Testimony of Dr. Supratik Guha
Director of the Nanoscience and Technology Division
and the Center for Nanoscale Materials, Argonne National Laboratory
before the
Subcommittee on Energy and the Subcommittee on Research and Technology
of the
U.S. House Committee on Science, Space, & Technology
October 24, 2017

Chairman Weber, Chairwoman Comstock, Ranking Member Veasey and Ranking Member Lipinski, and members of the subcommittees, thank you for the opportunity to appear before you today to discuss the status and future of quantum technologies, as seen from the perspective of the U.S. Department of Energy National Laboratories. I am Supratik Guha, Director of the Center for Nanoscale Materials facility supported by Basic Energy Sciences at the Argonne National Laboratory located in Lemont, Illinois. I am also a professor at the Institute for Molecular Engineering at the University of Chicago. Prior to joining Argonne and the University of Chicago in 2015, I spent twenty years at IBM: initially as a research staff member and then, between 2010 and 2015, as Director of Physical Sciences at IBM Research. During this time, IBM's quantum computing group reported to me and I played a key managerial and strategic role in its rapid growth. I am a materials scientist by training, and throughout my career I have specialized in taking demonstrations in exploratory science and converting them into technologies.

The cost of computing has decreased by about 10 orders of magnitude in the past 60 years, driven primarily by the Moore's Law scaling of microelectronics chips. Yet, the basic architecture of the computer—called the von Neumann architecture—has remained essentially the same. Recent developments in quantum information science raise the prospects of a new, rapidly emerging computing architecture. Quantum computing today is in its early stages. This technology will not replace conventional computing machines, but it offers unprecedented speed and efficiency advantages over conventional computing in three very important areas. The first of these is in cryptography—a quantum computer with its orders of magnitude advantage in speed would easily decrypt today's security codes. The second area is that of computational quantum chemistry and physics. For instance, a powerful quantum computer would be able to exactly solve the electronic structure of large molecules: this is unsolvable today using classical computers. We would be able to predict and invent new materials much quicker and cheaply instead of relying upon trial and error experimentation, as we do today. The consequences for basic science and industry in areas such as drug discovery, as just one example, are enormous. The third area is in complex data analytics, say, in large-scale traffic congestion routing problems. A quantum computer will possess a significant speed advantage in solving such challenges. These are three areas of application that we know of today; if the history of computers is any indication, then there will likely be many more in future.

Quantum computing is related to two other important and emerging fields—quantum communications, which enables secure information transfer over long distances; and quantum sensing, the ability to make physical measurements that are more accurate than those achievable by classical techniques. Quantum computing, quantum communications, and quantum sensing—referred together as "quantum information science" —depend upon "quantum entanglement", a subtle effect in quantum mechanics that can have profound end consequences. When two quantum devices are entangled, knowledge about the state of one increases our knowledge of the state of the other, no matter the physical distance between them. It is this property of entanglement that enables a quantum computer to probe information space rapidly, and simultaneously rather than sequentially, resulting in vast superiority over classical computing for some classes of problems. Quantum computing and quantum information can be enabling technologies with a crosscutting impact across a wide swath of our lives from national security, to drug design, to data analytics.

Quantum devices (called quantum bits) are the unit devices of a quantum information system and are the equivalent of a switch in a classical computer. Dramatic improvements in the quality of quantum bits over the past 10 years—brought about by improvement in materials and better physics-based designs—have enabled the building of small quantum processors containing few tens of quantum bits. These quantum bits are prone to errors and require error correction algorithms to be applied. At today's level of quantum bit perfection, it is believed that a quantum processor containing tens of thousands to a million quantum bits would be able to perform tasks of significance that could have clear advantages over classical machines. An example would be the accurate computation of the electronic structure of a large molecule containing hundreds of electrons involved in chemical bonding. As quantum bits improve and better error correction schemes are discovered, the processor will require fewer numbers of quantum bits in its circuitry. Building quantum processors with tens of quantum bits is a landmark demonstration that establishes feasibility. But today's state-of-the-art is a long way from where we wish to go. The challenge now lies in scaling this technology and doing the fundamental science and engineering necessary for this. Advances will require a combined effort in quantum devices and quantum architectures, and this will, in turn, be only as good as the materials on which these are based.

If we look at the history of electronics, there comes a time in the trajectory of technology development when massive scale materials research is needed to propel forward feasibility demonstrations driven by physicists and electrical engineers. This was true with silicon microelectronics, which has given us computing and the Internet. This was also true for compound semiconductor technology, which has given us solid-state lighting and telecommunications. The time for that materials ramp up has arrived for quantum technology. This will be materials science research of a fundamental nature that will inform the effort in devices and architectures that is also needed.

The fundamental materials research needs are numerous. To build their quantum processors a few major US technology companies have used quantum bits that operate at temperatures close to absolute zero —a showstopper for ubiquitous deployment. Opportunities exist for new types of quantum bits, particularly semiconductor quantum bits, which could operate at room temperatures and be scalable using the tools of conventional chip processing. There is a need for quantum channels that can connect different quantum chips together, and needs for new materials for quantum memory so that information can be processed entirely within the quantum space, thereby eliminating bottlenecks. One can think of a fully integrated quantum processor as a number of artificial atoms coupled together that compute and store information. It is important to re-emphasize that this is new territory for materials science and will require a deep scientific understanding of quantum effects and the creation and manipulation of individual quanta of information within materials. New materials hold the key to the ultimate development of mature quantum technologies, just as they have for other information technologies. Quantum computing is a long game, but one that we cannot afford to ignore. It will open up new horizons in information processing.

Fifty years ago, the large industrial research and development laboratories conducted a significant portion of the discovery science and underlying fundamental materials research that led to many of the technologies that we enjoy today, such as the Internet and the mobile phone. With changing business models and the increasingly complex nature of today's materials research, corporate entities are unable to perform this role today. The task does however play into the strengths of the Office of Basic Energy Sciences within the U.S. Department of Energy (DOE) and the DOE National Laboratories. These laboratories, offering unmatched capabilities in large-scale synthesis, nanofabrication, massive parallel characterization, and computational materials discovery under one roof, enable an integrated, focused effort. Further, their large user facilities—the Nanoscience Research Centers (NSRCs), light sources and the leadership computing facilities—anchor university-based ecosystems around them. The five highly successful NSRCs distributed across the nation, authorized and appropriated for funding by Congress a decade ago as part of the National Nanotechnology initiative, are well positioned to act as a springboard for a new National Quantum Materials initiative, partnered with academia and informed by the needs of the industry. One can argue that the emergence of quantum information sciences is a direct consequence of the National Nanotechnology Initiative and a Quantum Materials Initiative could be a sequel to this.

The United States continues to maintain leadership in quantum technologies, but rapid research growth in China and Europe may threaten this position. China has announced multi-billion dollar investments in quantum information research targeted towards specific centers of excellence. European investment is more spread out and totals between one to two billion dollars. China recently has made impressive strides in the demonstration of satellite based secure quantum links over a few hundred kilometers—a tour de force engineering demonstration.

Future quantum technologies will demand a new type of educated workforce with the multidisciplinary ability to engage in quantum mechanics as engineers. Universities nationwide have begun responding to this. The University of Chicago has launched one of the first Ph.D. programs in quantum engineering in the nation. The Center for Quantum Exchange, announced by the University of Chicago in partnership with the Argonne National Laboratory and the Fermi National Accelerator Laboratory in Batavia, Illinois, will develop a new generation of graduate students who will learn their skills in close collaboration with national laboratory scientists and academics.

DOE and its laboratories are strengthening their presence in quantum materials and information research. The laboratories possess the necessary skills across the entire ecosystem: from algorithm and system architecture to the materials science and physics. The Office of Basic Energy Sciences has prioritized investments in quantum materials and the national laboratories recognize quantum information science research as a strategic focus area. Unique equipment developed at Argonne for research in nanomaterials, such as synchrotron based x-ray microscopy, is being used to “see” exquisitely small distortions in crystals used for building quantum bits. The “Quantum Factory,” a comprehensive experimental facility for the synthesis of quantum materials with atomic layer precision has been set up at Argonne in joint collaboration with The University of Chicago.

Thank you for your time and attention to this critically important topic. I would be happy to respond to any questions that you might have.