What’s Quantum Technology?

Peter Knight  
*NQTP Strategic Advisory Board Chair*  
&  
Roger McKinlay  
*NQTP Challenge Director*

Quantum mechanics founders

- Planck, Einstein, Bohr, Heisenberg, Born, Dirac, Schroedinger
- but how can quantum mechanical principles of coherence and entanglement be employed?

““When two systems... enter into temporary physical interaction due to known forces between them, and ...... separate again, then they can no longer be described in the same way as before, viz. by endowing each of them with a representative of its own. I would not call that one but rather the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought. By the interaction the two representatives [the quantum states] have become entangled.”  
*Schroedinger, Camb Phil Soc*
20th century – the 1st quantum revolution

- Transformative outcomes across all of technology and society
- Industrial revolution, electricity etc. was built on classical physics
- Quantum physics, developed during the 1920s gave us much of our modern technology
- Examples:

  Lasers
  Microelectronics
  Broadband etc

Progress in quantum physics since 1990s is underpinning a 2nd quantum revolution with similar societal impact to 1st

The strange world of quantum - highly counter-intuitive! First and second quantum revolutions

Quantization

Wave Nature of Matter

Superposition

Entanglement

All quantities are discrete, for example, the energy levels in an atom

Lasers

Quantum 2.0

Semiconductors

Quantum matter can be in two different states at the same time: measurement causes a collapse to one state.

“connection” between separated particles where a measurement of one immediately affects the state of the other

UK has estimated ~5 year lead on time to technology insertion in key areas
UK NATIONAL QUANTUM PROGRAMME
A Brief Timeline

2013

Launch The UK National Quantum Technologies Programme (NQTP)

2014

PHASE 0:
Workshop at Chicheley Hall

PHASE 1:
Focus on converting research and excellence into technology prototypes and plugging the skills deficit

£380m investment over 5 years.

2019

PHASE 2:
Focus on driving commercialisation and economic impact (investment, supply chain growth, international collaboration)

Additional £350m over 5 years plus £153m for industry-led activities.

National Quantum Computing Centre (NQCC) launched Sept 2020

2023

PHASE 3
Publication of UK Quantum Strategy affirms UK continued commitment to quantum technologies for the next 10 years. Strategy provides an additional investment of £2.5 billion, starting in 2024

So far, NQTP has provided awards to over 123 businesses and 38 universities and RTOs collaborating in over 85 projects

2024

THE UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME (NQTP):
PARTNERS AND GOVERNANCE

UK Quantum Strategy lead department

Funds research and training in quantum, including:
1. a national network of research hubs;
2. centres for doctoral training;
3. domestic and international research grants;
4. fellowships.

Delivering a national challenge programme to develop new commercial quantum products involving academia, industry and Government

Delivering the Quantum Technologies for Fundamental Physics programme;
Home of the National Quantum Computing Centre

Home of the Quantum Metrology Institute (QMI)
Leads activities to test, validate and commercialise new quantum R&D

Government lead for defence applications of quantum technologies

Responsible for delivering MOD R&D programme in quantum technologies

Provides specialist technical support to national quantum programme partners

One of the UK’s Intelligence and Security Agencies

Home of the National Cyber Security Centre (NCSC); conducts research and provides advice on ‘post-quantum’ security

COORDINATING BODIES

Programme Board
Provides coordination and strategic direction for the programme with representation from each of the partner agencies. Chaired by Dame Lynn Gladden, Executive Chair, EPSRC.

Strategic Advisory Board
Provides independent advice to help steer the strategic direction of the programme and policy on quantum technologies, and is made up of eminent figures from across industry, academia and Government. Chaired by Sir Peter Knight.
The UK’s National Quantum Technologies Programme is a £1bn 10-year investment in the sector. In this phase, Research, Industry and Private Investment are key areas of focus.

Hub refresh further £100m from ‘24, £70M TMF, plus others
And new Phase 3 from 2024 led by the Quantum Strategy
Quantum Imaging

- **Time Correlated Single Photon Counting** uses single-photon source & accurate timing to scan objects and identify them at distances of 1km and greater.
- Several applications: target identification in free-space at kilometre distances; using remote multispectral depth information to extract structural and depth imaging eg highly scattering underwater environment
- Very promising for ranging/imaging applications: single-photon avalanche diode detector arrays, cameras where each pixel is a single-photon detector with single-photon sensitivity and picosecond temporal resolution.
- A variation: use correlated photon pairs for range-finding imaging, heralding the measurement with one photon and performing the range measurement with the other photon.
Ghost imaging: extreme covert imaging

Illuminate object in the infra-red, record image using correlated visible photons

Photon counting - ultra-low exposure imaging

Applications - Sensing
What’s Under your feet: Gravity – The Challenges

Improving Infrastructure Productivity

- Surveys reduce risks
  - ROI on utility surveying $3.41–£20
  - 5% of project budget for surveying ➔ reduce overspend to 25%
- 16% of utilities damaged by contractor in UK
- Sinkhole occurrence increased fivefold in 2014
- 30% of exploratory bore holes drilled are successful
- Exploration market ~£7bn
- Increasing black market for tunneling machinery in hostile & security critical environments

Seeing the Invisible

- Surveys reduce risks
- 1.37m streetworks p.a.
- 2.4m road openings
- Projected costs p.a.: £3.19bn
- Surveys reduce risks
- 16% of utilities damaged by contractor in UK
- Sinkhole occurrence increased fivefold in 2014
- 30% of exploratory bore holes drilled are successful
- Exploration market ~£7bn
- Increasing black market for tunneling machinery in hostile & security critical environments

Situational Awareness

- What’s Under your feet: Gravity
- 1.37m streetworks p.a.
- 2.4m road openings
- Projected costs p.a.: £3.19bn
- Surveys reduce risks
- 16% of utilities damaged by contractor in UK
- Sinkhole occurrence increased fivefold in 2014
- 30% of exploratory bore holes drilled are successful
- Exploration market ~£7bn
- Increasing black market for tunneling machinery in hostile & security critical environments

Imaging with Gravity

- Numerous applications in the societal challenge areas:
  - Security (hidden voids, dense objects)
  - Environmental monitoring (magma, buried material)
  - Prospecting: oil & gas
  - Space: attitude control

Interferometer fringes
Where am I? Quantum Navigation

Quantum Sensors and Timing: Opportunities in PNT

Map Matching for Positioning
- Gravity gradient
- Magnetic Fields
  - Providing absolute position without any communication (including under water)
  - Collision alert (?)

Inertial Sensors for Navigation
- Acceleration and Rotation
  - Low drift
  - Low bias
  - Ingredients for INS

Clocks for Timing
- On board holdover
- GNSS spoofing alert
- Time references
- Transportable time
What’s in your head: MEG

Quantum-Magnetoencephalography – Spin off from QT

Cerca:
Joint venture spin-off between Magnetic Shields and Nottingham University
Founded in 2020

First systems delivered internationally
£6M turnover in first year
>£50M requests for quotations

Impact Opportunities:
- Epilepsy: 60M people worldwide
- Dementia: 1% GDP
- Schizophrenia: 1% of population
- Trauma: 100,000/year in UK

Communications
In quantum physics, the act of measurement disturbs what you are measuring, so an eavesdropper reveals themselves and in any case can only access partial information.

Hardware based encryption may be secure if operated properly. But pay attention to human factors concerning use.

https://www.ncsc.gov.uk/information/quantum-key-distribution from my colleagues at GCHQ

---

Long distance Quantum Key Distribution with Trusted Nodes: secure communications

In quantum physics, the act of measurement disturbs what you are measuring, so an eavesdropper reveals themselves and in any case can only access partial information.

But .....
Basic idea of Quantum Computing

- Computation with $n$ Qubits.
- Main difference: build coherent superposition of states.
- State space grows exponentially with number $n$ of qubits: $2^n$.
- Behaves like a massively parallel computer.
- Solves problems in much fewer steps in carefully constructed algorithms: see https://quantumalgorithmzoo.org
QUBIT scale (adapted from John Martinis) - add one bit *doubles* the size

\[ (|0\rangle + |1\rangle)^n \]

- \( n=50 \): supercomputer
- \( n=300 \): more states than atoms in universe

Google's 53 qubit processor gives \( 2^{53} = 10^{16} \)

(Only 144,115,188,075,855,872 states)

Quantum Computer Hardware Startups

- **Superconducting**
  - Intel, IBM, Google, Rigetti

- **Optical**
  - Xanadu, PsiQuantum

- **Semiconductor**
  - Silicon Quantum Computing
Quantum Computing and the Crypto apocalypse

• Quantum computing changes whole nature of information processing

• Changes complexity classes: what was thought “hard” (nonpolynomial) may become “easy” (polynomial). Destroys our confidence in the security of the internet!

• Quantum Computing is NOT just about faster...Quantum can do things assumed impossible in a normal time.

• Yet "Hardness" assumptions underpin internet and comms security: problem!

• Shor (1994): Factoring hard classically becomes “easy” with a quantum computer

• Will render all public key infrastructure vulnerable. No RSA, TLS....Affects us all!

• Quantum computer at scale will emerge in a decade (best estimate);

• Need to retool all crypt primitives within that time to be quantum resistant.

The Industry Story
Only a product away…

- Computing
- Secure communication
- Sensing and timing - PNT
- Imaging

Catalytic Funding

The numbers

THE UK QUANTUM TECHNOLOGY CHALLENGE

7 years strategy (2018-2025)

TO DATE

£174M UK government investment awarded to

139 business-led projects involving

141 UK companies in collaboration

THE UK QUANTUM LANDSCAPE

Over £390M private investment since 2018

Global market forecast to be $21Bn by 2025

One of the UK’s 6 fastest growing sectors in 2020
Private Investment

Venture capital and other private funding make up nearly 80 percent of QT inflows; venture capital, private, and angel investments grew in 2022.

Total annual QT start-up investment hit the highest level of all-time, though it grew only 1 percent year over year.

The majority of investments are in US companies, driven primarily by private investors.

Seven out of ten deals in 2022 were valued at more than $100 million.

Where the investment is going

<table>
<thead>
<tr>
<th>Components</th>
<th>IUK Grant</th>
<th>Private Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>Sensing &amp; Timing</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>Comms</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>Computing</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>
Integrators and Primes (QLM)

Single photon generation and detection opens the door to imaging systems which cannot be achieved using conventional means, including:

- Portable, robust multi-gas imagers for gas emissions in infrastructure
- Vision through obscurance for lidar systems and imaging
- Non-line of sight imaging of obstacles

---

**Quantum companies in focus**

**Nu Quantum**

*Based: Cambridge*

*Technology chain: Components*

*Profile:*

*Start-up. Only company worldwide developing room temperature single-photon sources and detectors to enable the next generation of commercially-vaible photonic quantum technologies, quantum networking, computing*

---

**Quantum companies in focus**

**Riverlane**

*Based: Cambridge*

*Technology chain: Software & services*

*Profile:*

*Start-up. Builds ground-breaking software to unleash the power of quantum computers. QetaFlow OS is an operating system for quantum computers inspired by heterogeneous architectures*

---

**VCs**

---

---
Customers!

MANATIE
Single photons are the workhorse of the future quantum technology industry, being a fundamental component to high fidelity quantum computing, quantum communications, quantum imaging and some types of quantum sensors. They are also a fundamental step in ORCA’s plans to build a fully-scalable, optical fibre-based photonic quantum computing platform...

Quantum companies in focus
Covesion
Based: Southampton
Technology chain: Components
Profile:
Established SME: World leading designer, manufacturer of frequency conversion crystals – can change the wavelength of laser, single photon sources to suit user specifications or applications

Collaborations
High-BIAS²
• Lead: ColdQuanta
• 2020-2023
• Advancing the development of a cold atom-based Quantum Positioning System
• Enabling resilient navigation systems without the need for GNSS
Not just Start-Ups

Quantum companies in focus
Alter technologies
Based: Central belt, Scotland
Technology chain: Systems, packaging
Profile:
Large enterprise, package design and precision assembly services for a wide range of optoelectronic, microelectronic and MEMS devices. Offer end to end semiconductor manufacturing from wafer singulation to assembled product.

ALTER TECHNOLOGY

Quantum companies in focus
Oxford Instruments
Based: Oxford
Technology chain: Component (Platform)
Profile:
Established large enterprise, designs, supplies and supports market-leading cryogenic and high flux superconducting magnetic research platforms. They are a globally leading supplier of dilution fridge platforms for quantum computing.

Oxford Instruments

Full Stack
Deployment of full stack Rigetti platform in the UK
Accessible via the cloud
End use applications and new engagements
Case Study: The RLG – Complexity Can Be Mastered

The Classic Engineering Goals

- Smaller
- Cheaper
- More robust
- More reliable
- Lower noise
- More efficient
- For computing – Scalable!
Nuts and Bolts

• Materials
  • Silicon – Compound Semiconductors – Glass

• Fabrication
  • Nano – 2D Materials – heterogenous – 3D structures
  • Silicon meets glass.

• Optical
  • Gratings, cavities, optical waveguides, lasers, lasers, lasers, lasers..

Variables: A Lifetime of Work

• The Physics:
  • Electron spin.
  • Photon polarization
  • Atoms, Ions, artificial atoms/defect-centres

• Qubit Type:
  • Trapped Ion
  • Neutral atom
  • Silicon
  • Photonic

• Not just qubits.
  • Architecture
  • Error correction
  • Control/calibration
  • Gate control
  • Environment
  • Connectivity
  • Substrate
Conclusions on the Industry Story

• We’ve created an ecosystem in which companies are starting and growing.
• We’re attracting global companies to the UK.
• We’re seeing products and revenue.
• The £2.5B commitment from UK Government shows commitment for the long term.

conclusions

• UK is in top 3 world-wide
• 20 year £3.5Bn investment
• applications
• Beware of Export Regulation consequences

• you have nothing to do but mention the quantum theory, and people will take your voice for the voice of science, and believe anything- Bernard Shaw, Geneva (1938)