Quantum technology

Content and applications

Since Niels Bohr became a professor in theoretical physics 100 years ago, Copenhagen has been an important location for the understanding of quantum physics. Quantum technology is already now being used in such technologies as GPS, optical cables, superconducting magnets and in mobile phones. However, quantum technologies are on the verge of a new era in which their applications could revolutionise the world in several areas.

First and foremost, super computers based on quantum technology are expected to be able to set entirely new standards for processing big data. Quantum technology is expected to form the basis for a whole range of new devices that will make it possible to process and communicate data at a significantly higher level than today. The EU has named quantum technology as a major flagship initiative.

Key environments and star researchers

Greater Copenhagen has a very strong research environment within the area. At the Niels Bohr Institute at the University of Copenhagen, key researchers include Charles Marcus, Eugene Polzik and Peter Lodahl. At the Technical University of Denmark (DTU), leading names include Ulrik Lund Andersen at DTU Physics and Jesper Mørk at DTU Fotonik.

The quantum field is divided into two main areas, each of which contain several sub-disciplines. The area of solid state and quantum electronics is one of the main areas, while quantum optics and quantum photonics is the other.

Prospects for attracting investments

The area is highly relevant for attracting investment. Some of the technologies in the area are so novel that they will not be applicable for some years, while other applications, such as quantum-based cryptography, are already underway. Overall, however, the potential is considerable, indicated by the substantial investments made in the field by the EU, Innovation Fund Denmark, private foundations and companies. There is no doubt that the most important area of investment and applications will be the development of the supercomputers of the future.

Characteristics of the research area

Quantum research in Greater Copenhagen is especially anchored at the Niels Bohr Institute at the University of Copenhagen and at DTU Physics and DTU Fotonik, within each of which there are various specialized departments and centres. The Niels Bohr Institute and DTU each host about 70 researchers working in the quantum field. In all these environments, there are various postdocs and PhDs.

International top quality niches

Quantum research is divided into two main pillars. One is solid state research which contributes to the development of future electronics by researching the interaction between advanced materials and the quantum/ mechanical effects found in electronic nano components.

The second relates to quantum photonics and quantum optics, which especially aim to store and transmit digital information through optical beams, and the ability to store digital information in individual photons. Some projects aim to link the two areas of technology together. Research in Greater Copenhagen is well placed internationally within both pillars.

Bibliometric key figures

The bibliometric indicators for research production and quality confirm that Greater Copenhagen is at the international cutting edge. As shown in the table, the category of Condensed Matter Physics covers the solid state field of quantum technology. The Atomic and Molecular Physics and Optics category also covers the field of photonics and optics. Greater Copenhagen contributes with considerable research output, with a total of 6,700 articles in recognised journals over the past 10 years, amounting to a specialisation of around 1.

The quality of research is world-class. Greater Copenhagen takes a 2nd place when it comes to the proportion of research production in the top international 10% of most cited articles. This reflects the fact that quantum research in Greater Copenhagen is done in various smaller environments with international core competencies in a number of niche areas. With respect to the investment potential of the area, an equally important indicator is the proportion of co-publications with researchers from private companies which gives an indication of the commercial relevance of the research. On this indicator, Greater Copenhagen is placed 1st for both the above fields of research.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Condensed matter physics	0.8	5 (3636)	2 (19.7%)	1 (6%)
Atomic and molecular physics and optics	1.17	3 (3038)	2 (13.8%)	1 (10.9%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School (CBS) compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

Highly cited article ranking indicates Greater Copenhagen's ranking in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets).

Finally, co-publication ranking indicates Greater Copenhagen's ranking among the regions of comparison for the proportion of articles in the field of research published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

The full perspectives for the potential of quantum technology is long-term and some uncertainty still remains. But quantum technology is among the areas expected to foster a number of crucial technological breakthroughs in coming decades.

However, there have already been many discoveries in the area. In 2014-15, Quantum at University of Copenhagen had a total of 13 out of 145 announced discoveries, i.e. about 9%. This should be viewed in relation to the fact that quantum research only employs about 2% of the permanent researchers at the University of Copenhagen.

Star researchers and major scientific breakthroughs

A number of outstanding researchers have secured Denmark's position on the world map of quantum research.

Key names include Prof. Charles Marcus, who heads the Center for Quantum Devices at the University of Copenhagen. He works on quantum electronics. Researchers are developing techniques and technologies that could form the basis for the supercomputers of the future by controlling and exploiting the fascinating, strange quantum properties of atoms, such as quantum entanglement.

Prof. Peter Lodahl from the Niels Bohr Institute at the University of Copenhagen is the Director of the Center for Quantum electronics and he works on controlling photons via nanophotonic structures, special crystals that can be used in future quantum communication. Prof. Eugene Polzik, who heads the Center for Quantop - Quantum teleportation, also works at the Niels Bohr Institute. The technology forms the basis for the superfast communication networks of the future as well as for quantum sensors for measuring electromagnetic fields and acceleration.

Jan Westenkær Thomsen, also working at the Niels Bohr Institute, is Director of the Center for Ultracold Atoms, where they conduct experimental research on super accurate measurements, such as quantum-based atomic clocks that only lose a second in 300m years.

At DTU Physics, Prof. Ulrik Lund Andersen heads a quantum information team and works on quantum sensing and on processing quantum information, including how data can be transferred with 100% security. Prof. Jesper Mørk at DTU Fotonik leads the research into ultra fast communication in conjunction with the VKR Center of Excellence Nanophotonic Components for Terabit Communications, and Prof. Leif Katsue Oxenløwe who is the head of the Silicon Photonics for Optical Communications basic research centre.

In Europe, Greater Copenhagen is one of only three regions to have made great headway in the selected technologies. The other strong research environments include Delft in the Netherlands and ETH in Zürich. The three strong research communities in USA are Yale, Harvard and Santa Barbara in California. The research communities in other countries such as UK, Germany, Korea and Japan also do high level research.

So far, breakthrough research has been made on the development of new atomic clocks, satellite controls systems, cryptography and sensors. Future big research breakthroughs are expected to be within supercomputing, communication and ultra accurate sensing, areas in which Greater Copenhagen is in a global leading position.

Large talent pool

The University of Copenhagen and DTU both educate/train a considerable number of talented individuals. The Niels Bohr Institute has 700 physics students with about 150 Master's graduating every year, practically all of whom will have done studies in the quantum field. 40-45 PhDs graduate at the Institute every year. DTU also has 500 engineering students of whom 75% attend courses in the quantum field, with many continuing as PhDs. DTU has a Master's programme within quantum technology and a hands-on

QuantumLab for students.

These highly specialised talented researchers work closely on a day-to-day basis with some of the world's most skilled researchers in quantum science. This enables them to gain knowledge, which gives their collaborative partners entirely unique opportunities to be at the forefront internationally with respect to access to knowledge in this field, if they make use of opportunities for recruitment.

Unique research facilities

Over the past 10 years, a total of about DKK 200m has been invested in state-of-the-art research infrastructure at University of Copenhagen and DTU. This process has also been assisted by donations from the Villum Foundation, the Carlsberg Foundation, the Lundbeck Foundation, the Novo Nordisk Foundation, the Danish National Research Foundation and the Danish Council for Independent Research.

The list of infrastructure includes various instruments for making and characterising photonic and electronic quantum components. Among these an electron-beam writer dedicated to making ultra-high-definition quantum nano-structures. DTU Danchip is a national clean room for making quantum components, featuring international top class facilities and research infrastructure.

The quantum field has been highly prioritized, and has received considerable funding from the EU, the Danish National Advanced Technology Foundation and Innovation Fund Denmark. Researchers from the Niels Bohr Institute at the University of Copenhagen have thus been awarded a series of prestigious ERC Grants: Eugene Polzik (2011), Peter Lodahl (2010 and 2014), Anders Søndberg Sørensen (2012) and Albert Schliesser (2014). Three awards have been awarded in this field from the Danish National Research Foundation for the Center for Quantum Optics, the Center for Quantum Devices and the Center for Silicon Photonics for Optical Communication.

This field will probably have even greater priority in future. In the spring of 2016, Innovation Fund Denmark disbursed a grant of DKK 80m (the largest ever single award from the Fund), which will be used for developing new encryption methods and topological quantum computers.

The essential future investment might come from the EU. In the spring, a working group including EU Commissioner Oettinger, the Dutch Minister of Business Affairs and Charles Marcus and Eugene Polzik from the University of Copenhagen, released a Quantum Manifesto with guidelines for how the quantum field should develop in the future, new areas of application as well as an ambition to put Europe at the forefront of global developments in the quantum field. A vision, which will entail that the EU and EU member states invest a total of EUR 1bn in the field.

Eugene Polzik also has a seat on the steering group for quantum research set up by the EU as part of its process for so-called flagship technologies.

Strong collaboration with leading international research environments

There is great international interest in visiting the Niels Bohr Institute, which therefore gets visiting researchers from the whole world. The institute is itself active in collaborating with knowledge centres worldwide. One close partner is the University of Delft in the Netherlands, but the institute also works with quantum researchers at ETH Zürich, Yale and Stanford. Similarly, DTU has an extensive range of internationally recognised collaborative partners in the quantum field, such as Queensland University, University of California Santa Barbara and University of Delft.

Extensive corporate collaboration

The Niels Bohr Institute at the University of Copenhagen, DTU and Aarhus University have jointly established the Quantum Innovation Centre (Qubiz) in close collaboration with a range of Danish and international companies, all leaders in the commercial exploitation of quantum technology. Their ambition is to create a world leading innovation centre for commercial exploitation of quantum technology research.

Qubiz already collaborates with companies such as Accelink Denmark, Attocube Systems, Cryptomatic, Elionix, Foss, ID Quantique, Microsoft, Montana Instruments, M Squared Lasers, NIL Technology, NKT Photonics, Quantumwise, Scontel and Toptica.

Most recently, in the spring of 2016, Seier Capital invested millions of Danish kroner in a newly started quantum business, Sparrow Quantum, which supplies chip solutions to companies requiring sophisticated algorithms for simulating the properties of materials, for example. Sparrow Quantum is a spin-out from the quantum photonics environment at the Niels Bohr Institute at the University of Copenhagen and makes photonic chips designed to meet companies needs for advanced simulation algorithms. The investment was Seier Capital's largest and most surprising until now.

”If everything goes as planned, there is enormous potential. SPARROW QUANTUM is taking the first steps towards a future with super fast quantum computers, unbreakable encryption and possibly also quantum-based internet. “

- Lars Seier Christensen

Half of Qubiz´ collaborative partners are international. We interviewed Montana Instruments in Montana, USA.

”We are in the Wild West – both literally and figuratively speaking. We produce optical cryogen systems. With our now single photon developed with our Copenhagen partners, we can help our costumers all over the world produce new materials. We think the guys in Copenhagen are world class.”

- Luke Moritsen, Director, Montana Instruments, US

”We have been strongly inspired by the new Quantum Manifesto which has the backing of the EU Commission. We believe in a strongly growing market for quantum simulations, an area in which we do not so far have many competitors."

- Troels Marcussen, Civil Engineer, Quantumwise Denmark