

Materials for Quantum Technologies in the UK

The Case for Coordination

Strategic Summary Report



National Physical Laboratory (NPL)

Materials for Quantum Technologies in the UK

**We are the UK's National Metrology Institute (NMI),
a world-leading centre of excellence that provides cutting-edge
measurement science, engineering and technology that
underpins prosperity and quality of life in the UK.**

Contents

Contents	2
Executive Summary	3
Challenge	5
Solution	7
Impact	9
Case studies	10
References	17

Executive Summary

Importance of Quantum for humanity is recognized by a [Nobel prize in Physics](#) (2025). The UK is one of the early leaders in Quantum Technologies. The UK government has recognised the potential and confirmed Quantum as a frontier technology in the recently published Industrial Strategy. The government's five Quantum Missions set targets for up to 2035, including quantum computing for advanced materials and medicines, resilient navigation without satellites, precision sensing for infrastructure monitoring, and earlier diagnosis and treatment of conditions like dementia, epilepsy, and cancer. To deliver the quantum missions will require the translation of the UK's world-leading quantum research into reliable and scalable sovereign manufacturing capability to underpin and drive economic growth in the UK. This translation will require the development of reliable, fit for purpose materials for quantum, as building blocks for market ready technologies.

The UK's effort into materials for quantum landscape is currently fragmented and fails to support a future sovereign supply chain. While there are individual centres of excellence in the UK, there is no conduit to understand and meet the needs of the UK quantum industry.

To help turn the UK's research lead into market-ready quantum technologies, we propose a targeted "materials for quantum" focus within the National Quantum Technology Programme ([NQTP](#)), delivered through **a programme coordination and funding framework for targeted industrially-focussed research**. The key objectives are:

- A secure [and/or sovereign] supply chain for materials for quantum, supporting a critical technology and attracting inward investment.
- Efficient and coordinated use of existing infrastructure and capabilities, enabling clear prioritisation of spending and leading to delivery of cross- and beyond mission and cross-sectorial impact.
- Regional growth and strengthening of existing capabilities.
- An agile quantum-skilled workforce, trained for industrial environments and empowered to deliver strategic priorities.
- Economic growth of the quantum sector in the UK, supporting overall national economic and technical growth and prosperity.

The UK has an opportunity to leverage an existing world-leading strength in materials for quantum research to drive economic growth and prosperity, delivering Quantum Missions and the broader goals of the [Industrial Strategy](#), specifically underpinning such sectors as [Digital and Technology](#) and Advanced Manufacturing. Without this intervention, the UK risks being locked out of the future benefits of quantum technology and left reliant on insecure and unsustainable supply chains to support UK industry.

Challenge

The UK is in a global race to harness the transformative potential of quantum technologies, many of which were originally pioneered here. Recognising that materials science underpins the development of quantum devices and architectures, leading nations such as the USA, South Korea, Japan, and China are strategically investing in materials R&D and infrastructure to secure economic and technological advantage. Countries including Australia, the US, Japan, and Canada have established open-access fabrication and manufacturing facilities to support industry. Meanwhile, international competition is intensifying, with overseas companies developing proprietary methods for producing quantum-grade materials (see Case Study 1).

The UK's [NQTP](#) is already delivering prototype devices with the potential to revolutionise communications, computing, healthcare, and security, driving growth across the wider economy. The EPSRC-funded *Materials for Quantum Network (M4QN)* (2023–25) laid strong foundations by uniting the quantum and materials communities and producing a national roadmap. Complementary strategies, such as the [National Materials Innovation Strategy](#) and the [Advanced Materials Metrology Strategy](#), further reinforce this direction.

The UK quantum sector has benefited from existing strengths in materials science, supported by world-class infrastructure such as the photonics cluster in Scotland, the compound semiconductor cluster in South Wales, STFC facilities at Daresbury and Harwell, the Henry Royce Institute, and materials metrology at NPL.

However, to fully realise the benefits of quantum technologies, the UK must act now. Translating materials research into scalable, reliable products and services will be essential to positioning the UK as a global leader in Digital and Technology and Advanced Manufacturing sectors. This requires an integrated approach to ensure a robust supply of high-quality, well-characterised materials and the capability to manufacture them at scale.

Currently, the UK's quantum materials and infrastructure landscape is uneven, with critical gaps in areas such as superconductors, silicon photonics, compound semiconductors, and

diamond (see [Quantum Infrastructure report](#)). Addressing these challenges is vital to securing the UK's long-term competitiveness in quantum technologies.

The technical challenges are cross-cutting for applications and missions (Case Study 2), for example:

- Material scalability vs. material purity, homogeneity, and quality resulting in device uniformity, reproducibility, manufacturability, and yield, delivering the required quality and control of functionality.
- Manufacturability of materials for quantum and ability to practically assemble them into quantum devices.
- Material-dependent decoherence in quantum systems preventing efficient integration of quantum devices into networks.
- Advanced and internationally leading characterisation capability for quantum platforms, resulting in reliable, reproducible and accurate verification of material properties, quantum metrology, trustworthy operation and confidence.

The additional **coordination challenges** include, see also [Quantum Infrastructure report](#):

- Limited communication and coordination: there is a lack of effective communication between funding agencies, industry stakeholders, and research organisations, which hampers collaboration and strategic alignment.
- Insufficient awareness: stakeholders are unaware of existing infrastructure and struggle to understand how various initiatives interconnect.
- Inadequate open-access infrastructure for industry: the current open-access systems in the UK are not sufficiently tailored to meet the practical requirements of industry partners, limiting their engagement and utilisation.
- Fragmentation and duplication of efforts: the fragmented nature of the ecosystem results in duplicated initiatives, inefficient resource use, and missed opportunities for synergy and innovation.

Solution

To secure the UK's leadership in quantum technologies and ensure long-term return on public and private investment, a coordinated, multidisciplinary effort is needed to accelerate the development and deployment of materials for quantum. These materials are foundational not only to quantum innovation but also to other critical national capabilities, including Semiconductors and Advanced connectivity. Strategic investment in this area will directly support the UK's Quantum Missions and beyond, strengthen regional innovation ecosystems, and drive inclusive economic growth. As the next step, it is now crucial to build on the previous achievements through mechanisms that enable proactive, systematic, and balanced development of materials for quantum, aligned with the NQTP, [quantum missions](#) and national priorities (e.g., productivity, economic growth, support for regional innovation, supply chains in growth-driving sectors as outlined in [the UK Industrial Strategy](#) and [Strategic Defence Review](#)).

To meet this challenge, we propose 1) creation of **a programme coordination function** and 2) **a funding framework** for targeted translation research. Specifically:

1. The establishment of **a flagship coordination organisation** to provide strategic leadership and governance. Its main functions include:
 - Coordinating interaction between quantum industries, Hubs, academia and the government
 - Supporting a cross-disciplinary network, bringing together researchers in material science and quantum technologies.
 - Supporting cross-sectorial activities and convergence with the other critical technologies
 - Creating international opportunities with strategic allies, being influential in the global supply chain, standards and regulations
 - Supporting the translational research at the national level to meet the material and manufacturing needs of quantum industries
 - Assessing existing national capabilities, prioritising and developing business cases for future major open access infrastructure, e.g. supporting regional growth

- Establishing key sovereign capabilities and providing access to material and advanced manufacturing capabilities for industries
- Addressing skill shortages and supporting training at different levels, specifically in fabrication and industrial translation, creating a critical mass of professionals at the national level.

2. The development of a **funding framework** (coordinated by the organisation above) to support commercialisation in the quantum sector. This framework is crucial for developing a sustainable programme and enhancing national resilience in critical supply chains. The key goals of the framework are:

- Facilitate the industrial translation of quantum technology supported by metrology and standards, specifically focusing on mid-TRL activities.
- Improve UK resilience.
- Help make the UK an integral part of the secure global supply chain and a preferred location for investors and global talent.
- Attract investment from private sector and regional organisations into strategic technologies, ensuring sustainability of the approach.

Together it will lead to growth of the quantum sector in the UK, creation of new high-tech jobs and support overall national economic and technical growth and sovereignty.

With translational research as its core function, the coordination organisation will work closely with academia, Royce Institute, Catapults, Quantum Hubs, NQCC and industry, who will serve as its primary stakeholders. We aim for this organisation to operate in partnership with the UK's quantum industry association, Innovate UK, UKRI, the Office for Quantum, and other key stakeholders.

Impact

A material for quantum coordination programme will enable the timely and economically efficient delivery of the Quantum Missions and will result in:

- Economic growth through rapid commercialisation of Quantum Technology enabled by the development and commercialisation of relevant IP, licensing of technologies and open access to the infrastructure.
- Enhanced national resilience through the establishment of a robust and secure supply chain and access to facilities aligned with the growing user demand.
- Efficient investment through rational use of capabilities, avoiding duplication of investments and clear prioritisation of spendings, according to their national relevance and needs.
- Regional growth and positive impact to other key sectors (e.g. Semiconductors and Advanced connectivity).
- Increase in the share of private investment available for strategic technologies and frontier industrial sectors.
- Synergy between state-of-the-art infrastructure and a skilled, agile workforce enables the efficient translation of quantum research into scalable manufacturing, fostering a resilient and adaptive quantum ecosystem.

Without this intervention, the UK will be at risk of not building a sovereign supply chain and failing to realise the UK's policy ambitions. Investment and scale up will not happen in the UK, and future advanced manufacturing and jobs will take place outside of the UK.

Contacts:

Olga Kazakova (olga.kazakova@npl.co.uk); Tim Prior (tim.prior@npl.co.uk); Richard Curry (richard.curry@manchester.ac.uk)

Case studies

Case study #1: Superconducting materials for quantum computation

The need: Qubits based on superconducting technology are the most mature quantum computing platform. Typical material choices are superconductors: aluminium/aluminium oxide heterostructures and niobium; low-loss substrates: sapphire and high-resistivity silicon. Despite being studied for decades, the material challenges remain very much at research frontiers and will be critical to address in the coming years, as the community moves from noisy intermediate scale systems to large-scale, fault-tolerant systems. The main challenges can be grouped into two major categories (Table 1):

- Understanding the microscopic mechanisms that lead to noise, losses and decoherence (e.g. poorly controlled and characterised surfaces leading to dissipation beyond the limits imposed by bulk properties).
- Scalability to larger systems (i.e. variability of materials properties and lack of reproducibility in qubit characteristics giving rise to new material problems that are not present for single qubit measurements).

The solution: Developments for superconducting qubits has focused on improving interface and surface quality (e.g. to prevent forming of lossy oxides) and finding more reproducible and stable junction barriers. Some of the proposed solutions include systematic research into engineering of surfaces and interfaces such as various surface treatments, control of fluorocarbon residues, use of capping layers and chemically stable superconducting metals, e.g. tantalum (Table 1). Still, in many cases the current available solutions have an empirical nature, and the microscopic origin of the listed material challenges often remains unknown. Some material challenges can be partly offset through qubit designs that are less sensitive to noise, this however often leads to the unnecessary complexity of the system.

Table 1: Material-related challenges / solutions in superconducting quantum computing.

Challenge	Physical mechanism	Solution
Bulk noise	substrate dielectric loss	nascent technologies
	non-equilibrium quasiparticles in superconductor	engineering of the superconducting traps by combining materials with different gaps as well as surface states
Surface/interface noise	two-level systems associated with uncontrolled amorphous oxides and contaminants	stringent surface control to reduce lossy oxides and contamination before the growth of the superconducting metal; tantalum shunting capacitors (forming chemically robust oxides), capping layers
	surface spins causing flux noise; surface charges causing charge noise	passivation, thermal treatment and formation of stable oxides; no common solution
Scalability/reproducibility	variations in the tunnelling barrier thickness	nascent technologies
	ageing of the tunnelling barrier (e.g. oxygen diffusion, change of chemical composition)	nascent technologies

	3D qubit environment (additional dielectrics, wires) as additional loss channels	introduction of low-loss crystalline materials as ‘interposers’
--	---	---

The impact: One example of the crucial importance of materials is demonstrated by IBM’s recent advances in quantum computing using superconducting technology. For the last few years, IBM has been following a quantum-computing road map that roughly doubled the number of qubits every year. IBM revealed a 127-qubit chip called Eagle in 2021, followed by a 433-qubit Osprey in 2022 and Condor (1,121 qubits) unveiled in December 2023. To realise the later development, IBM researchers had to tackle distinct sets of technical challenges related among others to materials, supply chain and infrastructure reliability issues. Still, Condor performance was insufficient, and the company has dramatically changed the strategy by significantly lowering the number of physical qubits, while improving their quality (coherence). Simultaneously, IBM has introduced a much more complex on-chip architecture that relies on tuneable couplers - programmable electrical devices that connect different components - focusing on developing smaller chips with a fresh approach to ‘error correction’, see e.g. chip Heron (2023) with ‘only’ 133 qubits but demonstrating a record-low error rate^{1,2}. Heron marks a significant improvement in gate fidelity and performance and is expected to yield significantly better results on complex computations. Based on this success and aiming to solve all the relevant challenges, beyond 2033 the company has a highly ambitious goal to release Blue Jay a quantum centric supercomputer with 1000’s of logical qubits unlocking the full power of quantum computing³.

Case Study #2: Spin defects for quantum sensing and communication

The need: Defects in diamond, in particular a negatively charged nitrogen-vacancy centre, are a promising platform with the potential to enable technologies ranging from ultra-sensitive nanoscale quantum sensors to quantum repeaters for long distance quantum networks, to simulators of complex dynamical processes in many-body quantum systems, to scalable quantum computers. Diamond is a particularly attractive material for quantum technologies: it is a wide band gap semiconductor that is optically transparent, can be composed of stable nuclear-spin-free isotopes, and plays host to many energetically deep defects that can form qubits. Colour centres possess highly desirable properties such as exceptional spin coherence and optical addressability, while offering the potential to be integrated into compact devices and scalable technologies. However, common material issues such as paramagnetic impurities, electronic defects, strain, surface stability and environmental inhomogeneity as well as a lack of suitable characterisation techniques can significantly impede applications of colour centres in quantum devices⁴ (Table 2). The two main challenges for such class of materials include i) understanding and control of surfaces and ii) deterministic placement of colour centres at the sub-nanometre level. Additionally, while the sensitivity of defects to their environment sharpens these challenges, it also presents an opportunity to use them as probes of local material properties, opening a new frontier of using quantum probes for nanoscale materials characterisation.

The solution: The main material research over the last decade has been focused on development of the diamond film growth techniques, allowing for a nearly strain-free materials with low impurity concentrations. Significant progress has been achieved in defect and surface engineering by controlling the electronic states, e.g. by targeted implantation and delta-doping (Table 2). While the material challenges represent major technical and scientific hurdles, the rapid progress in the field over the past several decades combined with growth of commercial activities and a recent increase in interdisciplinary quantum science research gives us optimism that they can be overcome, opening the door to the realisation and adoption of a wide range of diamond quantum technologies.

Table 2: Material-related challenges / solutions quantum sensing based on colour centres in diamond

Initial challenge	Solution		Outstanding challenge
Growth and defect creation	purity	plasma-enhanced CVD	enhancement by electron radiation or ion implantation
	deterministic formation of colour centres	delta-doping; laser/FIB or mask writing	introduction of paramagnetic defects leading to dephasing, charge instability and strain; limited depth precision and in plane accuracy
	charge states	Fermi level engineering (e.g. doping with boron and phosphorus)	
Fabrication	surface roughness and sub-surface damage	no universal solution	
Surface	magnetic and electrical noise and contamination	use of surface preparation techniques; surface engineering; hydrogen-terminated diamond	insufficient coherence time at the sub-surface layer

	charge stability	controlled surface termination	successful only for selective species
Functionalisation	tuneable surface chemistry	soft wet chemical methods	successful only for nanodiamonds
		use of nanodiamonds	noise and charge traps
Characterisation techniques	limited chemical and spatial sensitivity of existing methods	no single solution, but techniques such as SIMS, ESR, optical spectroscopy provide complementary information	improving sensitivity of existing techniques and devising new analysis methods; using the NV centre itself to characterise other defects; correlation of surface spectroscopy with NV measurements
	rapid feedback techniques	XPS and AFM	low chemical sensitivity

The impact: High-purity CVD diamond substrates are now commercially available with less than 1 ppb nitrogen and boron and established isotopic purification up to 99.999% ¹²C. Already demonstrated applications of NV quantum sensors range from geology to complex biological systems to benchmarking of performance of other quantum systems, offering the potential to be integrated into compact devices and scalable technologies. Other notable achievements of NV centres include quantum repeaters for long distance quantum networks, diamond masers⁵, simulators of complex dynamical processes in many-body quantum systems, scalable quantum computers as well as recent advances in quantum

networking where two nodes hosting diamond spin qubits were connected over 25 km distance, i.e. connecting Delft and The Hague⁶. It has also been demonstrated that NV centres can be used as sensors to probe sources of material-induced decoherence in quantum computing platforms.

Further progress towards addressing materials issues in diamond will require a sustained, interdisciplinary, collaborative effort to eliminate sources of loss, noise, and decoherence.

Other prominent examples of materials for quantum technologies include 2D (and beyond) layered materials that have already shown outstanding potential as scalable components, including optically active spin qubits, quantum light sources, photon detectors and nanoscale sensors⁷. This group of materials has a specific advantage in applications that rely on light–matter interfaces. Examples include hosts of single photon emitters and detectors for quantum communications, *e.g.* tuneable by strain, spin–photon interfaces for quantum networks and computing, solid-state optical lattice analogues for quantum simulations, among others⁸. The UK has a leading position in the research and development of 2D quantum optical components. Another important example of a pioneering UK innovation is quantum Hall resistance metrology based on graphene⁹.

References

1. Google Quantum AI. 'Suppressing quantum errors by scaling a surface code logical qubit. *Nature*, 614, 676–681 (2023); <https://www.nature.com/articles/s41586-022-05434-1>
2. 'IBM releases first-ever 1,000-qubit quantum chip'. *Nature* 624, 238 (2023); <https://www.nature.com/articles/d41586-023-03854-1>
3. <https://www.ibm.com/quantum/technology#roadmap>
4. L. V. H. Rodgers, et al., Materials challenges for quantum technologies based on color centers in diamond, *MRS Bulletin*. 46 (2021) doi:10.1557/s43577-021-00137-w
5. J. D. Breeze, et al., Continuous-wave room-temperature diamond maser, *Nature* 555, 493 (2018) <https://www.nature.com/articles/nature25970>
6. Stolk et al., Metropolitan-scale heralded entanglement of solid-state qubits, *Sci. Adv.* 10, eadp6442 (2024) <https://www.science.org/doi/10.1126/sciadv.adp6442>
7. R.-P. Montblanch, et al. Layered materials as a platform for quantum technologies, *Nature Nanotechnology*, 18, 555 (2023); <https://www.nature.com/articles/s41565-023-01354-x>
8. Branny, et al., Deterministic strain-induced arrays of quantum emitters in a twodimensional semiconductor, *Nature Communications*, 8, 15053 (2017); <https://www.nature.com/articles/ncomms15053>
9. Tzalenchuk et al., Towards a quantum resistance standard based on epitaxial graphene, *Nature Nanotechnology*, 5, 186 (2010) <https://www.nature.com/articles/nnano.2009.474>

Materials for Quantum Technologies in the UK

Providing the measurement capability
that underpins the UK's prosperity
and quality of life

To find out more about NPL:

npl.co.uk

To get in touch:

npl.co.uk/contact

020 8977 3222

Hampton Road

Teddington

Middlesex

TW11 0LW

**Please consider the environment
before printing this document**