Quantum Engineering
From Einstein's spooky action to sustainable technology?

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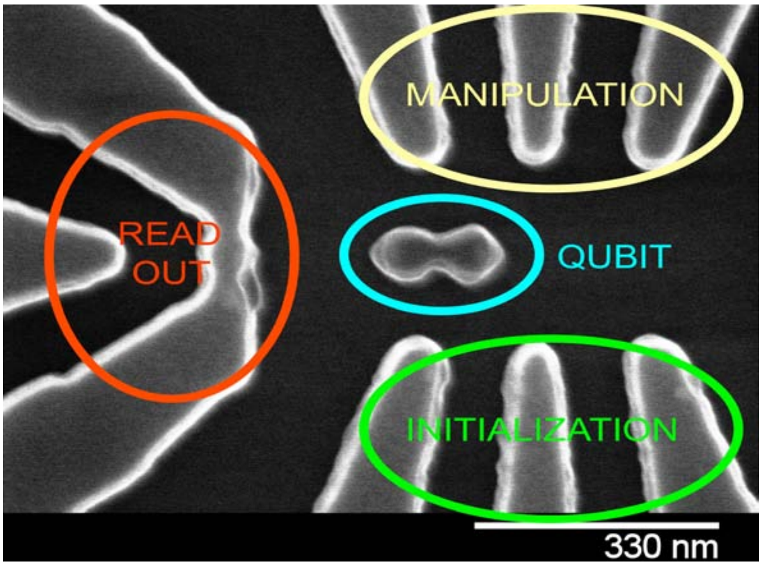
Quantum physics is often associated with a range of phenomena that are at odds with our usual understanding of how the world works. Indeed famous scientists such as Einstein used the predictions of quantum theory to argue that the theory must be incomplete as they could not accept the notion of reality implied. Unlike in classical physics, the state of a quantum system is described by a complex probability distribution (wavefunction) that determines the likelihood of obtaining certain measurement outcomes. The wave-like properties of these distributions enable systems to exist in so-called superposition states that can interfere with each other and lead to a phenomenon called entanglement, the possibility of instantaneous non-local correlations between quantum states and measurement results. Other important features are the impossibility of measuring all physical properties of a system simultaneously due to uncertainty relations and the fact that measurements alter the state of the measured system. These peculiar features may explain why many scientists and engineers prefer to avoid quantum mechanics.

Yet, beyond philosophical issues, quantum phenomena are today well supported by experiments and play a vital role in many conventional technologies such as semiconductors, superconductivity or laser technology. Even entanglement, referred to by Einstein as spooky action at a distance, is well established, forming the basis for secure quantum communication and cryptography. Current technology, though, utilizes only a small range of quantum effects and the possibilities for future quantum technologies are vast, from electronic circuits that exploit quantum properties such as spin (spintronics/magentoelectronics) or coherence (coherent electronics) to create more or less conventional electronic devices with novel functionalities to perhaps quantum computers, with communication, imaging and more accurate and novel measurement technologies along the way. Furthermore, quantum effects such as tunnelling and interference are unavoidable on the quest to reduce feature size of conventional integrated circuits to increase speed and efficiency and lower energy requirements.

Progress and potential applications in this area, especially spintronics, was one of the key topics discussed at a recent industry workshop on physics for sustainability organized by the Hitachi Cambridge Laboratory (http://www.hit.phy.cam.ac.uk/) in Cambridge (UK). To mention a few possibilities, novel components, such as a Datta-Das-Spin-transistor-like device, may provide the basis for new devices in electronics, storage and communication. Organic semiconductors may make the materials such devices are made of more sustainable and utilizing the self-organizational properties present in certain (purple) bacteria may lead to devices collectively optimizing their efficiency. Novel electron microscopy techniques enable us to observe nano-structures on an atomistic level to better understand their operation.

While the rich physics of quantum phenomena continues to provide amble opportunity for physics research, this shows that what were once considered strange effects have moved into the realm of engineering as novel means to find innovative solutions to current problems. However, there are many challenges that must be overcome to make such technologies a reality, including building tools to model, design, simulate and control such devices. A further challenge is to find novel ways to utilize quantum effects and innovative device designs, and to integrate them with current technology. This requires an interdisciplinary effort and presents an opportunity for many engineering disciplines such as nano-engineering, material science, electronic engineering and control systems engineering to work together with computer science, physics and mathematics. It may sound like fantasy to create devices that are faster and smaller while requiring less energy, are easy to recycle and are made from ubiquitously available materials, but quantum engineering may well solve at least some of these problems. What do you think? Join us on the Quantum Engineering discussion group on LinkedIn (http://www.linkedin.com/e/vgh/3047752/).

David Williams speaking at Hitachi Cambridge Lab's 20th anniversary seminar on Physics for Sustainability.



Prototype silicon qubit with control and readout circuit fabricated by Hitachi Cambridge Labs (2005).