LAND BRANDENBURG

BERLIN

Quantum Technology Roadmap Brandenburg

THE GERMAN CAPITAL REGION

excellence in photonics

Quantum Technology Roadmap Brandenburg

Journeying Toward a Shared QT Future in the German Capital Region

Contents

Preface

Second-generation quantum technologies – i.e., the harnessing of quantum effects in the fields of sensor technology, communication, computing, and materials – are going to permanently revolutionize our lives through new insights, products, and services. Quantum effects are the foundation of modern technologies such as microchips, lasers, and satellite navigation. They are drivers of innovation – both in the context of basic research and in a large number of user industries such as healthcare, mobility, logistics, battery research, and finance. In the eyes of the experts, they have the potential to be disruptive and groundbreaking for society, existing markets, science, and the economy.

Secure communication, faster data processing, disruptive computing, and new sensor types are just a few examples of the enormous capabilities that this key technology has to offer.

The German capital region is home to a large number of scientific institutions that are recognized nationally and internationally for their excellence in photonics, computing, and microelectronics.

Companies there are already addressing global markets with their products.[1] Quantum technology was identified as a key topic in the Master Plan of the Photonics Cluster Berlin Brandenburg[2] that was published back in 2019, and it became a focal point of activities. Over recent years, it has become evident from conversations with the stakeholders in Brandenburg who have been involved in this roadmap that innovations in all areas of quantum technology are primarily leveraged and driven forward through the interaction of different disciplines. The successful transfer of scientific knowledge to industry is of crucial importance.

For years, scientific stakeholders in Brandenburg have been developing new quantum technology solutions independently of one another as part of their research and development projects. However, their expertise has not yet been combined and made visible at both a national and international level. In 2021, funding was approved for the DESY-Center for Quantum Technology and Applications (CQTA) in Zeuthen, suddenly providing the necessary impetus to change this situation. The recent linking of the CQTA and the Photonics Cluster has not only enabled resources to be pooled, but now offers a unique opportunity to bring together all quantum technology stakeholders in Brandenburg and beyond into one innovative network. This network will be characterized by openness, integration, and the power of the stakeholders as a driving force.

This roadmap provides an up-to-date overview of the stakeholders in Brandenburg and outlines the common goals, activities, and research topics that the Brandenburg network has already successfully implemented or is set to implement in the future. It highlights the potential strengths and opportunities associated with quantum technology and identifies goals that are to be achieved by working together.

Sincerely Yours, Anne Techen and Karl Jansen, April 2024

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1 Economic Development Agency Brandenburg (2020): Photonics Cluster Report | https://www.optik-bb.de/files/media/publications/Flipbook_Clusterreport.pdf [accessed on: March 28, 2024]

2 Economic Development Agency Brandenburg and Berlin Partner (2019): Master Plan for Photonics | https://www.optik-bb.de/files/media/publications/Masterplan_Cluster_Optik_Photonik_Web_neu_2020.pdf [accessed on: March 28, 2024]

1 Our Shared Mission

The Brandenburg Quantum Technology Network will work transparently in partnership with regional, national, and international stakeholders from science and industry to develop the capital region as an attractive location for new applications of quantum technology. By bringing together existing competencies, it will facilitate the progress of science, business, and society, while actively helping to shape them. In turn, this will help to significantly expand activities in all areas of quantum technology within the region.

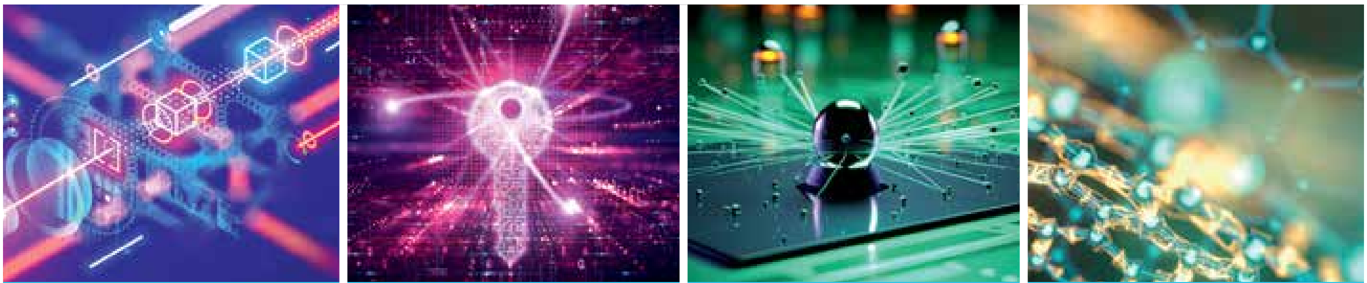
2 Quantum Technology: A Key Technology of the Future

The market for second-generation quantum technologies is still at a very early stage of development worldwide. However, when viewed from a long-term perspective, this provides a unique opportunity to unlock the enormous potential that this future technology offers for exploring completely new products and markets. As a result, it is vital to promote the transfer of scientific expertise between institutions and on to industry. Furthermore, new fields of application for quantum technology should be developed along with solutions of relevance to industry. The relevant fields of application include chemistry, physics, biology, materials research, information and communication technology, medicine, pharmaceutics, food and agriculture, transport and logistics, energy technology, automotive, and aerospace. However, this is by no means an exhaustive list.

3 Quantum Technologies in Brandenburg

Brandenburg already has a huge wealth of scientific expertise in all areas of quantum technology (sensor technology, computing, communication, and materials) (see Fig. 1). Brandenburg's technical universities, universities, and non-university institutions have been researching quantum technologies for years – sometimes collaboratively – as part of federally and EU-funded projects, and have established partnerships at both the national and the international level. Examples include the **QUASAR**[3] and **HIQuP**[4] projects funded by the Federal Ministry of Education and Research (BMBF), and the **The Innovation Campus Electronics and Microsensors in Cottbus (iCampμs Cottbus)**[5]. The significance of this key technology has been recognized at federal state level and funding has been made available. For example, the exceptional project **DESY-Center for Quantum Technology and Applications (CQTA)**[6] in Zeuthen is being funded to the tune of 12.8 million euros from Brandenburg's Future Investment Fund.

- This funding represents the starting point for establishing a quantum technology network in Brandenburg.



Quantum Computing

- DESY CQTA
- IHP
- THB
- THWi Micro & Nanoelectronics
- THWi Automation Technology
- THWi Life Science Informatics
- THWi Telematics
- University of Potsdam
- BTU Computer Engineering
- iCampμs

Quantum Communication

- IHP
- THWi Photonics
- THWi Automation Technology
- University of Potsdam
- BTU Computer Engineering
- BTU Experimental Physics
- iCampμs

Quantum Sensor Technology

- DESY CQTA
- THB
- THWi Micro & Nanoelectronics
- THWi Automation Technology
- THWi Photonics
- THWi Telematics
- University of Potsdam
- BTU Computer Engineering
- BTU Experimental Physics
- iCampμs

Materials

- DESY CQTA
- IHP
- BTU
- THWi
- IAP

Figure 1: Thematic pillars and stakeholders: initial review in Brandenburg (own presentation; valid as of May 2024)

3 BMBF: Halbleiter-Quantenprozessor mit shuttlingbasierter skalierbarer Architektur (Semiconductor Quantum Processor with Shuttling-based Scalable Architecture) | https://www.quantentechnologien.de/forschung/foerderung/quantenprozessoren-und-technologien-fuer-quantencomputer/quasar.html [accessed on: March 28, 2024]

4 BMBF: Hochintegrierte und skalierbare Interfaceschaltungen für Quantenprozessoren (Highly Integrated and Scalable Interface Circuits for Quantum Processors) | https://www.quantentechnologien.de/forschung/foerderung/enabling-technologien-fuer-die-quantentechnologien/hiqup.html [accessed on: March 28, 2024]

5 https://icampus-cottbus.de/ [accessed on: March 28, 2024]

6 https://www.desy.de/aktuelles/news_suche/index_ger.html?openDirectAnchor=2192&two_columns=0 [accessed on: March 28, 2024]

Photonics companies have discovered quantum technologies as a new market (e.g., DiGOS Potsdam GmbH[7] or MKS | Spectra-Physics®[8]) and the first start-ups have chosen the capital region as the location for their businesses.

- An excellent foundation exists for developing a regional quantum technology value chain.

However, the competencies are not yet sufficiently visible nationally and internationally, and are not adequately networked. There is, therefore, an urgent need for action in terms of visibility and strategic cooperation between scientific institutions and companies.

7 https://digos.eu/ [accessed on: March 28, 2024]

8 https://www.spectra-physics.com/en/n/quantum-applications [accessed on: March 28, 2024]

4 Phases in the Development of the Brandenburg Quantum Technology Network

Cluster Management (CM) Photonics at the Economic Development Agency Brandenburg (WFBB) has set itself a clear goal in conjunction with DESY and Technical University of Applied Sciences Wildau (THWi): to bring together stakeholders from science and industry from across different sectors in order to establish a quantum technology network. The first step will be to establish the network in Brandenburg and the second to extent this to the capital region and beyond. The phases are shown in Fig. 2 and the specific objectives under point 8.2 of the Appendix.

Phase 1: The strategic discussion on the establishment of the Brandenburg Quantum Technology Network started at the end of 2021. In October of that year, the CM organized a round of talks that brought together DESY and the Leibniz Institute for Innovative Microelectronics (IHP). Three further meetings followed over the course of 2022 with the aim of integrating further stakeholders. The range of stakeholders was expanded to include working groups from the THWi, Chairs from the Institute of Physics at the University of Potsdam, and representatives from the Brandenburg University of Technology Cottbus-Senftenberg (BTU). IBM was also involved in the discussions. The reason for this is that the CQTA at DESY became an “IBM Quantum Innovation Center” in 2022. A virtual event on the use of quantum technologies in the chemical industry was organized at the end of 2022 in conjunction with the Brandenburg Cluster Plastics and Chemistry (Fig. 3).

Roadmap for the Quantum Technology Network

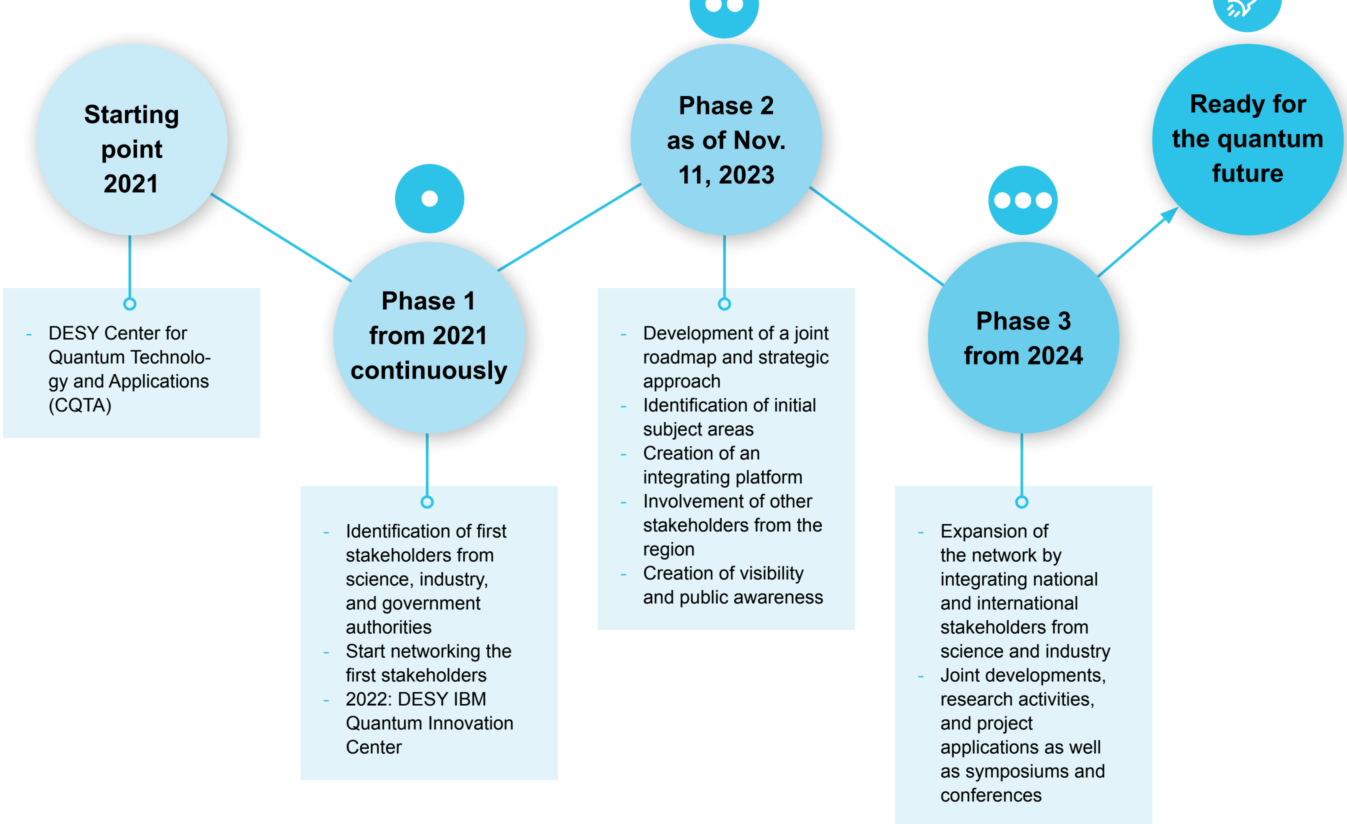


Figure 2: Phases for establishing the regional quantum technology network

Milestones and Implementation of Phase 1

Milestones

- Bringing together of the first stakeholders (rounds of talks and events)
- Identification of common themes

Implementation: Achieved

Phase 2: On January 11, 2023, a network meeting of the participating institutions and representatives of the Brandenburg Ministry of Science, Research and Culture took place under the direction of DESY and the CM (see Fig. 4). During the meeting, the delegates discussed the potential of quantum technologies in Brandenburg (sensor technology, computing, materials, teaching) and decided to establish a Brandenburg quantum technology community. This roadmap is the result of this meeting and is intended to help with the development of a quantum technology network. The **Steering Committee** is currently made up of DESY, THWi, and CM.

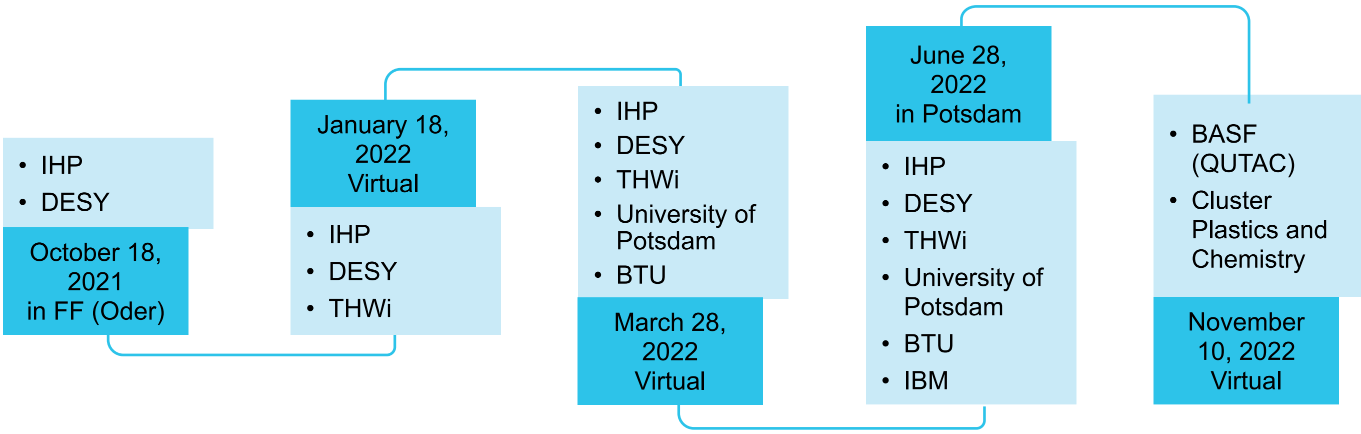


Figure 3: Networking of stakeholders in Brandenburg in 2021 and 2022

Figure 4: Quantum technology meeting at DESY in Zeuthen on November 1, 2023 | © DESY

The capital region has a large number of scientific institutions that need to be networked even more closely in the quantum technology fields (see Fig. 5). During network development phase 2, further regional partners are to be recruited, visibility is to be generated, and research topics are to be evaluated.

Milestones and Implementation of Phase 2

Milestones

- Expanding the network to user industries and other key stakeholders in Brandenburg and beyond
- Getting the regional economy involved (on a cross-sectoral basis)
- Initialization of the roadmap
- Discussion and finalization of the roadmap
- Implementation of further discussion rounds and networking events

Implementation

- Agree with the stakeholders who will lead the development of the network at DESY and CM
- Organization and implementation of discussion rounds at DESY in Zeuthen (January 11, 2023, and May 10, 2023), in Potsdam (September 13, 2023), and at IHP in Frankfurt (Oder) (January, 19, 2024)
- Organization and implementation of events related to quantum technologies (e.g., LASER World of Photonics and World of QUANTUM in June 2023 in Munich; Photonics Days Berlin Brandenburg from October 9 to October 10, 2023, in Berlin-Adlershof; Photonics Cluster Conference on November 9, 2023, in Berlin; LASER World of Photonics and World of QUANTUM 2025 in Munich)
- Application for joint initiatives (teaching and research topics) in preparation
- Introduction and establishment of a new “Workshop for Quantum Technology in Brandenburg” format
- Addressing society, raising awareness of quantum technologies (PR activities, interviews, television – RBB, radio)
- Establishment of a LinkedIn group called “Quantum Technologies in Brandenburg” or integration into existing LinkedIn channels (e.g., Photonics Cluster Berlin Brandenburg) and a dedicated website
- Distribution of current information on quantum technology (newsletter)
- Analysis of needs: Company interviews to identify challenges in the user industries (aerospace, automotive, logistics)
- Benchmarking of quantum technologies

Phase 3: In phase 3, stakeholders from outside the region and international partners are to be recruited for the network. The network will be actively promoted at national and international conferences. In addition, there will be a focus on research and development projects, as well as the hosting of symposiums and specialist events, in order to identify challenges in user industries. The profile of the topic is to be more clearly defined and broad visibility achieved.

Milestones and Implementation of Phase 3

Milestones

- Establishment of a structure (expansion of the Steering Committee, Advisory Board)
- Realization of concrete projects between the stakeholders
- Organization of the region's first quantum technology conference, which is to be an annual event
- Submission of concrete project applications
- Making the capital region's quantum technology activities visible at both a national and international level
- Establishing our own quantum technology brand by focusing on applications and use cases
- Development of new hardware for new quantum sensors/sensor technologies and algorithms for data evaluation on a quantum computer
- Incorporating AI expertise into big data analytics and developing new quantum AI models

Implementation

- Acquisition of state funds for quantum technology projects
- Identification of suitable funding (state, federal and EU)
- "From Theory to Practice: Quantum Computing from Brandenburg" – joint presentation by DESY and IHP at the FMD Innovation Day 2024 on April 25, 2024
- Presentations at the iCampµs Conference Cottbus (May 14 to May 16, 2024) on "Quantum Computing for New Technologies" (company presentation by Heike Riel, IBM; presentations by DESY CQTA, IHP, BTU) and participation in the accompanying exhibition
- 2024: Implementation of a format with the working title "Quantum Technology Week – made in Brandenburg": Summer School IHP 2024, iCampµs and DESY CQTA, lectures at the THWi
- Ensuring access to quantum hardware

Future Prospects after Phase 3

The long-term goal is to establish a quantum technology network that pools the expertise of stakeholders from Brandenburg and Berlin. Deeper collaborations with scientific partners from Berlin – in particular with "Berlin Quantum" – are to be established and expanded for this purpose. Existing partnerships, such as the one that DESY has with the Einstein Research Unit and the Physikalisch-Technische Bundesanstalt (PTB), are to be intensified. Furthermore, use cases are to be carried out with industry and presented to the public. The involvement of companies and research institutions from the Cluster ICT, Media and Creative Industries (IMK) is regarded as important for the further development of the capital region's expertise and all areas of quantum technology.

It is not only regional partnerships that are essential for building a quantum technology community in the capital region. A close alliance with national and international stakeholders is also deemed necessary in order to generate visibility and drive innovation in quantum technology. Existing cooperations between stakeholders, e.g., from Poland or Cyprus, will provide a decisive advantage in this regard.

The network will focus intensively on the key topics of start-ups and the training and recruitment of skilled workers. The aim is to establish an initial and continuing training system that spans countries, universities (and technical colleges), and research institutions, and to make this system visible both nationally and internationally. This will increase the attractiveness of quantum technologies in the region.

The aim of the network will be to drive forward the development of components for hardware platforms with significant support from the IHP, and to research new quantum sensors and apply them to industry. In addition, the CQTA is to be made independent. Having an autonomous transfer unit for the region's quantum technology knowledge would create enormous opportunities for economic innovation.

5 Roadmap for the Brandenburg Quantum Technology Network

The Brandenburg Quantum Technology Network has defined a set of overarching objectives, developed some unique selling points, and identified the region's strengths, weaknesses, opportunities, and risks in quantum technologies. Furthermore, the topics of the application fields have been identified, and the goals and activities for implementation of the network have been discussed and compiled.

5.1 Overarching Objectives

The Quantum Technology Network in Brandenburg will work on the implementation of the following objectives:

Development of Brandenburg into a new **"role model" for quantum technology applications** with the open involvement of all stakeholders

Focus on **new practical applications, use cases,** and concepts for **initial and continuing training** in quantum technology

The goal is to achieve **prominence** nationally in the medium term and internationally in the long term.

5.2 Specific Features and Positioning of the Region (Focus: German Capital Region)

Photonics and Microelectronics as Enablers for Quantum Technologies

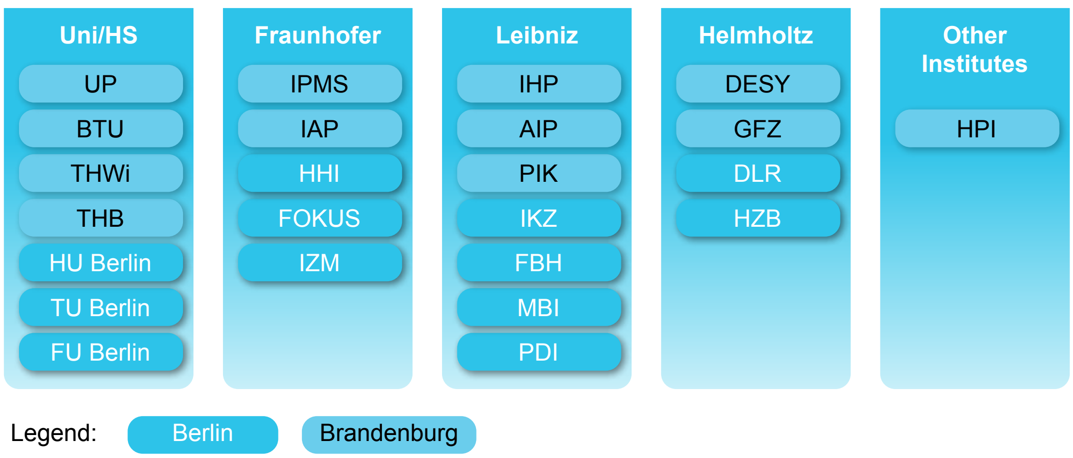


Figure 5: Overview of scientific institutions in the capital region related to quantum technologies

The capital region has an excellent research landscape (technical colleges, universities, non-university research institutions) when it comes to high technologies or "key enabling technologies". There is a good distribution of non-university research institutions with complementary focal areas, resulting in healthy competition (see also SWOT analysis in the Appendix).

The Photonics Cluster has established various event formats (Optik-Tag, Cluster Conference, Photonics Days Berlin Brandenburg) that facilitate networking and both national and international visibility.

The experts at Brandenburg's universities (and technical universities) are not only conducting excellent research in the field of quantum and neuromorphic computing but are also carrying out AI and quantum technology research at the highest level (e.g., BTU, THWi). As the world's leading center for silicon photonics, the IHP possesses expertise in the production of photonic integrated circuits. It creates new quantum sensors and evaluates hardware for quantum computing. DESY CQTA develops quantum computing applications and algorithms, researches quantum sensor technology, and provides low-threshold access to quantum computing hardware.

Cross-University Excellence in the Initial and Continuing Training of Quantum Technology Specialists

Collaboration in the training of quantum technology specialists (including quantum engineers) across universities, technical universities, and scientific institutions will not only pool existing resources at these locations. Rather, it will deepen cooperation and lead to the development and implementation of new cross-institutional courses. The broad range of options offered by the scientific institutions will enable the capital region to increase its attractiveness as a center of education.

The foundations for this have already been laid in the form of the Joint Lab (THWi/IHP "Photonic Components and Thin-Film Technologies") for practical training in the fields of integrated photonics, surface technology, microsystems technology, and material diagnostics. The CQTA at DESY in Zeuthen has the quantum computing expertise required for the training of scientists and engineers in this field.

Cross-university and cross-institute cooperation in the training of quantum technology specialists (pooling of resources)

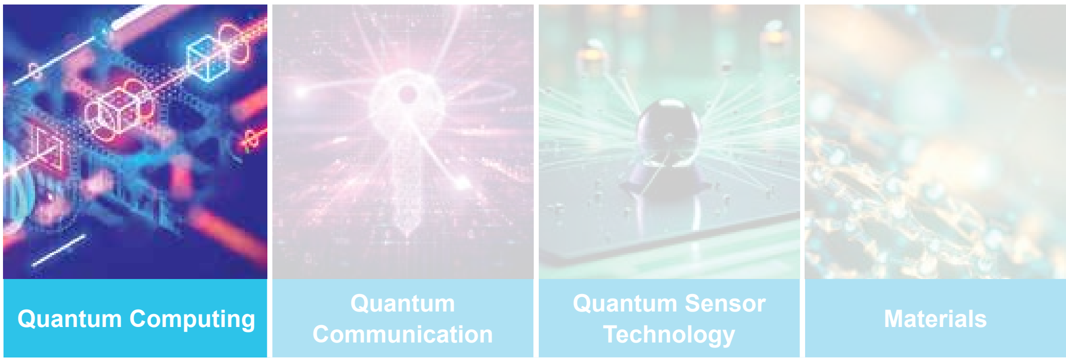
Joint Labs (THWi/IHP) for practical training in the fields of integrated photonics, surface technology, microsystems technology and material diagnostics

Development of new cross-institutional courses

5.3 Opportunities for and Potential of the Region

Strategic and scientific cooperation between stakeholders from research and industry will enable a quantum technology network to be established across federal state lines. This will boost innovation (see also SWOT analysis in the Appendix) and have a lasting impact on science and industry. There are many examples of applications for quantum technologies in the local and regional economy (logistics in rural areas; decentralized administrations, decentralized healthcare systems, battery research, medicine, finance). New concepts for initial and continuing training in quantum technology will generate visibility and attention – a decisive advantage when it comes to attracting and retaining skilled employees.

5.4 Common Themes Running through the Fields of Application



- Development of quantum algorithms and methods (e.g., QML)
- Solving of classical optimization problems
- Solutions from basic research
- Substrate technologies and materials research
- Si-based technology platforms
- Interface with classical electronics (at low temperatures)

To help actively shape the future of quantum technology, the network will focus on specific subject areas. A multidisciplinary approach will be adopted in order to explore the possibilities of the quantum world and put them into practice. The key focal points are as follows:

Development of quantum algorithms and methods: The aim is to develop innovative quantum algorithms and methods that will contribute to the efficient solution of current and future challenges such as mobility, battery research, health (development of new drugs, e.g., against COVID-19) or finance – to name just a few fields of application.

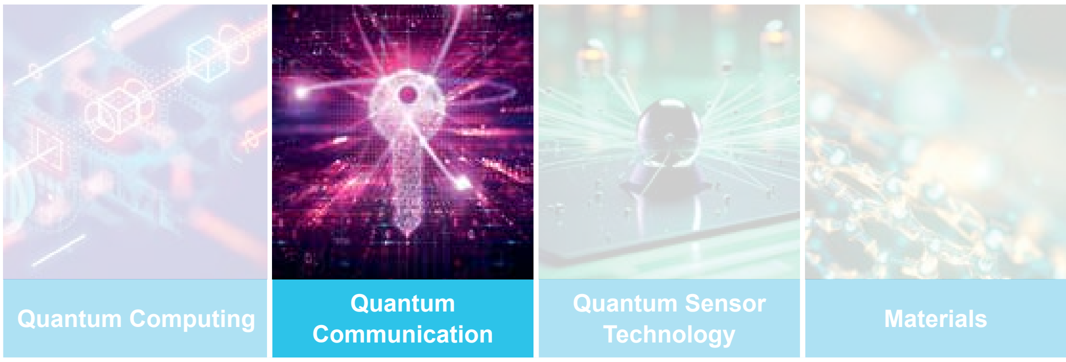
- Within this context, **quantum machine learning algorithms (QML)** are an outstanding example of how the power of superior quantum technology can be harnessed to handle complex tasks even more effectively.
- The network will also elevate **solutions for classical optimization problems** – such as those found in logistics or finance – to the quantum level. This is expected to increase efficiency and speed in solving such problems, which will have a potentially transformative impact on a very wide range of industries.
- **Solutions from basic research:** Basic research, such as that conducted at DESY in Zeuthen, can make a significant contribution to understanding quantum technologies and finding

new and improved approaches to quantum algorithms. For example, findings from theoretical high-energy physics have, on several occasions, led to ideas that have made current quantum algorithms more efficient. This illustrates a direct path from basic research to practical application, whereby quantum technologies undergo further development and new avenues for innovation are opened up.

Substrate technologies and materials research and interfaces: The work within the network also includes research into substrate technologies and materials that are crucial for the development of quantum computers and quantum sensors. The aim is to identify and optimize materials with the desired quantum properties.

- **Si-based technology platforms** play a central role in research and development within the network, serving – for example – as the basis for implementing quantum bits (qubits).
- To enable the integration of quantum technologies into existing systems, solutions are being developed at the interfaces **between classical electronics and quantum hardware**. This is crucial for the practical applicability of quantum computers.

Overall, the Quantum Technology Network strives to push the boundaries of what is possible in quantum technology and create innovative solutions to real-world challenges. The multidisciplinary approach makes it possible to operate successfully at various levels of quantum research and application, and to exert a positive influence on science and industry.



- Secure data transmission
- Quantum cybersecurity
- Novel cryptographic methods
- Sensor and technology developments for quantum cryptography

The Quantum Technology Network is also committed to shaping a more secure digital future and is making the areas of security and cryptography further focal points of its work. The potential of the quantum world must be tapped for the purpose of protecting sensitive information. The following key focal points are at the center of our efforts:

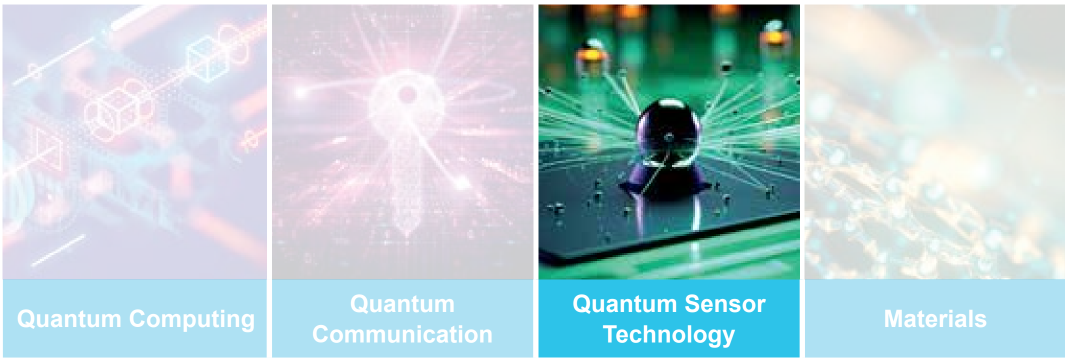
Secure data transmission: Technologies for secure data transmission are being researched based on the principles of quantum cryptography. These approaches enable data to be transmitted with a level of encryption that surpasses what is achievable with conventional methods.

Quantum cybersecurity: The goal is to develop quantum cybersecurity solutions in order to protect companies and organizations from the ever-growing threats from the digital space. The unique properties of quantum technologies make it possible to develop defense mechanisms capable of detecting and neutralizing cyber attacks at an early stage. Quantum optimization and quantum machine algorithms also have a significant role to play in this regard.

Novel cryptographic methods: Quantum computers and algorithms can lead to new cryptographic methods. These methods offer enhanced protection against attacks because they are based on the fundamental principles of quantum mechanics and leave conventional approaches standing.

Sensor and technology developments for quantum cryptography: Another key area is R&D that focuses on improved sensors and technologies for quantum cryptography systems. The aim is to make quantum systems more reliable and efficient for quantum communication.

In summary, the Quantum Technology Network wants to be involved in establishing the foundations of digital security and strives to create innovative solutions for protecting sensitive information against threats from the digital space. The achievements of the quantum world are a crucial tool for overcoming the challenges of digital security and cryptography.



Quantum sensor technology refers to a range of sensor technologies that use the principles of quantum mechanics to improve the precision and sensitivity of measurements. In the case of conventional sensor technology, measurements are limited by factors such as the sensitivity of the instruments or sensor components and the effects of external noise. Quantum sensor technology uses the unique properties of quantum systems to overcome these limitations.

The most important principles used in quantum sensor technology include:

- **Superposition:** Quantum systems can exist in several states at the same time. This property enables quantum sensors to measure several parameters simultaneously, which can increase their efficiency.
- **Entanglement:** Quantum entanglement is a phenomenon in which two or more particles correlate with each other in such a way that the state of one particle immediately affects the state of another, regardless of the distance between them. The entanglement can be used to improve the precision of measurements.
- **Quantum interference:** The quantum states of particles are manipulated in order to improve or suppress certain measurement results, leading to a higher level of sensitivity.

The application of these new measurement techniques opens up the field known as **quantum metrology**. Quantum metrology is an area within quantum sensor technology that is concerned with using the aforementioned quantum properties to perform measurements with a degree of precision that goes beyond the classical limits. This can be particularly useful not only in areas such as time measurement, magnetometry, and gravimetry, but also in basic research of the kind carried out at DESY.

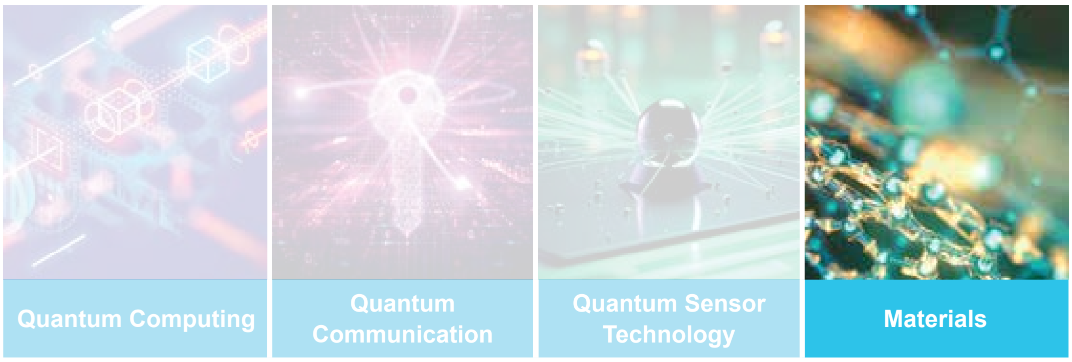
Quantum sensors have the potential to revolutionize various areas and applications. The following are just a few examples:

- Navigation and geophysics: Quantum sensors can be used to achieve more precise measurements in navigation systems (e.g., gyroscopes and accelerometers) and in geophysical applications (e.g., for detecting mineral resources).
- Medical imaging: Quantum sensors can improve the sensitivity of imaging techniques such as magnetic resonance imaging (MRI).
- Environmental monitoring: Quantum sensors can improve the accuracy of environmental monitoring measurements, e.g., when detecting small changes in magnetic fields or gravitational forces.
- Exploring the nature of dark matter in the universe

Research in the development of quantum sensor technology is currently evolving rapidly, with photonic components – in particular – representing a key tool here due to the quantum nature of photons or light particles. The various technology platforms (laser, Si-photonics, III/V QW, etc.) are another particular focus of research in Brandenburg. As these progress, they are expected to lead to the development of more sensitive and precise measuring devices for use in various scientific and technological fields. Examples of these sensor systems include, for example, optical quantum magnetometers. These sensors use quantum optics to measure magnetic fields with a high level of sensitivity. Examples include atomic magnetometers, which use the quantum properties of atoms to detect magnetic fields and whose quantum state is determined using optical measurement methods. This also encompasses methods for quantum imaging. Here, optical quantum sensors are used to improve the resolution and sensitivity of imaging processes, e.g., in quantum-enhanced microscopy and quantum-enhanced imaging in poor lighting conditions.

Alongside these, other sensor systems are already in existence, such as quantum thermometers, which use superconducting materials and their quantum properties to measure temperature with high precision.

To reiterate, quantum sensors are a highly topical and interesting field of research and development, and most types are not yet being produced commercially on a large scale. The challenges here are the verification of quantum physical operating principles, the reproducibility of the sensor elements, and their stability and reliability for the intended functionality.



The Brandenburg Quantum Technology Network aims to research materials, components, and technologies with a view to pushing forward the development of these sensors. These include:

- Development of materials for quantum technologies, and the evaluation and characterization of materials
- Low-temperature characterization of materials (e.g., magnetotransport)
- Isotopically pure Si/SiGe and Ge/SiGe quantum wells on a laboratory scale and in pilot lines
- Ultra-cold atoms, ion and atom traps, superconductors
- Carbon nanotubes, graphene nanoribbons, semiconductor quantum dots
- Creation of thin layers
- Incorporation of point defects (e.g., in the diamond)
- Doped crystals and polymers
- Hybrid photonic structures, non-linear optical materials
- Specialized optical fibers

6 Profiles: Stakeholder Competencies

Brandenburg University of Technology Cottbus-Senftenberg | Chair of Communication Technology

Quantum-inspired AI methods make use of mathematical modeling (e.g., matrix mechanics, algebraic quantum theory, Hilbert and Fock space representations, quantum logic as the logic of orthogonal projectors) but do not generally take account of quantum physical effects, particularly discontinuous changes in state due to measurement processes.

The Chair conducts research into quantum-inspired methods of symbolic artificial intelligence. In contrast to numerical AI methods (e.g., deep neural networks, Bayesian networks and classifiers, support vector machines, etc.), symbolic AI works with inherently understandable and interpretable data structures (e.g., grammar or logic rules or relational databases) and corresponding calculi (e.g., logic calculi or lambda calculus).

The connection to algebraic quantum theory is established through representations of symbolic data structures in high-dimensional vector spaces (vector symbolic architectures, VSA). Operations on symbolic data are expressed by operators in the vector space representation.

The Chair's research focuses particularly on the application of quantum-inspired AI and machine learning methods for the behavioral control of technical cognitive systems (e.g., voice dialog systems, intelligent agents, or control systems for industrial machines).

Quantum-inspired AI methods can be technically implemented on conventional digital computers as well as on neuromorphic and quantum computers.

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Deutsches Elektronen-Synchrotron (DESY) | Center for Quantum Technology and Applications

The DESY-Center for Quantum Technology and Applications (CQTA) is an ecosystem for innovative research in the fields of quantum sensing and quantum computing. In addition to developing algorithms and methods, and providing training in quantum computing, CQTA offers researchers at DESY – as well as partners from research and industry – privileged access to commercial quantum computers for the purpose of computing existing problems and designing and optimizing new applications for quantum computers.

- Quantum computing
- Quantum sensing
- Quantum device hardware access
- Development of applications and use cases
- Quantum algorithms and methods
- Training in quantum technologies

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https://quantum-zeuthen.desy.de

Fraunhofer IPMS | Innovation Campus Electronics and Microsensor Technology Cottbus (iCampµs Cottbus)

The Innovation Campus Electronics and Microsensor Technology Cottbus (iCampµs Cottbus) is a research cooperation between the two Fraunhofer Institutes IPMS and IZM, the Leibniz Institutes IHP and FBH, BTU Cottbus-Senftenberg, and Thiem-Research GmbH. The focus of the research is microsensor technology.

The aim is to collaborate with small and medium-sized enterprises (SMEs) from Lusatia in order to develop and establish innovative products in the research fields of process and environmental sensor technology, digitalization/ Industry 4.0, Agriculture 4.0, and medicine/life sciences. Cooperation between scientific institutions and industry is intended to contribute to the innovation and competitiveness of regional companies.

Funding of 20 million euros has been secured under the German government's immediate action program for structural change in coal regions to support the second phase of the scientific project up until the end of 2026.

The first iCampµs Cottbus Conference iCCC2024 was a particular highlight of the project. More information at www.iccc2024.de.

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Leibniz Institute for Innovative Microelectronics – IHP and Wildau Technical University of Applied Sciences | Departments of Technology and Materials Research Plus Micro- and Nanoelectronics

- Ge-/Si-/SiGe-based material development on 200 mm for quantum wells, 2DEGs, 2DHGs, spin qubits
  - Growth of complex heterostructures
  - Structural and chemical material analysis (XRD, XRR, Raman, SIMS, XPS, AFM, SEM, STEM)
  - Electrical properties of heterostructures (magnetotransport at 1.5 K and 12 T, DLTS, C-V/I-V)
- Component, module, and process development for 200 mm-based technology platforms
  - Contact modules, gate positions, ...
  - Test structures, reverb bars, ...
- Si photonics for quantum applications (sensitive PD, fast analog IC)
- Analog electronics for cryogenic temperatures for the development of control and readout circuits in quantum computing and QuCom systems
- Cryogenic PDK environments for "first-time-right" control and read-out IC (ROIC) developments in quantum systems

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Technical University of Applied Sciences Wildau

Specialist areas

- Photonics and optical technologies
- Instrumental analysis and applied surface physics
- Laser and plasma technologies

Expertise/competencies

- Development and characterization of photonic imaging and processing systems for structures in the nanometer range up to macroscopic objects
- Development of new materials for optoelectrical, electro-optical, and non-linear optical components based on organic, inorganic and mixed molecular and quantum systems
- Structural, electronic, and magnetic investigations of nanoparticles, molecular systems, and thin films
- High-vacuum coating, spin coating, Langmuir-Blodgett technique, vacuum deposition polymerization
- Structuring of thin layers, reactive-ion etching
- Laser cutting, laser ablation, laser deposition, plasma activation and coating of surfaces
- Synthesis of low-molecular compounds, conjugated polymers, chromophores, and nanoparticles
- Stationary UV/VIS/NIR and IR spectroscopy, time-resolved transmission and emission spectroscopy, ellipsometry, surface plasmon spectroscopy, M-line spectroscopy, laser-induced plasma spectroscopy
- Spectroscopy with synchrotron radiation, e.g., analysis of the absorption fine structure (XANES), magnetic circular dichroism (XMCD), and linear dichroism (XLD, XMLD), as well as the far-edge X-ray absorption fine structure (EXAFS)
- Scanning probe microscopy, Raman microscopy, scanning electron microscopy with EDX, digital microscopy

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Technical University of Applied Sciences Wildau | Department of Automation Technology

Measurement, control, and regulation technology; AI application; voice control; robotics

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Brandenburg University of Applied Sciences

Quantum and environmental photonics
- Laser beam sources for quantum optics, single-photon and ultra-brilliant sources of entangled photons, highly stable diode laser systems with external resonators, single-mode high-power diode lasers
- Quantum imaging, two-photon induced fluorescence with entangled photons, ultracold atoms, laser spectroscopy of single stored ions, single atom temperature imaging
- Photon statistics, ultra-fast detection of correlated photons with two-photon absorption
- Environmental photonics and spectroscopy, remote sensing, water analysis with photonic instruments, sustainable lighting, effect of artificial light on ecosystems, light pollution, skyglow

Theoretical solid state physics and financial mathematics
- Prediction, analysis of material properties with density functional theory and dynamic molecular field theory
- Theory of unconventional superconductivity, including in copper-based, iron-based, and organic crystals
- Theory of topological quantum materials, including anomalous Hall effect, quantum anomalous Hall effect, quantum spin Hall effect
- Theory of quantum magnetism
- Applications of quantum computing in the financial sector (portfolio optimization, derivatives valuation, risk management)

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University of Potsdam, Institute of Mathematics | Chair of Algebra

Operator algebras
- Mathematical language of quantum mechanics and quantum field theory
- C* algebras and Von Neumann algebras
- Structure and classification

Group theory and generalized symmetries
- Symmetry groups of discrete structures
- Tensor categories
- Quantum groups

Mathematical quantum information theory
- Modeling entanglement through non-local games
- Group-based quantum algorithms

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7 List of Abbreviations

AIP	Leibniz Institute for Astrophysics Potsdam (AIP)
BTU	Brandenburg University of Technology Cottbus-Senftenberg
CM	Cluster Management Photonics Berlin Brandenburg
CQTA	Center for Quantum Technology and Applications
DESY	German Electron Synchrotron DESY
DLR	German Aerospace Center (DLR)
FBH	Ferdinand-Braun-Institut gGmbH, Leibniz Institute for High Frequency Technology
FOKUS	Fraunhofer Institute for Open Communication Systems FOKUS
FU Berlin	Free University of Berlin
GFZ	Helmholtz Center Potsdam, German Research Center for Geosciences
HHI	Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, HHI
HPI	Hasso-Plattner-Institut für Digital Engineering gGmbH
HS	University/technical college
HU Berlin	Humboldt University of Berlin
HZB	Helmholtz Center Berlin for Materials and Energy
IAP	Fraunhofer Institute for Applied Polymer Research IAP
iCampμs	Innovation Campus Electronics and Microsensor Technology Cottbus
IHP	Leibniz Institute for Innovative Microelectronics (IHP)
IKZ	Leibniz Institute for Crystal Growth (IKZ)
IPMS	Fraunhofer Institute for Photonic Microsystems IPMS
IZM	Fraunhofer Institute for Reliability and Microintegration IZM
MBI	Max Born Institute (MBI) for Nonlinear Optics and Short Pulse Spectroscopy
PDI	Paul Drude Institute for Solid State Electronics (PDI)
PIK	Potsdam Institute for Climate Impact Research (PIK)
QML	Quantum Machine Learning
QT	Quantum technology
THB	Brandenburg University of Applied Sciences
THWi	Technical University of Applied Sciences Wildau
TU Berlin	Technical University of Berlin
UP	University of Potsdam

8 Appendix

8.1 SWOT Analysis

Strengths

- Excellent research landscape (technical colleges, universities, non-university research institutions)
- Appropriate density/distribution of non-university research institutions with complementary focal areas → healthy competition
- CQTA
- Established photonics companies
- Quantum technology start-ups
- Industry networks
- Cross-border cooperation at all levels
- Established event formats (Optics Day, Cluster Conference, Photonics Days Berlin Brandenburg) in the Photonics Cluster, which facilitate networking and national and international visibility

Weaknesses

- National and international visibility of competencies
- Shared public image
- Increasing shortage of skilled employees
- Structural problems, time factor (inefficient process chains at universities and scientific institutions)

8.2 Objectives and Implementation Activities

Objectives	Implementation Activities	Stake-holder	Phase
Establish a quantum technology network with joint projects	Establish a governance structure, e.g., a Quantum Technology Advisory Board (“Steering Committee”), and organize meetings and events Publish a newsletter for the quantum technology community	DESY, CM, THWi	2
Link existing fields of application and develop new ones in projects	Organize joint events and symposiums with the involvement of industry	Cross Cluster CM	3

Transfer research results to industry (finance, logistics, pharmaceutical, and chemical industries; battery research; medicine; transport; or automotive manufacturers)	Organize events, symposiums Identify project topics and submit project applications Cooperation agreements Generate and present best-practice examples Publish a newsletter for the quantum technology community OpTecBB → Use Photonics Days Berlin Brandenburg as a platform	THWi, OpTecBB	3
Advance initial and continuing training in quantum technology	Develop joint, cross-university initial and continuing training concepts in quantum technology (block seminars, integration into the respective courses, joint course catalog, recognition, credit points, Microelectronics Academy → module handbook)	DESY, THWi, HU Berlin, Uni Potsdam, FU Berlin	2
Highlight the special features of the region	Compile expertise (brochure, use cluster website to showcase expertise), demonstrate local added value Organize and conduct workshops to enable strategic discussions	CM	3
Implement joint R&D projects and submit coordinated third-party funding applications	Routine exchange of information and ideas among the stakeholders Identify suitable funding programs	All partners	3
Increase the national and international visibility of the stakeholders	Promote the capital region's expertise and quantum technology community at national and international conferences Embed into federal initiatives such as FMD-QNC through IHP	IHP, THWi	3
Reduce bureaucracy (for attracting skilled employees) Build agile structures (fast track)	Address political representatives “Swap” skilled employees between institutions	All partners	3
Gather technological challenges and questions from industry	Run cross-industry workshops (on a cross-cluster basis)	CM	2

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Our goal: Your success!

Berlin and Brandenburg promote the Optics and Photonics Cluster through a cross-state economic policy. Cluster management is carried out by Berlin Partner für Wirtschaft und Technologie GmbH, Optec-Berlin-Brandenburg (OpTecBB) e.V., and the Economic Development Agency Brandenburg (Wirtschaftsförderung Land Brandenburg GmbH).

Our goal is to comprehensively support companies and scientific institutions in the fields of optics, photonics, microelectronics, and quantum technology in their development at the location.

We assist with:

- **Location search**
- **Funding and financing**
- **Technology transfer and R&D cooperation**
- **Collaboration in networks**
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Feel free to contact us at any time!
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