100 quantum bits, engineered with external optical control systems to quantum entangle and manipulate large-scale atomic systems for quantum sensors and atomic clocks. QILab technology may feature the engineering of photonic quantum networks and supporting technologies for enabling long-distance (greater than 100 km) transmission of quantum information through a quantum internet, for linking nodes of a distributed quantum computer operating with more than 100 quantum bits, and for distributed sensing applications. QILab efforts may involve quantum-enabled sensing applications including subsurface imaging, biomedical imaging, and GPS-free navigation.

The **QRNet** program will support fundamental research of QT by funding individual efforts to investigate and collaborate with QILab technologies, combine different QT for hybrid quantum systems, and uncover promising quantum systems for future quantum bit realization and QT development. QRNet will also investigate new quantum algorithms and its enabling software to drive existing QT, with potential applications in the areas of quantum chemistry and materials development, artificial intelligence and machine learning, and optimization.

The **QCAP** will support the activities of the QILab and QRNet programs by providing access to the most advanced American quantum computing systems and simulators. The most advanced commercially available American-made quantum computing systems will be made available via secure cloud access to all QILab and QRNet projects, applicable advanced scientific computing projects, and U.S. government researchers. The facilities will include technology from multiple American vendors and at least two different underlying quantum computing hardware technologies. Additionally, the QCAP should leverage high-performance computing resources to allow application developers to simulate aspects of the quantum algorithms and hardware in the QILab and QRNet programs.

Creating a Quantum Workforce

A key challenge in the development of QT in the U.S. is the workforce gap between university research efforts and industrial development. University laboratories cannot properly engineer QT, given their central mission of education and research, and lack of dedicated engineering teams. Industrial QT efforts just underway in the U.S. will produce first-generation quantum technologies. However, there is a limited engineering workforce to fabricate and test this new type of technology and a severe shortage of quantum software developers to bring quantum computers and devices to users. The transition from quantum research to usable quantum technology in the marketplace is impeded by several challenges:

- The mismatch between the quantum research community, which does not engineer or manufacture products, and the industrial engineering community, which does not have a sizable workforce with training in the quantum sciences.
- The disparity between small-company innovators and their yet-to-be developed marketplaces.
- An ecosystem of conventional technologies to support quantum devices that has not been developed because quantum technologies are not yet used in high-volume applications.
- Conventional device manufacturers typically do not have the expertise to develop products targeted at quantum systems.

The NQI will become a proving ground for academic, government, and industrial scientists and engineers to pool their resources for technology developments and to provide a QT talent pool for the future development of quantum computers, quantum communication networks, and quantum sensors.

The NQI will serve as a catalyst to spur the urgently needed quantum economy, much like early investments by government sparked the development and growth of the Internet. The overarching goal of the NQI is to remedy these gaps in capabilities and marketplaces in order to hasten the development and deployment of quantum information technology, while propelling the United States into a continued leadership role in this vital field.

Budget and Administration

The QILab, QRNet and QCAP components of NQI will be administered through the civilian agencies NSF, NIST, and DOE with an overall budget of $800 million over an initial 5-year phase. This includes a $500 million budget for the QILabs, with some funded at higher levels around $25 million per year, while others will have lower funding needs. The QRNet will be funded at $200 million, or $40 million per year, and the QCAP will be funded at a level of $100 million over five years.

Each QILab will involve additional in-kind support, including facility space, research infrastructure, and scientific and administrative personnel from the host institutions. Joint research-and-teaching programs will be provided by satellite partner universities, supported by grants from the QILabs or other mechanisms. Funds will also be made available by QILabs to support research by non-university off-site groups contributing research relevant to the QILabs goals. Industrial members of the QILabs will embed industrial researchers and engineers for termed periods, with the goal of these industrial employees returning with expertise in quantum technology. Industrial stakeholders will also provide student fellowships and internships at the QILab host universities or laboratories, with opportunities for these researchers to intern both at the QILabs and at the engaged industrial partner locations. Intellectual property invented at the QILabs will be shared among the participants, with each QILab determining an IP plan suitable for its performers. In addition, support from the Small Business Innovative Research and Small Business Technology Transfer Research programs will be directed toward supporting the Initiative.

QILabs/QRNet/QCAP will be administered and funded in a coordinated fashion by an appropriate grouping of programs within NSF, NIST, and DOE, to be decided jointly by those agencies, and informally advised by QT experts selected by NSF, NIST, DOE, and the Department of Defense (DOD) and Intelligence agencies, accounting for recommendations by industry. These agencies will coordinate their existing programs in underlying quantum science and technology with the QILabs. The QILab and QRNet performers will be selected by the above agencies based on existing solicitation and evaluation procedures. Each QILab will be led by a scientific and administrative director, who will coordinate the operation of the QILab with the above agencies.

Conclusion

The NQI Action Plan is intended to provide a framework for implementing a comprehensive quantum initiative across the federal government. It will require significant investments in research and infrastructure but at the same, holds tremendous promise for solving some of our most pressing communications and security challenges.

These investments will put the U.S. in a position of global leadership in terms of quantum information technology development, economic growth and advanced research in areas ranging from health to national security. In order to realize these goals in the future, we must make investments and commitments today.

I – along with the consortium of leaders from industry and academia that signed onto the NQI Action Plan and who have extensive knowledge in information technology and quantum science and technology – will continue to be available to this Committee and others as they work to draft comprehensive quantum legislation.

I thank you, Mr. Chairman and members of the Committee, for the opportunity to speak on quantum computing and the need for a nationally focused effort to advance quantum information science in the United States.