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Research group Ultrafast Quantum Optics seeks to develop non-invasive quantum electron microscope within an international research collaboration

By observing molecules in a new way, innovation would allow scientists to make unexpected discoveries and answer fundamental questions about life that have never before been approachable.

Moving closer to creating a microscope that can peer through atoms and molecules without disturbing them, leading physics researchers have joined together with support from the Gordon and Betty Moore Foundation to launch an international collaboration to lay the groundwork for the development of a novel quantum electron microscope.

The $4 million, three-and-a-half-year effort will be spearheaded by Dr. Mark Kasevich at Stanford, Dr. Peter Hommelhoff at The Max Planck Institute of Quantum Optics, Drs. Fatih Yanik and Karl Berggren at Massachusetts Institute of Technology and Dr. Pieter Kruit at Delft University of Technology in the Netherlands. The research groups will work together to demonstrate interaction-free measurements with electrons, which, if successful, would form the basic principles for future development of an electron microscope with the potential to yield important discoveries in many areas of science.

The theory was first proposed by Dr. Yanik's team at MIT in a paper for *Physical Review Rapid Communications* in October 2009 (Phys Rev A 80, 040902(R) 2009). This new international collaboration will begin testing the theory, making significant strides towards its realization.

“The Gordon and Betty Moore Foundation’s Science Program seeks to support high-impact scientific research, and we see this project as exactly that kind of opportunity,” said Vicki Chandler, chief program officer for Science at Moore. “We expect that the work this team is doing will enable exciting new science through technology, and the scientists will acquire fundamental new knowledge in quantum mechanics and manipulation of electrons.”

Although light and electron microscopes have shaped our modern understanding of biology—with discoveries as fundamental as the eukaryotic cell, bacteria and viruses, to name just a few—major barriers to answering fundamental biological questions remain, including the inability to visualize molecules interacting within living cells. The light microscope can image living things, but not at molecular resolution. The electron microscope, on the other hand, can image molecules and atoms, but cannot be used to study live samples due to the intense radiation the sample is exposed to. A quantum electron microscope, however, promises to overcome these deficiencies in current imaging technologies by allowing scientists to peer into living cells at molecular resolution without radiation damage, dramatically expanding our understanding of how cells work.

“Our first step will be to demonstrate that the interaction-free quantum measurement principle indeed works with electrons. We have already accomplished some of the most important technical requirements – wave guide structures for the controlled steering and manipulation of the quantum properties of electrons,” Prof. Peter Hommelhoff explained. “The

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development of a microscope that will image biological samples non-invasively and with high resolution will be the next step. This microscope would greatly reduce the radiation dose in the sample, thereby avoiding damage of its structure. It would be fascinating to make movies from living cells with the new device – with the spatial resolution of an electron microscope."

"The necessary technological development is a fantastic challenge. It is designing a combination of a miniature storage ring of the type used in synchrotrons and a superresolution electron microscope, held together by an electron beam splitter of only a few atoms thick," said Pieter Kruit, one of the principal investigators in the project and best known for his innovations in electron optics instrumentation.

"The quantum electron microscope uses a fundamental and surprising aspect of quantum mechanics--that observations of a part of a system can affect the evolution of the entire system, including those parts that were not themselves directly observed. In this microscope, the sample acts as an observer, and its presence in the electron beam influences a measurement made elsewhere in the microscope," said Karl K. Berggren, one of the principal investigators in the project. "It's as if a sample is in one box, and an electron is in another. If you look in the box that should contain the electron, and it's still there, then you learn something about the sample even though the electron never technically went into that other box. The consequence is that samples might be imaged with electron-microscope-level resolution, without being exposed to high levels of damage that are typically present whenever high-energy electrons bombard an object."

"This research will advance our understanding of the technological limits for quantum control of individual electrons. In addition to providing a foundation for the development a non-destructive electron microscope, we hope to be surprised by new, unanticipated applications," said Mark Kasevich, Professor of Physics and Applied Physics at Stanford University.

Recent advances in the quantum-level control of electrons open the door to development of an electron microscope based on non-destructive quantum measurement principles. These instruments may enable real-time, non-destructive imaging of biological samples. A three-year, coordinated program to develop the foundational ideas in support of this technology will involve each university team taking parallel but distinct technical and scientific approaches.

Throughout its history, science has relied on technical advances and surges in new knowledge that have offered researchers unexpected breakthroughs—and new questions. The quantum electron microscope will offer transformational new approaches, with the potential for an enduring impact on fundamental physics, engineering and biology.

About TU Delft

Delft University of Technology was founded in 1842 and with its 3300 scientists and 19000 students from 100 nationalities is still the largest in the Netherlands. Ranked among the top universities of technology in the world TU Delft's research and education are backed by outstanding facilities in areas such as nanotechnology. Activities in the Faculty of Applied Sciences range from fundamental research on life at the nanoscale to pursuing innovations in physics instrumentation in close cooperation with industry.

About the Research Laboratory of Electronics

The Research Laboratory of Electronics (RLE), MIT's leading entrepreneurial interdisciplinary research organization, provides a collaborative and vibrant intellectual community for more than 600 researchers. Through RLE faculty, the Laboratory has made significant discoveries over the years in various areas including Optical Coherence Tomography (OCT) and High-Definition Television (HDTV), and has celebrated achievements such as a Physics Nobel Prize win and the emergence of Bose Corporation. Originally rooted in the exploration of Airborne Radar, RLE aims to create a stimulating and supportive environment for visionary and diverse research, and strategically deploys resources to achieve excellence in research and education, and to support translation of engineering innovations to application technologies that are relevant to today and critical to tomorrow.

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About the Max-Planck-Institute of Quantum Optics

Research at the Max Planck Institute of Quantum Optics explores the interaction of light and quantum systems, exploiting the two extreme regimes of the wave-particle duality of light and matter. For more information, please see http://www.mpq.mpg.de/cms/mpq/en/index.html.

About Stanford Physics

Located in the heart of Silicon Valley, Stanford University is recognized as one of the world's leading research and teaching institutions. Leland and Jane Stanford founded the University to "promote the public welfare by exercising an influence on behalf of humanity and civilization." Stanford opened its doors in 1891, and more than a century later, it remains dedicated to finding solutions to the great challenges of the day and to preparing our students for leadership in today's complex world. Stanford Physics is a teaching and research department. Undergraduates, graduate students and postdoctoral fellows are mentored and involved in research in astrophysics, cosmology, particle physics, atomic and laser physics, and condensed matter physics. The department enjoys close connections to Applied Physics and departments at SLAC.

About the Gordon and Betty Moore Foundation

The Gordon and Betty Moore Foundation, established in 2000, seeks to advance environmental conservation, patient care and scientific research. Believing in the inherent value of science and the sense of awe that discovery inspires, the Foundation's Science Program invests in the development of new technologies, supports the world's top scientists and brings together partnerships with the aim to transform, push the boundaries of—and even create—entire fields of scientific research. For more information, please visit www.moore.org.

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