Note of the Quantum Technologies workshop

3 October 2013

Introduction

EPSRC held a Quantum Technologies workshop in London on 3 October 2013 as part of on-going activities to help develop the UK's capabilities in Quantum Technologies. This workshop was aimed at engaging researchers across research areas and communities, to scope out the technological challenges that need to be addressed to take the science through to technology.

Background

In the context of this workshop the term Quantum Technology is used to describe the exploitation of quantum superposition and quantum entanglement. The reader might find it useful to think in terms of quantum information being generated, stored, transmitted, manipulated or otherwise exploited.

A simple description of superposition and entanglement is:

- Quantum superposition: where a particle exists in two or more different states simultaneously, until you look at it.
- Quantum entanglement: a special type of connection between two particles, existing even when they are far apart.

At present the bulk of research in the UK in this domain can be described as fundamental research, where the focus is on the study and control of quantum superposition and quantum entanglement that underpin technological and scientific applications, and the outputs are primarily high quality research publications.

The exploitation of quantum superposition and quantum entanglement offer the prospect of significant impact and the ultimate improvements in precision, sensitivity, accuracy and speed that the laws of physics allow[1], in a range of areas within Quantum Technologies, which include:

- **Quantum secure communications:** which offer the prospect of fundamentally secure communication channels (as one could prove through the laws of quantum physics that no information was intercepted);
- **Quantum metrology**: where quantum entanglement is exploited in the undertaking of high-resolution and highly sensitive measurements of physical parameters;
- **Quantum sensors**: which achieve sensitivities that are unachievable through classical techniques. For example the capability to image individual biomolecules (with benefits for structural biology and, ultimately, healthcare) or jamming proof positioning systems (as they would not rely on communication from satellites);
- **Quantum simulators:** which enable the accurate modelling of real molecules and

[1] The Age of the Qubit, Institute of Physics, http://www.iop.org/publications/iop/2011/file_52078.pdf

materials and provide a step change in research into new types of material or drug development, by allowing many possibilities to be tested at once through software, rather than costly laboratory trial-and-error;

- **Quantum computation**: finally, the ultimate quantum technology, the most complete computing device we can envisage based on the known laws of physics, which would have the capability to solve certain problems many orders of magnitude faster than any classical computer;

In order to take science through to Quantum Technologies, there are a number of factors that need to be addressed. Two key ones are, 1) that researchers from a number of areas with potential relevance to advancing Quantum Technologies need to be involved / engaged. 2) that an increased profile of Quantum Technologies is required, this is essential to encourage involvement of researchers from a range of areas and for Government and Industrial / User buy-in.

Through members of the academic community and EPSRC the profile of Quantum Technologies is growing in the UK. EPSRC has formed a Quantum Technologies working group whose membership covers a range of expertise to provide advice relating to Quantum Technologies (See annex 2 for group members). The Science Minister David Willetts attended an EPSRC-led Roundtable in July 2013 which brought together a range of academics, users and government organisations to highlight the UK's competitive position with respect to Quantum Technologies and the willingness to work together in a national endeavor to translate scientific leadership into economic benefit (a note on this meeting can be found on the EPSRC website here http://www.epsrc.ac.uk/SiteCollectionDocuments/other/QuantumTechnologyRoundtableNote.pdf)

The workshop

The main objective of this workshop was to increase the awareness of Quantum Technologies amongst researchers working in a range of domains and encourage them to get engaged thus recognising the potential benefits their expertise could bring to progress on Quantum Technologies.

The five technology areas listed above were selected following engagement with EPSRC's Quantum Technologies working group and attendees at the roundtable meeting. They cover a range of technological maturity in Quantum Technologies, with a mix of potential short term, medium term and long term developments. EPSRC recognises that there are Quantum Technologies outside of these five areas, and will continue to support high quality research in areas outside of these through its normal processes.

The morning of the workshop was dedicated to presentations and networking. Liam Blackwell (EPSRC ICT Theme Leader) opened the workshop and provided background information about what had led to the workshop (including the Roundtable with the Science

Minister David Willetts in July and the on-going work of EPSRC and the EPSRC Quantum Technologies working group) and the objectives of the day.

Following this, Professor Ian Walmsley from Oxford and Professor Tim Spiller from Leeds gave presentations. These covered an introduction to the science, the importance of Quantum Information, the need to get researchers from a variety of fields together to tackle the challenges and the need and potential hurdles of getting industry / users involved.

Following the presentations, there was an hour and a half of networking providing attendees the opportunity to talk to researchers across a range of expertise about their research interests and how these are / could be relevant to Quantum Technologies.

In the afternoon, two breakout sessions were used to discuss the five Quantum Technology areas (outlined in the background above). Each session had 5 parallel groups, each working on one of the five areas.

The working group members and EPSRC helped facilitate these sessions highlighting the following questions to be addressed by the groups for each area:

1. What is the potential vision for this area over the next 5 years and over 10 to 50 years?

2. What prevents this vision being realised?

   This included research challenges and scientific or technological issues / barriers

3. What can the UK do to deliver this vision

   This included what we currently know, what the UK should do differently, what we need to know and which approach may bear fruit for the technology

4. Who should be involved? This included the opportunity for individuals to sign up to show their interest in helping to take the area forward.

Brief summaries from the outputs in the breakout sessions are (full outputs from the sessions can be found in Annex 3):

Quantum Secure Communications – One vision identified in this group was that a quantum communication system will develop that will seamlessly integrate with the classical communications industry and provide unprecedented security. Barriers identified included the need for defined standards (including standard measures of performance; security standards and validation and certification) and for improved / new components i.e. Detectors, sources.

Quantum Metrology – Whilst considering what needs to be known to deliver the vision in this technology area, it was noted that it is important to think about what sophisticated engineers can achieve and how to get them engaged. Challenges and barriers in this area included the need for significant progress below the shot noise limit, efficient measurements, and more theoretical tools for many-body problems.

Quantum Sensors – Two questions raised during the sessions when considering challenges and barriers were: who outside of university laboratories will be able to manufacture devices? Can anyone design and manufacture something that the rest of the world wants to buy? Going from lab experiments to useful sensors that are portable, robust etc. and fabricating robust (error-resistant) protocols without roughness / defects / materials problems are some of the challenges to overcome.

Quantum Simulators – for realistic simulations of quantum molecular of material systems to compete with the best quantum chemistry techniques, significant numbers of qubits (at least 50-100) will be necessary. For special-purpose simulations of model systems with more restricted Hilbert spaces (e.g. Hubbard models, spin systems) smaller numbers might be sufficient. In either case validation of the simulation will be a key issue. Use of quantum methods to simulate classical optimization problems (e.g. by quantum annealing) was felt to be an interesting area to explore. Challenges common with other themes include the number of qubits and the degree of control needed; specific challenges include understanding role of noise and errors in the simulations.

Quantum Computation – The vision for the next 5 years included better understanding in a number of aspects including what counts as non-classical; fault tolerance thresholds; barriers to scaling and noise models in diverse/ new quantum proposals. Some of the challenges to overcome were scalability in different systems, manufacturing reliability and convincing industry to invest.

Following the breakout sessions, Liam Blackwell brought everyone back together to give a brief summary of key points from the sessions and to consider the next steps following the workshop. The key message was that in order to continue to get buy in from Government and researchers:

- A wide range of people need to be involved to take technologies forward and to raise awareness of Quantum Technologies,

- The communities with potential relevance to any of the Quantum Technologies need to be encouraged to come together to try and develop a common voice on the technological needs and challenges and the current state of the art.

Attendees were given the opportunity to sign up for any of the five Quantum Technologies covered by the breakout sessions to show interest in helping to develop the areas.

EPSRC encourages those interested in taking these areas forward to be proactive.

A list of attendees of the workshop is provided in Annex 1, the members of the EPSRC Quantum Technologies work group are listed in Annex 2 and the outputs from the breakout sessions are included in Annex 3.

Since the workshop, the Quantum Technologies working group have met. They were all pleased and encouraged by the attendance and discussions at the workshop. They were particularly pleased to see contributions and involvement from researchers from a range of disciplines and research communities. They noted how this could readily translate into multidisciplinary teams working effectively on Quantum Technologies.

Their observation was that people should not get too distracted by defining what a quantum technology is. In order to take the research towards useful technologies, the key is to deliberately harness quantum mechanical effects rather than to focus on quantum mechanical explanations. Potentially, if a technology is useful they noted that the users / industry will not care if all elements of the technology are quantum or not. The working group acknowledged the appetite shown by delegates to focus on the key technological challenges that need to be addressed and interest in taking the science through to technology.

Annex 1 – Attendees of the workshop

Ali	Alavi	University of Cambridge
Gerardo	Adesso	University of Nottingham
Oleg	Astafiev	Royal Holloway University of London
Mete	Atature	University of Cambridge
Crispin	Barnes	University of Cambridge
Steve	Barnett	University of Glasgow
Jon	Barrett	University of Oxford
Simon	Benjamin	University of Oxford
Simon	Bennett	TSB
Silvia	Bergamini	Open University
Richard	Biers	DSTL
Liam	Blackwell	EPSRC
Kai	Bongs	University of Birmingham
Sougato	Bose	University College London
Andrew	Bourne	EPSRC
Vincent	Boyer	University of Birmingham
Fernando	Brandao	University College London
Andrew	Briggs	University of Oxford
Sue	Carter	EPSRC
Subhasish	Chakraborty	University of Manchester
Stewart	Clark	Durham University
Roger	Colbeck	University of York
Simon	Cornish	Durham University
Irene	D'Amico	University of York
Mike	Davies	University of Edinburgh
Gabriele	De Chira	Queens University Belfast
Artur	Ekert	University of Oxford
Laurence	Eaves	University of Nottingham
Daniele	Faccio	Heriot Watt University
Rob	Felstead	EPSRC
Alex	Feresidid	University of Birmingham
Andrew	Fisher	University College London
Chris	Ford	University of Cambridge
Mark	Fox	University of Sheffield
Tom	Freegarde	University of Southampton
Mark	Fromhold	University of Nottingham
Ivette	Fuentes	University of Nottingham

Barry	Garraway	University of Sussex
Simon	Gay	University of Glasgow
Brian	Gerardot	Heriot-Watt University
Harald	Haas	University of Edinburgh
Robert	Hadfield	University of Glasgow
Richard	Haley	Lancaster University
Steven	Harris	BAE Systems
Paul	Harrison	University of Leeds
Robin	Hart	National Physics Laboratory
Jon	Heffernan	BT
Winfried	Hensinger	University of Sussex
Ortwin	Hess	Imperial College London
Stephen	Hogan	University College London
Amanda	Howes	EPSRC
David	Hutchings	University of Glasgow
Dieter	Jaksch	University of Oxford
Paul	John	E2V
Elham	Kashefi	Edinburgh University
Myungshik	Kim	Imperial College London
Peter	Kruger	University of Nottingham
Stefan	Kuhr	University of Strathclyde
Robert	Lamb	Selex-ES
Vlado	Lazarov	University of York
Peter	Leek	University of Oxford
Wolfgang	Langbein	University of Cardiff
Noah	Linden	Bristol University
Brendon	Lovett	University of St Andrews
Stephen	Lynch	University of Cardiff
Alan	Marshall	Queens University Belfast
Paul	Mason	TSB
John	Morton	University College London
Ray	Murray	Imperial College London
Antti	Niskanen	Nokia
Rupert	Oulton	Imperial College London
Miles	Padgett	University of Glasgow
Yuri	Pashkin	University of Lancaster
Mauro	Paternostro	Queens University Belfast
Doug	Paul	University of Glasgow

Susan	Peacock	EPSRC
Periklis	Petropoulous	University of Southampton
Jonathan	Pritchard	DSTL
Nick	Proukakais	Newcastle University
John	Rarity	Bristol University
Erling	Riis	University of Strathclyde
Majid	Safari	University of Edinburgh
Simone	Severini	University College London
Andrew	Shields	CRL-Toshiba
Daniel	Shiu	GCHQ
Alasdair	Sinclair	National Physics Laboratory
Maurice	Skolnick	University of Sheffield
Charles	Smith	University of Cambridge
Peter	Smowton	Cardiff University
Tim	Spiller	University of Leeds
Kei	Takashina	University of Bath
Robert	Taylor	University of Oxford
David	Tew	University of Bristol
Mark	Thompson	University of Bristol
Stephen	Till	DSTL
Yoshishige	Tsuchiya	University of Southampton
Floriana	Tuna	University of Manchester
Christina	Turner	EPSRC
Ben	Varcoe	University of Leeds
Shashank	Virmani	Brunel University
Peter	Wahl	University of St Andrews
Ian	Walmsley	University of Oxford
Paul	Warburton	University College London
Craig	Wrigley	Lockheed Martin

Annex 2 – EPSRC Quantum Technologies working group members

Gerald Buller	Heriot-Watt University
Martin Dawson	University of Strathclyde
Andrew Fisher	University College London
Antti Niskanen	Nokia
Jeremy O’Brien	University of Bristol
Andrew Shields	Toshiba
Ian Walmsley	University of Oxford

Annex 3 - Outputs of the breakout session (available as separate documents on the webpage: http://www.epsrc.ac.uk/newsevents/pubs/reports/Pages/physsci.aspx

(Questions 1 to 3 for each area are included. The sign- up sheets that formed question 4 have not been included as these have already been distributed amongst attendees; however, details of who attended are listed in Annex 1).