US national labs best positioned to advance quantum materials research

US science and policy experts say a big push is needed to deliver the promise of quantum information systems.

The ability to quickly predict and invent new materials at low cost, analyze and resolve traffic congestion in large metropolitan areas, and enhance national security through impossible-to-break cryptography are three areas of vital national interest that will become feasible with viable quantum information systems (QISs) that harness the power of quantum mechanics phenomena at the atomic scale, acording to many US experts.

However, the promise of QISs and computers, the earliest models of which are now being built, is premised on a gigantic leap forward for quantum materials research to provide the technologies that will undergird new computer architectures built on quantum principles, says Supratik Guha, a research director at Argonne National Laboratory (ANL), who heads the Nanoscience and Technology Division and the Center for Nanoscale Materials at ANL.

Beamlines at US Department of Energy Advanced Photon Source enable studies of quantum materials. Photo Credit: DOE.

"Quantum materials is a label that has come to signify the area of condensed-matter physics formerly known as strongly correlated electronic systems. Although the field is broad, a unifying theme is the discovery and investigation of materials whose electronic properties cannot be understood with concepts from contemporary condensed-matter textbooks," Joseph Orenstein, a professor of physics at University of California, Berkeley and a researcher at Lawrence Berkeley National Laboratory, wrote in a 2012 article in *Physics Today*.

"Much of the effort to develop practical QIS applications depends on the availability of materials with the appropriate quantum properties and the ability to package hardware that may currently fill several large laboratory tables," says a July 2016 report on advancing quantum information sciences prepared by former US President Barack Obama's National Science and Technology Council.

QISs won't replace the computers everyone uses today, Guha says. Rather, "they will augment classical computing devices, opening new frontiers in the sciences by being able—via quantum mechanics principles—to probe information space with unprecedented speed and efficiency."

Cryptography, computational chemistry and physics, and complex data analytics are just three areas of research identifiable now that will enter a new realm of possibilities with the capabilities of quantum processors, Guha says. And, as has happened with the blossoming of classical computing over the past 60 years, we can expect many more benefits from quantum computing not yet recognizable, he adds.

US policy on quantum materials research needs to stay apace of the demand for quantum computing advances, Guha told members of the US House of Representatives Committee on Science, Space, and Technology on October 24, 2017.

China, Europe, and other competitors with the United States are working hard to capture the technical know-how, intellectual property, and economic benefits that the realization of quantum materials and technologies can deliver, Guha says.

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"The US leads the world in quantum materials research today," he says, "but we are now at a point of moving this to the next phase where it changes from being a largely academic physics activity to the beginnings of technology and the development of materials science, computer science, and so on, ecosystem around quantum information systems. It is important that the US continue significant investments in this area."

"If we look at the history of electronics," Guha says, "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. The time for that ramp up has arrived for quantum technology."

As for government funding, "I'm not certain what financial investment the US needs to make in [quantum materials research] to maintain its lead—it is difficult to provide a ready number," Guha says. "Europe has decided to invest €1 billion over the next 10 years and China—significantly more than that."

Asked if a Manhattan Project-like approach to quantum materials research might be appropriate, Guha says, "There needs to be focused research here ... of a multi-disciplinary nature and which has a broad set of goals and milestones that are coordinated with discipline. A 'Manhattan-project' analogy applies in this context."

According to Guha, evolving business models and the sheer expense and complexity of today's research in quantum materials make it difficult for this task to be carried out by the large industrial R&D labs as was the case in the United States 50 years ago. Universities, by themselves, are also not the right places for this type of research. On the other hand, the US National Laboratories, with their large scientific, operational, and management infrastructure, and university and industrial R&D ecosystems around them, are the optimal locations for this type of goal-oriented research, he says.

"Take for example the challenging task of building a high brightness x-ray beamline, intended to be the most powerful 4th-generation storage ring-based light source facility in the world, that Argonne National Labs is undertaking. It involves exquisite levels of scientific design, engineering design, understanding of the basic science we wish to do, a commitment to operational discipline and efficiency, and costs in the hundreds of millions of dollars," Guha says. "A task such as this that has so many scientific and engineering nuances, is one that the National Labs are primed for. A large program in Quantum Information Systems will benefit from this type of experience."

Asked where the private sector fits into the quantum materials research needs, Guha says industry is contributing heavily to quantum computing research "and this therefore includes some work in quantum materials research, most importantly work on superconducting qubits which has been the focus of the leading private sector companies in this space. However, in terms of work on a wide array of different quantum materials, there is a lot of untapped and unexplored opportunity."

"Real quantum materials [for QISs] require synthesis," J. Stephen Binkley, Deputy Director of the Office of Science at the US Department of Energy (DOE), told legislators at the October hearing. The DOE oversees operation of the National Laboratories, including ANL.

Binkley said the research challenges, while very large and complex, hold great promise. Resulting functionalities, he said, could include superconductivity and maintenance of quantum states in conditions approaching room temperature, so-called neuromorphic computing that mimics biological information processing, and other advances that would apply across many fields of science.

"Quantum information science technology is rapidly evolving," Binkley said. "Federal coordination and investment is critical to continued US scientific leadership in this area with implications for not only advancing scientific discovery in a number of fields, but continued US economic competitiveness and national security."

William G. Schulz

EU use of critical raw materials needs improvement for circular economy

Critical raw materials are not used to their full extent as part of the circular economy and there are several opportunities for improvement to reuse and recycle these materials, according to a recent report, "Critical Raw Materials and the Circular Economy," published by the EU Joint Research Centre.

The report provides a detailed analysis for some specific sectors, such as extractive waste, electric and electronic equipment, batteries, automotive, and renewable energy, describing the current state of play for key critical raw materials and identifying a number of good practices in each sector.

The report concludes that for several economic sectors in the EU, the use of critical raw materials is far from being fully circular. The gaps are due to various factors, including the loss of materials during collection and recycling of end-of-life products.

The report identifies opportunities and formulates advice for future actions. It discusses policy actions at the EU level to improve the legislative framework to increase the availability of secondary critical raw materials through improved waste collection and treatment.

The report also points to further R&D as key for making available more innovative, efficient, and cost-effective technologies for the extraction of critical raw materials.

The report argues that research and industry initiatives should also foster material-efficient solutions in the use of critical raw materials in various sectors and that not only recycling, but also reuse, product lifetime extension, and new business models be considered.

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