2017

Annual Report

In accordance with the ‘Partnerconvenant QuTech’

Foreword

On behalf of the whole of QuTech, I am proud to present the yearly report for 2017. It presents an overview of the research 'roadmaps' along with several other activities, such as QuTech partnerships, outreach and academy.

In my view, 2017 marks the completion of the first phase of QuTech, in which we have transitioned to a mission-driven research program, enabled by both scientific breakthroughs and engineering efforts. Most PhD students that started their research in the pre-QuTech era have now graduated. The roadmaps of QuTech have a clear direction and demonstrate a strong synergy between science and engineering. The scientific foundation of QuTech is stronger than ever with, for example, four publications making it into top scientific journals Nature and Science in 2017, with three further published early in 2018. At the same time, we have pushed engineering to a level mature enough to embark on building demonstrator systems: full stacks for a quantum computer and for a quantum internet that are universally programmable by users without any knowledge of the underlying architecture. In the coming years, we will be able to show the exciting fruits borne from these efforts!

In 2017, QuTech has attracted some of the best researchers in quantum technology to join our mission. Prof. Barbara Terhal (0,8 FTE) and part-time Prof. David DiVincenzo, both leading experts in quantum information theory and error correction, started at QuTech in September. From our own ranks, Dr. Srijit Goswami has been contracted as a senior researcher on topological qubits.

With the internal research programs now running at full steam, QuTech is ready for its next phase, in which we will form stronger connections to the outside world. The demonstrator projects will allow external researchers to connect to and use our hardware and software platforms. The establishment of a Microsoft research lab – formally agreed upon in a joint signing ceremony in June 2017 - marks the start of a Quantum Campus in Delft. The start of the EU Flagship has stimulated the building of new consortia with the best research and industry partners across Europe.

Despite the rapid evolution, QuTech remains a place with a unique culture. For me, it is this culture in combination with world-leading research that makes QuTech such an exciting place to work. I am already looking forward to the coming years!

Ronald Hanson

Scientific Director QuTech

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Executive Summary

QuTech is the advanced research centre for Quantum Computing and Quantum Internet, a collaboration founded in 2014 by Delft University of Technology (TU Delft) and the Netherlands Organization for Applied Scientific Research (TNO). Within TU Delft, the Faculty of Applied Sciences (AS) and the Faculty of Electrical Engineering, Mathematics and Computer Sciences (EEMCS) are both involved in QuTech. This document presents the most important developments concerning QuTech in the year 2017.

The three mission-driven roadmaps - Fault-Tolerant Quantum Computing (FT), Quantum Internet and Networked Computing (QINC) and Topological Quantum Computing (TOPO) - have made important progress towards the scalability of the quantum systems. The FT roadmap has reached key milestones in both programmability and control. In partnership with Intel, hardware is explored and developed to reach an even larger number of qubits. The QINC roadmap has worked towards a robust architecture for quantum networks, yielding entanglement distillation, first results on optical cavities and theoretical characterization models. The TOPO roadmap has attained key milestones in the generation and control of Majorana Fermions, due to improved design and control methods. Supported by technicians and engineers (see roadmap 'Shared Development') control and measurement devices have been improved. Simulators and demonstrators have been further developed. Details regarding the highlights of the scientific and technological roadmaps can be found in the 'Research' section.

To remain at the forefront of quantum information science and technology, new partnerships and collaborations have been formed, whilst the existing partnership with Intel has progressed significantly. This year, a long-term collaboration between TU Delft and Microsoft was officially initiated.
In this public-private partnership, QuTech and Microsoft aim to build topological quantum bits into a working quantum computer. Besides this significant partnership, QuTech has joined forces

with other quantum institutes. Forschungszentrum Jülich and RWTH Aachen University, both partners in the Jülich Aachen Research Alliance (JARA), have intensified pre-existing collaborations with QuTech through the signing of official agreements. The 'Quantum Helix Vision 2020' connects the institutes' researchers with a number of innovative companies, while the 'Quantum Internet Alliance' joins institutional forces to the end of building a large-scale quantum internet.
A particularly important highlight of 2017 is the Gravitation programme. This grant of 18.8 million euros unites researchers from QuSoft, Centrum Wiskunde & Informatica, Leiden University, QuTech, TU Delft, University of Amsterdam and the Vrije Universiteit in pursuing state-of-the-art research programs in this emerging field of quantum information science. Besides this grant, Ronald Hanson was awarded the ERC Consolidator Grant, and Tim Taminiau has been awarded a Vidi Grant. Furthermore, Ronald Hanson won the John Stewart Bell prize. Julia Cramer won the NWO Physics Minerva prize and Bas Hensen won the NWO Physics Thesis Award 2017, and was awarded a Rubicon grant.

On the outreach and communication side, there have been numerous highlights. QuTech was involved in several public events, such as 'Het Gala van de Wetenschap'. Multiple YouTube movies were created to explain the various publications in just three minutes each. A movie on the unboxing of a 17-qubit quantum chip by Leonardo DiCarlo in collaboration with Intel accrued 60.000 views. Stephanie Wehner spoke at TEDxVienna about the quantum internet. Finally, two of our quantum chips made it to the renewed Boerhaave Museum in Leiden.

QuTech Academy increased its visibility by launching its own website and corresponding social media. A series of four courses at TU Delft were created, introducing students to the diversity of quantum information technology at QuTech.

The 'Organisation' section offers some insight into the governance of QuTech. Furthermore, it includes a number of graphs on staffing levels and structure. Over the year 2017, QuTech has had successes within all roadmaps, intensified collaborations and grown both in excellent staff as well as in equipment and space. The number of people working in QuTech has grown from 164 to 180. This number is expected to increase in the coming years to about 340. The lab and office spaces have been expanded from 2700 to 3381 m^2, and the number of experimental setups has increased from 36 to 51. These illustrate a steady growth over the past year which we expect to continue into the future.

The 'Financial overview and expenses' section provides information on QuTech budgets within the framework of the Partnerconvenant. Finally, in the appendices, we present an overview of current QuTech peer-reviewed scientific publications in 2017, as well as our graduated PhD researchers, BSc and MSc students.

Research

ROADMAPS

Photo credit:
Marcel Krijger

Fault-Tolerant Quantum Computing

> ROADMAP LEADERS: **LIEVEN VANDERSYPEN, LEONARDO DICARLO**

Fault-Tolerant Quantum Computing (FT) - The FT roadmap aims at realising a complete quantum computer stack based on spin qubits in semiconductors and on superconducting qubits, constructed and operated to be resilient to errors from decoherence.

For spin qubits, the main focus lies, and will remain, in extending spin qubit registers to larger sizes and networking these registers together on a chip. We obtained three major scientific results in 2017, all to be published in top journals.

First, we have realised a programmable two-qubit device based on Si/SiGe quantum dots and tested it by implementing all instances of the two-qubit Grover search algorithm and the two-qubit Deutsch-Jozsa algorithm (*Nature*, 2018). This is the first time that sufficient control of two quantum dot spins was reached to allow flexible programming of their evolution. Second, we have achieved the so-called 'strong-coupling regime' between a single electron spin in a Si/SiGe quantum dot and a microwave photon in a superconducting cavity (*Science*, 2018). This regime allows for the coherent transfer of a quantum bit back and forth between the spin state and the photon state and creates a path to creating coupled networks of spin qubit registers on a chip. Third, we published our work on quantum simulation with quantum dots (*Nature*, 2017), in which we investigate and explore in detail the transition from Coulomb blockade to collective Coulomb blockade in a GaAs triple quantum dot array. This transition is the finite-size analogue of the important metal to Mott-insulator transition.

We are now continuing our research on quantum simulation using a 2x2 array of quantum dots. >>

>> Other highlights include a study of the spin relaxation time and charge noise in a Si-MOS quantum dot as a function of temperature, with encouraging results for the possible operation of spin qubits at ‘elevated’ temperatures from 1.5K up to even as high as 4K. Both locally at QuTech and together with our partner Intel, we have continued to optimise the mobility and valley splitting of Si/SiGe heterostructures. We also obtained record mobilities for holes in Ge quantum wells and have begun testing Ge quantum dots. The first quantum dot devices entirely made in the Intel cleanrooms are expected in the first part of 2018. Together with Intel, we have nearly completed an integrated cryogenic control chip that will be capable of driving both spin qubits and superconducting qubits. Furthermore, we completed the design and testing of a low-noise amplifier and oscillator at cryogenic temperatures (ISSCC2017). A final milestone was the addition of a silicon qubit experiment to the demonstrator platform, in which last year we showed the integration of superconducting qubits and a full quantum architecture stack.

For superconducting circuits, 2017 constituted a significant consolidation of efforts towards the realisation of an error-protected logical quantum bit, with significant steps forward in the parallel-running QuTech-Intel partnership and IARPA LogiQ project.

Our partnership with Intel maintained its focus on the fabrication of scalable quantum hardware, producing test chips using the patented unit-cell concept developed in 2016 by TNO and TUD colleagues. A first 17-qubit test chip, co-designed by QuTech and Intel, was delivered to QuTech in October, followed by a 49-qubit version in December. Both events were marked by significant media attention driven by Intel, and a popular video produced in QuTech (receiving nearly 60.000 views). These 17- and 49-qubit test chips will be measured in QuTech in 2018, using our newly wired dilution refrigerators accommodating the growing number of interconnect lines. Feedback from such measurements drives a steady stream of

NEW GROUP LEADERS IN 2017

Barbara Terhal (Theory) – 0,8 FTE

During her PhD research, Barbara developed the concept of an entanglement witness as opposed to a Bell inequality test for the detection of quantum entanglement. After her PhD thesis, she worked as a postdoctoral researcher at IBM Research at Yorktown Heights, NY and Caltech, before returning to IBM as a research staff member in 2001. Notable work during her IBM period includes the exploration of the computational power of low-depth quantum circuits or stoquastic (sign-free) Hamiltonians; the use of perturbative gadgets for quantum simulation and quantum complexity theory;

and the development of quantum information protocols such as remote state preparation, quantum locking and quantum data hiding.

David DiVincenzo (Theory) – part-time position
After receiving his PhD at the University of Pennsylvania in 1983 and conducting a postdoctoral research post at Cornell University, David was a member of the IBM research staff from 1985 to 2011. His final position at IBM was as manager of the Physics of Information group at the T. J. Watson Research Center. He has worked on quantum information theory since 1993. He proved that two-qubit gates are universal for quantum computing. In 1996 he introduced, together with Daniel Loss, the concept of quantum dot computing. He authored the seven 'DiVincenzo criteria' for the physical implementation of quantum computers.

improved versions of these test chips, which Intel now produces and delivers in roughly bi-weekly cycles.

Our IARPA project has kept its focus on the development and integration of room-temperature electronics for controlling quantum hardware. A key highlight is the development by TNO of a 32-channel vector switch matrix that routes the microwave pulses for single-qubit gates in a scalable manner. A second highlight is the co-development by TUD and SME Zurich Instruments of firmware allowing the ZI UHFLI lock-in amplifier to function as a powerful engine for multiplexed qubit readout. First steps are now being taken to commercialise this firmware, which will generate a new revenue stream for QuTech. Lastly, we have learned to multiply our own arbitrary waveform generator (the QuTech QWG), producing dozens of copies of the prototype developed over the first four years of QuTech. The combination of these efforts allows controlling 17 and 49 qubits with only one rack of instrumentation: a significant achievement in integration.

Furthermore, we continued to develop the software layers of the quantum computer stack in the context of the open-work packages of the QuTech-Intel partnership. Key highlights include the development of a second open-source quantum simulator (QuantumSim), the compiler OpenQL, a quantum-instruction-set architecture for the FPGA hardware controlling the above electronics (which led to three awards at international conferences), and a true web interface allowing control of the quantum computer from anywhere in the world using a standard web browser. All of these features have been integrated into the superconducting-qubit demonstrator and were successfully presented at the yearly QuTech-Intel review in November 2017. The development of this demonstrator into a full service in the cloud is the main subject of a TUD-led proposal in the ramp-up phase of the EU FET Quantum Flagship. If successful, this proposal will expand the involvement of European industrial partners in the QuTech ecosystem, including the nascent Quantum Campus.

Quantum Internet and Networked Computing

> ROADMAP LEADER: **STEPHANIE WEHNER**

Quantum Internet and Networked Computing (QINC) — The internet, a vast network that enables simultaneous long-range classical communication between any two points on earth, has had a revolutionary impact on our world. The long-term vision presented in the QINC roadmap is to build a matching quantum internet that will operate in parallel to the internet we have today.

Photo credit:
Pim Top

Achieving our goal poses formidable challenges, which demand unique solutions spanning physics, material science, computer science and engineering. To realise this vision, we have started to work on an extensible architecture for entanglement-based quantum networks with a team covering expertise from physics, optical engineering, systems engineering and computer science. A demonstration outside the lab of a four-city network is planned to be realised by the end of 2020.

Scientific highlights of 2017 continued the path set by the breakthrough of 2015, the loophole-free Bell test, and our robust quantum memory demonstration of 2016. These results paved the way for demonstrating the creation of a high-fidelity entangled pair of qubits by combining multiple low-quality pairs into one (*Science*, 2017). This method is an essential building block for achieving long-distance quantum communications.

In addition, the rate of entanglement generation between network nodes can be significantly enhanced by incorporating the network qubits in an optical cavity. We have designed and characterised the first of such integrated devices. The first results show that our design may enable several orders of magnitude gain in the speed of the future quantum network (*Appl. Phys. Lett.*, 2017).

Several theoretical breakthroughs have been achieved in 2017. The highlight of these involved the introduction of a new method called 'capacity estimation'. This method allows us to characterise quantum memories in the presence of arbitrarily correlated errors. This procedure can also be used to test quantum error correcting codes and to assess the performance of quantum repeaters (*Nature*, 2018).
Quantum networks distributed over distances greater than a few kilometres will be limited by the time required for information to propagate between nodes. In a joint-theory experiment, we analysed protocols that are able to circumvent the bottleneck by employing multi-qubit nodes and multiplexing (*Quantum Science and Technology*, 2017).

Furthermore, we have released SimulaQron, a simulator written to provide an essential tool for software development for a quantum internet. Specifically, SimulaQron delivers a distributed simulation of several quantum processors, connected by simulated quantum communication channels. It can be used as a tool for software development in all areas ranging from the implementation of the actual applications, development of application-level abstractions and programming libraries, to exploring the implementation of a quantum network stack. (http://www.simulaqron.org)

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INAUGURAL SPEECH PROFESSOR STEPHANIE WEHNER

Quantum Internet

QINC roadmap leader Stephanie Wehner was appointed by TU Delft as an Antoni van Leeuwenhoek professor of quantum engineering, within the faculty of Electrical Engineering, Mathematics and Computer Science, at the end of 2016. These chairs are intended to allow the promotion of bright young minds to professorships. In October 2017, she gave her inaugural speech.

Professor Wehner's goal is to create the very first quantum internet in TU Delft. 'We want to realise a quantum internet connecting quantum processors via long-distance quantum communication. Our long-term vision is to build a quantum internet matching the internet of today. This quantum internet will enable long-range quantum communication to achieve unparalleled capabilities that are impossible to prove using only traditional means.'

Wehner explicitly calls computer science students into action: 'In the absence of quantum devices in the real world, mathematical analysis is the only way to argue about quantum technologies. In the future, we will see a new form of quantum computer science. It will integrate ideas from computer science with intimate knowledge of quantum information to test and control quantum devices. And, as small quantum devices become available, I expect we will see the development of many heuristic algorithms, as is indeed the case in classical computing. So, a call to all the students, as there is only one big obstacle: the lack of quantum computer scientists ready to take on this new adventure.'

Topological Quantum Computing

> ROADMAP LEADER: **MICHAEL WIMMER**

Topological Quantum Computing (TOPO) - The focus of the TOPO roadmap is to develop, build and demonstrate the first topologically protected quantum bit based on Majorana-bound states. We continued our efforts in combining material science, theory, and novel device design to obtain more control of the underlying constituents of the topological qubit.

In 2017, the TOPO roadmap developed and characterised novel material systems tailored to create and control Majorana-based quantum bits. The size of the topological gap is of particular importance for the protection of the topological qubit and benefits from a strong Rashba spin-orbit strength. We observed, for the first time, a direct signal of this spin-orbit interaction in the form of a helical gap in the quantum point contact conductance of InSb nanowires. This also allowed us a quantitative characterisation of the spin-orbit strength (*Nature Communications*, 2017).

The formation of Majorana-bound states in nanowires requires the application of a magnetic field. It is then beneficial to work with materials with large g-factors. We showed theoretically how the device geometry could give rise to strongly enhanced g-factors, explaining previous experimental data and allowing for new device design principles (*Physical Review Letters*, 2017). Having a hard superconducting gap without subgap states is essential for topologically protected qubit operations. By combining material science and novel process development, TOPO achieved several breakthroughs in 2017.

First of all, through careful optimisation of the fabrication process, we achieved excellent gap hardness in the established InSb/NbTiN material system. The combination of transport measurements and theoretical simulations allowed us to prove that these devices were very clean and that the superconductivity has a ballistic nature. With this improved device design, we observed very clear transport signatures of Majorana-bound states (*Nature Communications*, 2017; *Nano* 2017; and *Nature Nanotech.*, 2018).

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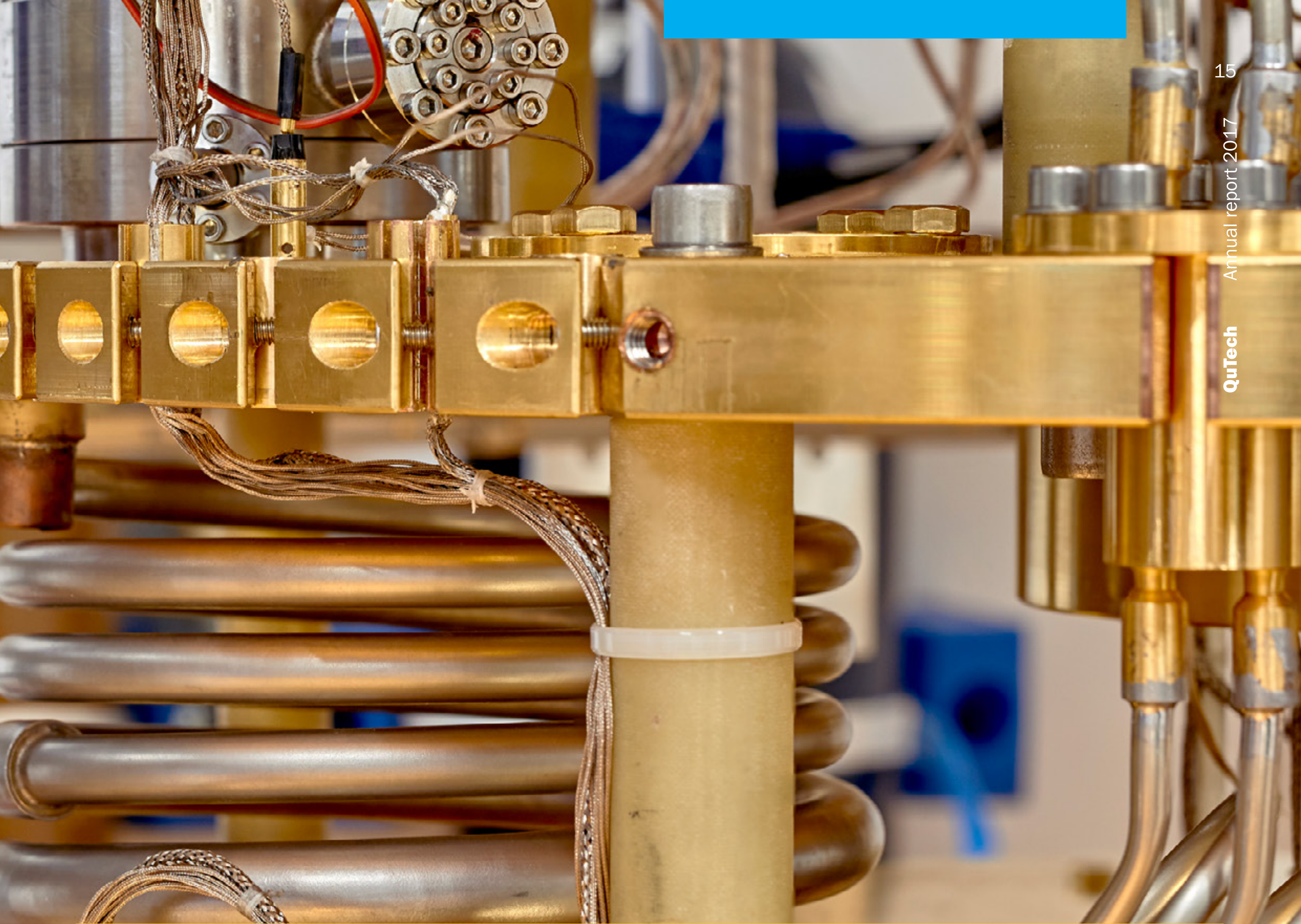
>> For an alternative approach, we intensified collaborations with the University of California, Santa Barbara and Eindhoven University of Technology. In this collaboration, we developed a new material system: InSb nanowires with an epitaxial aluminium shell. Using this approach, we obtained a gap of unsurpassed hardness. This allowed us to observe for the first time the theoretically predicted quantisation of the conductance due to Majorana-bound states, a clear indication of the quality of these devices. In addition to that, our approach also allowed us to successfully grow wire networks, a prerequisite for qubit operations (*Nature*, 2017; *Nature*, 2018).

In 2017, TU Delft entered a formal collaboration agreement with Microsoft regarding research on topological quantum computing. This collaboration has already led to many interactions between Microsoft and QuTech researchers. It also serves as an incubator for additional collaborations, such as with the University of Copenhagen and with Purdue University in the USA. These collaborations provide access to novel materials such as two-dimensional electron gases with epitaxial superconductors, or selected area-grown complex nanowire networks. With these novel systems and the established platforms, we will continue our path in 2018 towards the topological quantum bit.

Photo credit:
Pim Top



NEW SENIOR RESEARCHER

Srijit Goswami

Srijit Goswami is a tenure-track team leader within the topological quantum computing roadmap in QuTech. During his graduate studies, he studied electrical and thermoelectric transport in low-dimensional systems in semiconductor two-dimensional electron gases. Funded by the Gates-Cambridge Scholarship, he received his PhD from the University of Cambridge in 2011.

As a postdoctoral researcher at the Indian Institute of Science and TU Delft, Srijit studied mesoscopic transport and superconductivity in two-dimensional systems such as semiconductor quantum wells, oxide interfaces and graphene.

Srijit's group aims to use semiconductor-superconductor hybrids to develop scalable two-dimensional platforms for Majorana-based topological quantum computing.

Shared Development

> ROADMAP LEADER: **GARRELT ALBERTS**

Shared Development (SD) — In the SD roadmap, technology developments are managed for the three mission-driven roadmaps of QuTech. Furthermore, the SD roadmap facilitates the taking of quantum technology to market (technology push) and constitutes a portal to QuTech for third parties who want to access state-of-the-art quantum technology (technology pull).

TOPO – We developed new technologies to create a Majorana device, which can act as a very stable and scalable qubit. Nanowires are a critical component of quantum computers based on Majorana quasiparticles. In 2015, a new and very advanced system for material deposition was installed in the cleanroom in Delft. This unique MBE/ALD setup for the growth of semiconductor nanowires has been installed and tested in the Van Leeuwenhoek Laboratory. In 2016, as a first proof-of-concept, the MBE was successfully used to grow InAs nanowires. Now, in 2017 we demonstrated in-plane InAs nanowires by selective area growth (SAG). Furthermore, we performed detailed studies on materials and nano-fabrication workflows, such as a 3D substrate fabrication that results in the manufacturing of complex nanowire networks.

FT – To measure and control of the newest 17- and 49-superconducting Transmon qubit devices, we developed a new technology. This technology is the next generation in the successful vector switch matrix, designed and built for qubit control by frequency reuse. Two prototype QWG devices (Quantum Waveform Generator, dedicated to quantum control) were finalised. On the spin-qubyte device, a 5-dot system was created for the first time. We developed tools for measuring and using virtual gate matrices and the work on the automatic tuning of tunnel barriers was completed.

QINC – We demonstrated the feasibility of technology that converts the frequency of single photons from an NV-centre to telecommunication wavelength. The integration of microwave lines in qubit cavities was successful, and essential for qubit control. The implantation of nitrogen-vacancy centres on predefined locations in a diamond was achieved, which opens new roads towards isolated quantum memories. Furthermore, we developed NetSQUID, a quantum network simulator for researching quantum internet protocols.

With the ultimate goal to enable a worldwide quantum network using satellites to connect quantum nodes on the ground, we started the Quantum in Space activity. The first step was successfully executed in 2017: a study consisting of a thorough investigation of existing QKD protocols and free-space systems, requirements, missions concepts and architectures, as well as a market and stakeholder analysis to find common needs and potential partners.

Prototype Demonstrator and Development

We defined a fully functional and architectural breakdown for a full-stack prototype quantum computer as well as a quantum internet demonstrator. Furthermore, we supported the development of the Quantum Infinity demonstrator. The Quantum Infinity is a full-stack quantum computer demonstrator on which simple quantum algorithms can be executed on a 2-qubit Transmon processor as well as on a 2-qubit electron-spin processor.

Bringing quantum technology to society

Quantum Technology development support for the Intel and the QuSurf projects continued in 2017. For the Dutch Defense department, several consultancy activities related to Quantum Computing, Communication and (post-) Quantum Cryptography were performed. We started a cooperation with SurfSara on making Quantum Technology available to the Dutch academic society. First step is to make QuTech's quantum simulators (QX and NetSquid) available by porting these simulators to SurfSara's national supercomputer.

Photo credit:
Marieke de Lorijn

QuTech Academy

> ROADMAP LEADER: **MENNO VELDHORST**

The QuTech Academy strives to provide top-quality education in order to bring about generations of excellent quantum scientists, to inform the public and policymakers about quantum technology, and to further quantum information science across the globe.

Last year, a series of four courses were given at TU Delft introducing students to the field of quantum technology. These courses provide the fundamentals of quantum information, teach about quantum communication and cryptography, and introduce students to the required quantum hardware to realise a quantum computer and quantum internet. Online courses, 'MOOCs', were provided and focused on principles of quantum cryptography and introduced students to the area of topological matter. A new MOOC is currently being finalised, which will start in early 2018 and will provide an overview of the challenges and opportunities that exist in developing quantum computers and quantum internet.

Detailed information regarding on-campus and online courses can now be easily found via the new QuTech Academy website, along with exciting opportunities for masters projects and past student projects.

ON-CAMPUS

Quantum Communication & Cryptography

by Stephanie Wehner

Students who have learned the fundamentals discover how quantum communication can be used to solve cryptographic problems. This course explained some of the most well-known quantum cryptographic protocols, such as quantum key distribution. Students were taught how general quantum cryptographic techniques could be used to design and analyse quantum protocols at large.

ON-CAMPUS

Electronics for Quantum Computation

by Carmina G. Almudever and Fabio Sebastiano

To make a quantum computer and quantum internet function, we also need traditional hardware and software to control and instruct the quantum device. In this class, students learned about the relevant concepts while practising to interface with a quantum computer.

MOOC

Quantum Cryptography

by Stephanie Wehner and Thomas Vidick

Stephanie Wehner and Thomas Vidick, assistant professor in Computing and Mathematical Sciences at the California Institute of Technology, created this interdisciplinary course as an introduction to the exciting field of quantum cryptography. The course answers the question 'How can you tell a secret when everyone can listen in?'. Participants learned how to use quantum effects, such as quantum entanglement and uncertainty, to implement cryptographic tasks with levels of security that are impossible to achieve classically.

ON-CAMPUS

Quantum Hardware

by Ronald Hanson and Lieven Vandersypen

This class delved into how qubits and quantum operations can be realised in real quantum hardware. Students learned the critical challenges in achieving quantum hardware and technology. The course provided an overview of the current state of the technology and explained the most promising approaches to realising quantum hardware. A critical assessment of the strengths and weaknesses of each approach followed. Conceptual similarities and differences between the various technologies were also discussed.

ON-CAMPUS

Fundamentals of Quantum Information

by Leonardo DiCarlo and David Elkouss

In this intoductory class, students were taught the fundamentals of qubits, quantum gates and measurements. An introduction was given to quantum entanglement and applications such as quantum teleportation. Students learned how the best-known quantum algorithms exploit quantum information to achieve speedup in computation, as well as the basics of quantum error correction.

MOOC

Topology in Condensed Matter

by Anton Akhmerov

In collaboration with Maryland University, Anton Akhmerov created a course that provides a simple, hands-on overview of topological insulators, Majoranas and other topological phenomena.

Research

> HIGHLIGHTED PUBLICATIONS

Entanglement distillation between solid-state quantum network nodes

Photo credit:
Marieke de Lorijn

Researchers in Delft and Oxford have managed to distil a strong entangled link by combining multiple weaker quantum links into one. This method is essential to realise a trustworthy quantum network between several quantum nodes. This innovative new work has been published in Science magazine.

N. Kalb, A. A. Reiserer, P. C. Humphreys, J. J. W. Bakermans, S. J. Kamerling, N. H. Nickerson, S. C. Benjamin, D. J. Twitchen, M. Markham, and R. Hanson Science ***356****, 928 (2017)*

The demonstrated method is an important step towards the quantum internet. Norbert Kalb, one of the leading authors of the paper, explains: ‘To realise such a network, we need all the ingredients of the current internet: a memory, a processor and networking links. Now we have demonstrated that nuclear spins can be employed as memories that are not disturbed by regenerating entanglement between the electron spins, the processors.’

In this publication, Hanson and his team showed that entanglement can be stored in nuclear spins while regenerating entanglement between electron spins. Hanson explains the future possibilities: ‘We could now entangle electrons in additional quantum nodes such that we can extend the number of networking links towards a first real quantum network. Scientifically, a whole new world opens up.’ This entanglement distillation is essential for the future quantum internet, which requires multiple networking links of high quality. Hanson thinks the future is within reach: ‘In five years we will connect four Dutch cities in a rudimentary quantum network.’

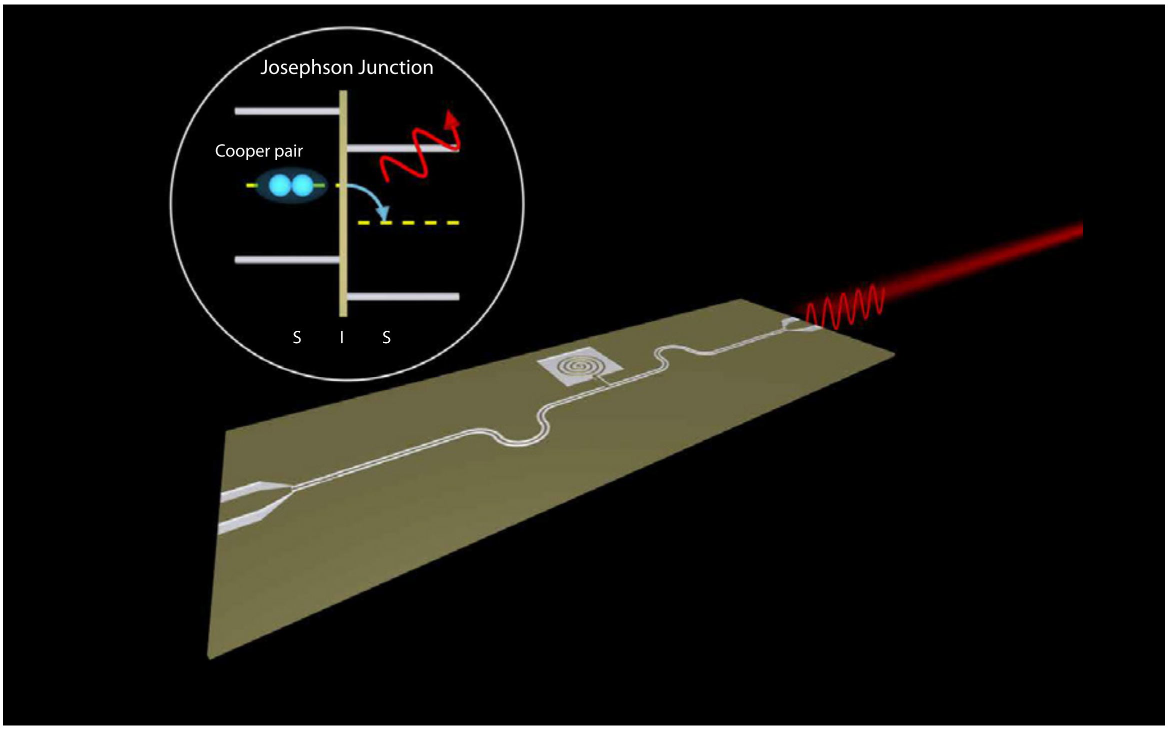
Demonstration of an AC Josephson junction laser

Lasers are everywhere nowadays: doctors use them to correct eyesight, cashiers to scan purchases, and quantum scientist to control qubits in the future quantum computer. For most applications, the current bulky, energy inefficient lasers are adequate, but quantum scientists work at extremely low temperatures and on microscopic scales. For over 40 years, they have searched for efficient and precise microwave lasers that won't disturb the extreme environment in which quantum technology works. A team of researchers led by Leo Kouwenhoven at TU Delft has demonstrated an on-chip microwave laser based on a fundamental property of superconductivity: the AC Josephson effect. They embedded a small section of an interrupted superconductor, a Josephson junction, in a carefully engineered on-chip cavity. Such a device opens the door to many applications in which microwave radiation with minimal dissipation is key, for example in controlling qubits in a scalable quantum computer. The scientists have published their work in Science.

M. C. Cassidy, A. Bruno, S. Rubbert, M. Irfan, J. Kammhuber, R. N. Schouten, A. R. Akhmerov, L. P. Kouwenhoven
Science **355**, *939–942 (2017)*

Low-loss quantum control

Efficient sources of high-quality coherent microwave light are essential in all current designs of the future quantum computer. Microwave bursts are used to read out and transfer information, correct errors and access and control the individual quantum components. While current microwave sources are expensive and inefficient, the Josephson junction laser created at QuTech is energy efficient and offers an on-chip solution that is easy to control and modify. The group is extending their design to use tunable Josephson junctions made from nanowires to allow for microwave burst for fast control of multiple quantum components. In the future, such a device may be able to generate so-called 'amplitude-squeezed' light which has smaller intensity fluctuations than conventional lasers and is essential in most quantum communication protocols. This work marks an important step towards the control of large quantum systems for quantum computing.



T. Hensgens, T. Fujita, L. Janssen, Xiao Li, C. J. Van Diepen, C. Reichl, W. Wegscheider, S. Das Sarma & L. M. K. Vandersypen
Nature **548**, *70–73 (2017)*

Quantum simulation of a Fermi-Hubbard model using a semiconductor quantum dot array

Quantum behaviour plays a crucial role in novel and emergent material properties, such as superconductivity and magnetism. Unfortunately, it is still impossible to calculate the underlying quantum behaviour, let alone fully understand it. Scientists of QuTech, the Kavli Institute of Nanoscience in Delft and TNO, in collaboration with the ETH Zurich and the University of Maryland, have now succeeded in building an 'artificial material' that mimics this type of quantum behaviour on a small scale. In doing so, they have laid the foundations for new insights and potential applications. Their work is published in Nature.

Photo credit:
Marieke de Lorijn

Partnerships

Photo credit:
Pim Top

Microsoft and TU Delft collaboration officially starts

Microsoft and TU Delft have officially started their renewed long-term collaboration: Microsoft and TU Delft's quantum institute QuTech will be collaborating intensively on the development of topological qubits, which have the potential to become the building blocks of a future quantum computer. As part of the collaboration, in the second half of 2018, Microsoft will open its own lab on campus, 'Station Q Delft', led by Prof. Leo Kouwenhoven, employed by Microsoft as of the end of 2016. In this public-private partnership, QuTech and Microsoft aim to build topological quantum bits into a working quantum computer.

Tim van der Hagen, president of the Executive Board of TU Delft, is also pleased with the new partnership: 'Microsoft is now coming to our campus in Delft and will be investing heavily in staff and facilities. This will not only give a major boost to our research but will also help us to attract the very best scientists and students to Delft. We will be able to build further on the Netherlands' leading role in quantum technology, with the TU Delft campus at the heart of it all.'

The celebration of the new partnership took place in attendance of Henk Kamp, Minister of Economic Affairs and ambassador of National Icon QuTech.

Photo credit:
Roy Borghouts

Quantum Internet Alliance

The quantum internet cooperation is between QuTech, The Institute of Photonic Sciences, the University of Innsbruck and The Paris Centre for Quantum Computer. A 'Letter of Intent' was signed by all parties on the 9th of October 2017. A 'Memorandum of Understanding' between QuTech and the Paris Centre for

Photo credit:
Marieke de Lorijn

New Quantum Helix initiative entangles researchers and companies in 'Vision2020'

On 9 October 2017, professor Stephanie Wehner kicked-off the Quantum Helix initiative at QuTech in Delft. This initiative, within the Horizon 2020 program, opens the door to an active community linking researchers and companies on quantum information technology. The Quantum Helix is supported by the FET Quantum Flag-

Quantum Computing (PCQC) was announced. These agreements represent a pioneering step towards the Quantum Internet Alliance within the EU FET Quantum Flagship call. The long-term ambition of this quantum internet alliance is to build a large-scale quantum internet that ultimately allows quantum communication between any two points on earth.

Delft, Aachen and Jülich join forces to build scalable quantum technologies

QuTech, Forschungszentrum Jülich and RWTH Aachen University (both partners in the Jülich Aachen Research Alliance (JARA)) have intensified their collaboration through an official agreement signed in April 2017. The partners aim to enhance scientific and technical developments in the field of solid-state quantum computing and unitise joint activities in the context of the EU FET Quantum Flagship on quantum technologies.

The signed agreement is a step towards strong collaborations between two of Europe's key players in solid-state quantum information processing (QIP) and high-performance computing (HPC).

ship, in which QuTech is highly involved.
QuTech is proud to have created the Quantum Helix to generate an approachable network in quantum research and engineering. As a recognised scientific member of the quantum community, Professor Stephanie Wehner will lead the Quantum Helix.

QuTech – Intel collaboration continues successfully

In 2015, QuTech and the US-based chip manufacturer Intel Corporation started a 10-year collaborative relationship to accelerate advancements in quantum computing.

The combination of the expertise of both Intel engineers and QuTech scientists has already shown to be successful: at the end 2017, Intel delivered a co-created 17-qubit superconducting test chip, shortly followed by a 49-qubit test chip. Furthermore, to control both superconducting qubits and spin qubits, QuTech and Intel collaborated in the development of an integrated cryogenic control chip.

Outreach

Photo credit:
Judith de Keijzer

Quantum Software Consortium receives 18.8 million euro in the Gravitation Program

The Ministry for Education, Culture and Science has awarded a 'Gravitation grant' for large-scale research in quantum software. This grant of 18.8 million euros unites researchers from QuSoft, CWI, Leiden University, QuTech, TU Delft, UvA and the VU in pursuing state-of-the-art research programs in this emerging field. The Gravitation grants, awarded by Minister Jet Bussemaker, reach a total sum of 112.8 million euros and give world-class Dutch scientists the opportunity to carry out innovative research with the potential of yielding revolutionary breakthroughs. The Quantum Software Consortium unites researchers from computer science, mathematics and physics to develop and demonstrate such quantum software.

Tim Taminiau receives NWO Vidi grant

Tim Taminiau has been awarded a 'Vidi grant' by the NWO (Netherlands Organization for Scientific Research) for his work on the protection of quantum computations. The NWO grants experienced researchers 800,000 euros to develop an independent and innovative line of research.

Tim Taminiau will focus on the fault-tolerant protection of quantum information by storing the information in multiple quantum bits within diamond quantum processors. Making quantum information tolerant to errors is essential for large-scale quantum computations. The results of the research will provide experimental insights into possibilities and limitations of fault-tolerance and error correction under realistic noise in quantum systems. Furthermore, the experimentally developed multi-qubit diamond processors will be powerful building blocks for future quantum networks.

Photo credit:
Bob Bronshoff

John Stewart Bell Prize awarded to Ronald Hanson

The 2017 biennial 'John Stewart Bell Prize for Research on Fundamental Issues in Quantum Mechanics and Their Applications' has been awarded to Professor Ronald Hanson of TU Delft/QuTech. The prize is named after John Stewart Bell, who in 1964 came up with a famous test for proving the existence of quantum entanglement. It was the French scientist Alain Aspect who first succeeded in carrying out the Bell test, in 1982, but at the time two important loopholes remained that allowed alternative explanations for the measurement result.

Ronald Hanson received the prize on the 31 August 2017, together with Sae Woo Nam (NIST/VS), and Anton Zeilinger (University of Vienna), for their experiments demonstrating that instantaneous interaction between entangled quantum particles exists. In 2015, Hanson's group was the first to demonstrate this entanglement without loopholes (possible alternative explanations for this physical phenomenon). Shortly after this, independent experiments in the USA and Vienna confirmed the result.

Ronald Hanson receives ERC Consolidator Grant

Ronald Hanson received 1.63 million euros for his ‘QNETWORK’-project. Hanson plans to realise the first multi-node network based on quantum entangled links.

The QNETWORK project, now funded by the European Research Council (ERC), connects multiple spin nodes in diamond defects via single-photon links. Professor Hanson: ‘I will study fundamental physics of multi-particle entanglement in these hybrid quantum systems and demonstrate a network based on fully controlled multi-qubit nodes.’

Outreach highlights

3

MARCH 2017

Quantum Night with Leo Kouwenhoven and Julia Cramer

https://youtu.be/wH3sZ6km2ts

7

JULY 2017

Book release “De Quantumcomputer” by George van Hal (New Scientist)

8

AUGUST 2017

Quantum Revolution at Lowlands

Ronald Hanson (QuTech, TU Delft) and Harry Buhrman (CWI, QuSoft and UvA).

10

OCTOBER 2017

Quantum Physics Meets Intel Engineering

Unboxing the Intel 17-qubit superconducting chip with Leonardo DiCarlo (QuTech) and Dave Michalak (Intel)

https://youtu.be/qEvrPYmvBIY

11

NOVEMBER 2017

Gala van de Wetenschap in Amsterdam

— with Ronald Hanson and Julia Cramer

12

DECEMBER 2017

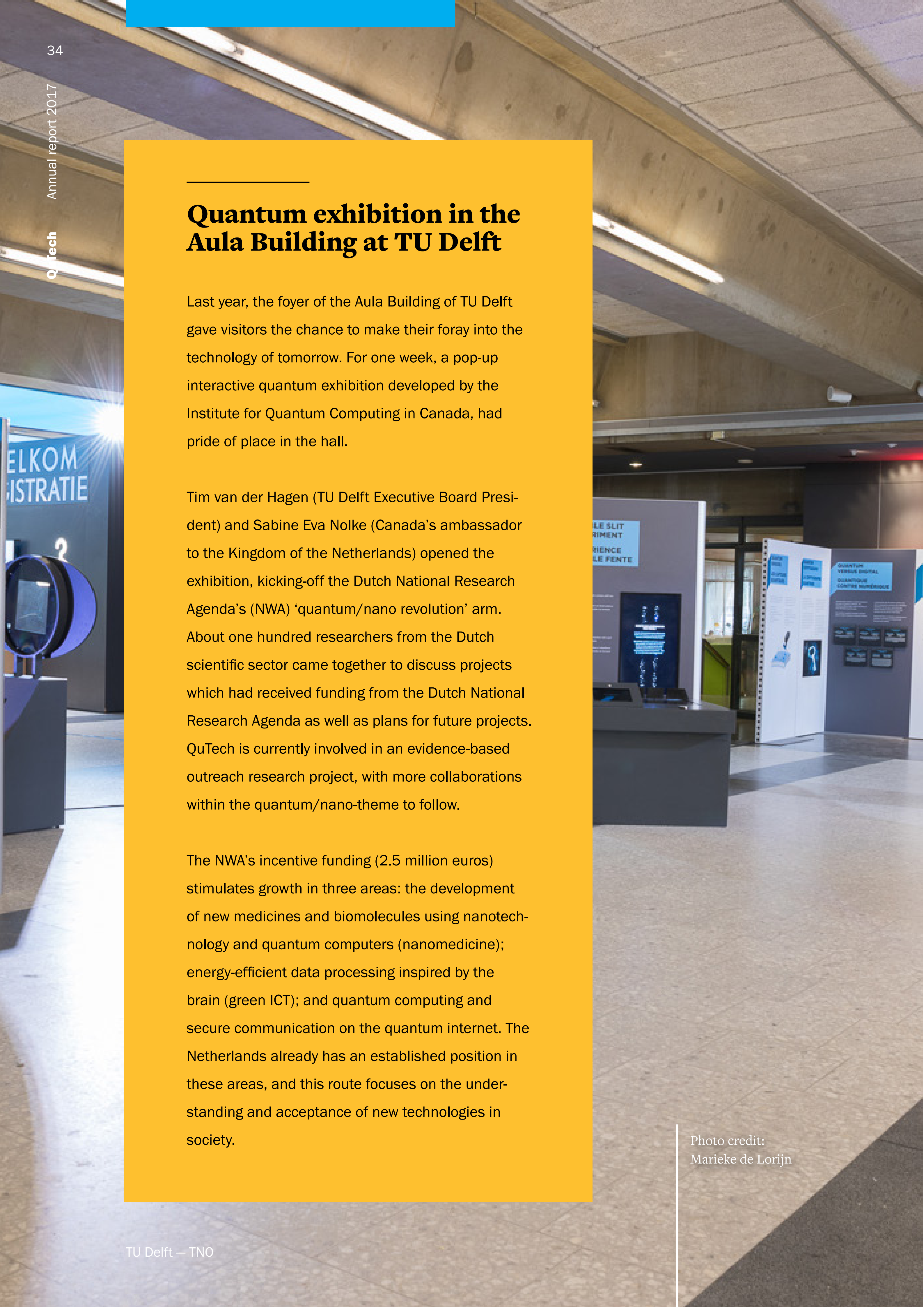
Quantum chips in Museum Boerhaave Leiden

12

DECEMBER 2017

The Quantum Internet by Stephanie Wehner at TEDx Vienna

https://youtu.be/XzPi29O6DAc



Quantum exhibition in the Aula Building at TU Delft

Last year, the foyer of the Aula Building of TU Delft gave visitors the chance to make their foray into the technology of tomorrow. For one week, a pop-up interactive quantum exhibition developed by the Institute for Quantum Computing in Canada, had pride of place in the hall.

Tim van der Hagen (TU Delft Executive Board President) and Sabine Eva Nolke (Canada's ambassador to the Kingdom of the Netherlands) opened the exhibition, kicking-off the Dutch National Research Agenda's (NWA) 'quantum/nano revolution' arm. About one hundred researchers from the Dutch scientific sector came together to discuss projects which had received funding from the Dutch National Research Agenda as well as plans for future projects. QuTech is currently involved in an evidence-based outreach research project, with more collaborations within the quantum/nano-theme to follow.

The NWA's incentive funding (2.5 million euros) stimulates growth in three areas: the development of new medicines and biomolecules using nanotechnology and quantum computers (nanomedicine); energy-efficient data processing inspired by the brain (green ICT); and quantum computing and secure communication on the quantum internet. The Netherlands already has an established position in these areas, and this route focuses on the understanding and acceptance of new technologies in society.

Photo credit:
Marieke de Lorijn

Photo credit:
Marcel Krijger

Julia Cramer wins the NWO Minerva Prize for 2017

Julia Cramer is the winner of the NWO's 'Minerva Prize' for 2017. Cramer received the prize for her research in the field of quantum science and technology. Once every two years, the NWO Domain Science (ENW) awards the prize for the best physics publication by a female researcher. The committee was very impressed by the quality of an article that appeared in Nature Communications, in 2016, of which Cramer was lead author. In that article, she and her co-authors showed that it is possible to protect certain quantum states against errors.

The biennial Minerva Prize for the best physics publication by a female researcher is part of the NWO Physics/f incentive programme. The prize aims to bring excellent female physicists into the limelight and to boost the career of the laureate.

Bas Hensen wins prize for best physics thesis

Bas Hensen has won the NWO's 'Physics Thesis Award' 2017 with his thesis 'Quantum Nonlocality with Spins in Diamond'. In his thesis, Hensen – who conducted his PhD research at QuTech – outlines the world's first loophole-free Bell test. The test provided conclusive proof of the existence of quantum entanglement.

NWO Rubicon grant

Bas Hensen was also awarded an NWO 'Rubicon grant'. With this grant, he is continuing his academic career as a postdoctoral research fellow at the Centre for Quantum Computation and Communication Technology at the University of New South Wales, Australia.

Organisation

Photo credit:
Frank van der Burg

Governance

The governance model of QuTech in 2017 is shown in Figure 1. The colours of the arrows and boxes indicate ‘supervision’, ‘ownership’, ‘performance’, ‘justification’, ‘steering’, ‘advising’ and ‘executive power’.

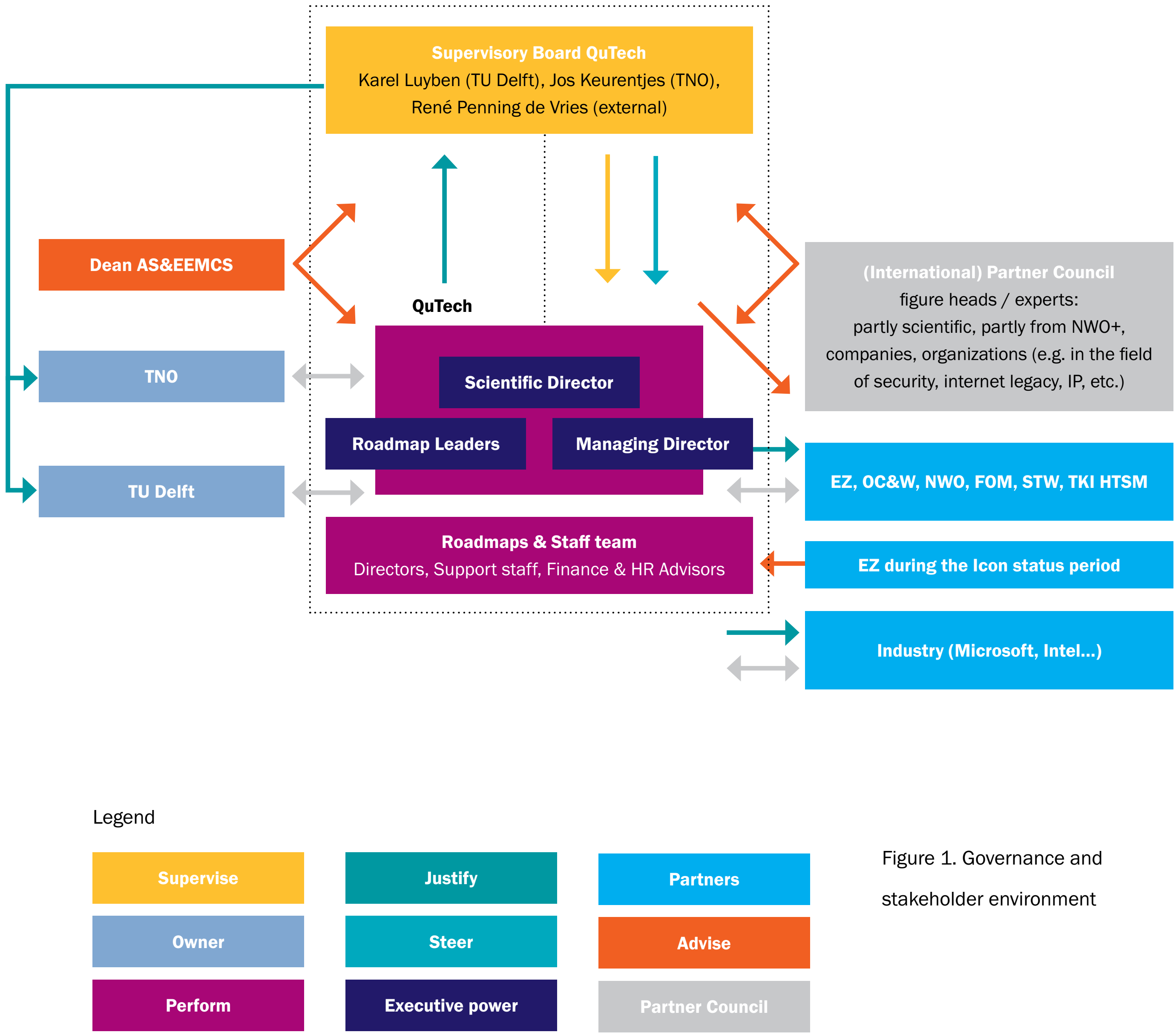
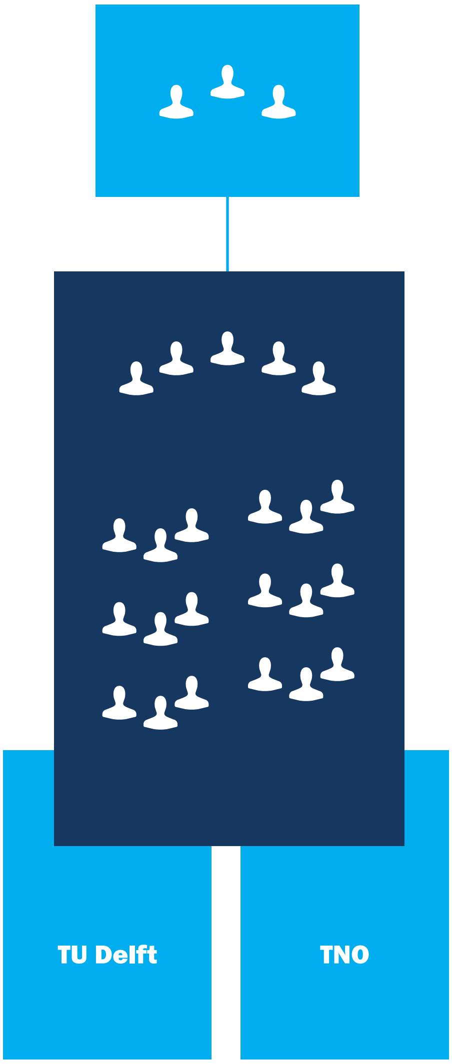


Figure 1. Governance and stakeholder environment

QuTech is organised around 'roadmaps', as shown in Figure 2. A large part of the activities takes place within these roadmaps. General support is organised centrally. Each roadmap has a roadmap leader (RL), who is responsible for the principal investigators (PIs, both from TNW and EWI faculties), postdocs, PhD candidates, MSc students, engineers and roadmap-dedicated technicians.



Supervisory Board: Karel Luyben, chair (Rector Magnificus TU Delft), Jos Keurentjes (Chief Scientific Officer TNO), René Penning de Vries (Figure Head ICT of the Ministry of Economic Affairs)

Roadmap Leaders: Leonardo DiCarlo, Michael Wimmer, Lieven Vandersypen, Garrelt Alberts, Stephanie Wehner, Menno Veldhorst

QuTech Faculty: about ~30 members (scientists)

Management and staff:

- Scientific Director: Ronald Hanson
- Managing Director: Kemo Agovic
- Management Support staff: ~10
- Technical staff: ~20

Figure 2. QuTech governance, roadmap leaders, staff

Roadmaps are organised as illustrated by example in Figure 3, where the roadmap consists of a specific amount (n) of clusters led by a principal investigator (PI). There are two categories of senior scientists: team leaders and group leaders. Group leaders have more extensive supervision responsibilities. In practice, a person can work within several roadmaps. The coloured dots show the (current) contributions over the boundaries of the roadmaps.

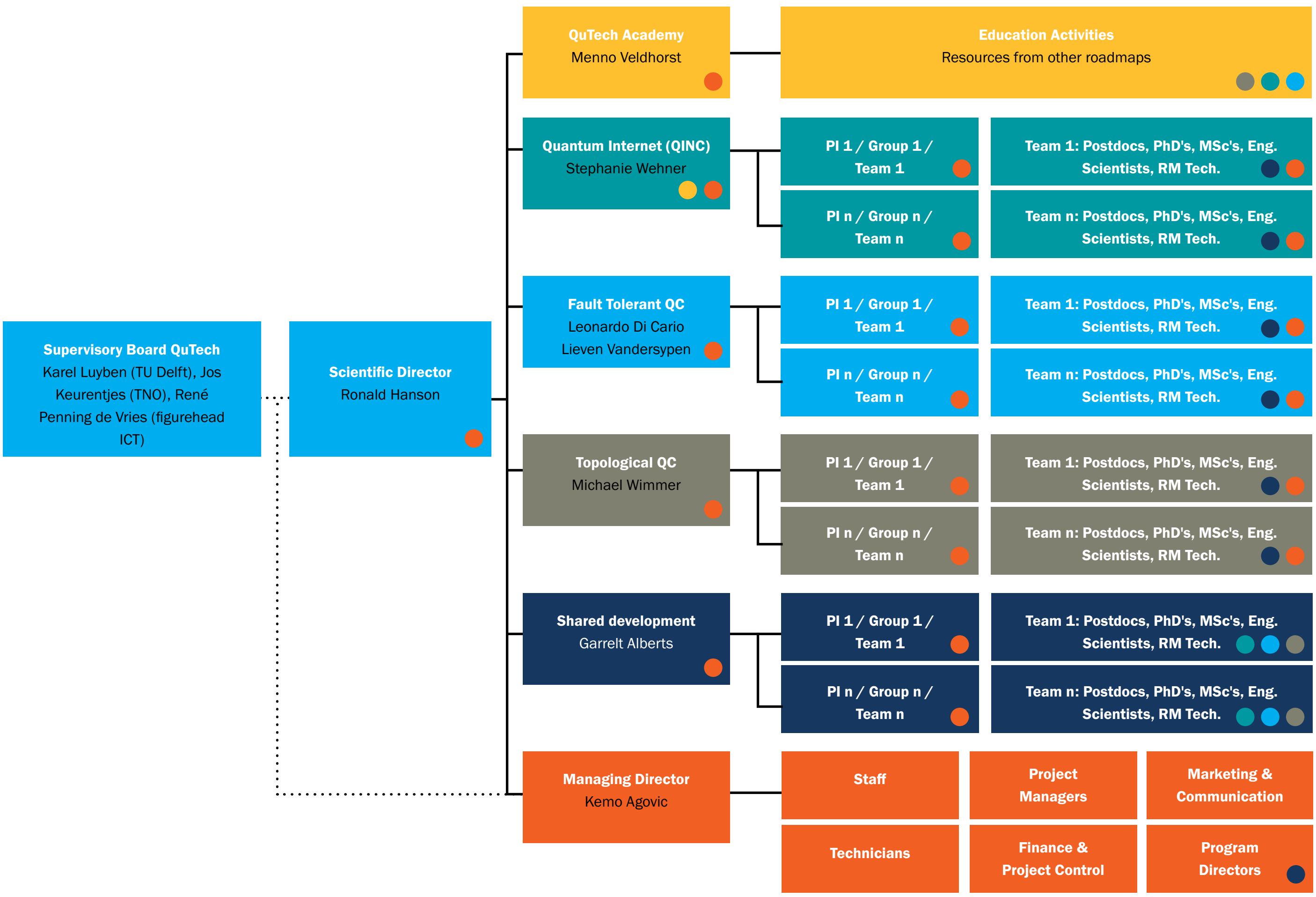
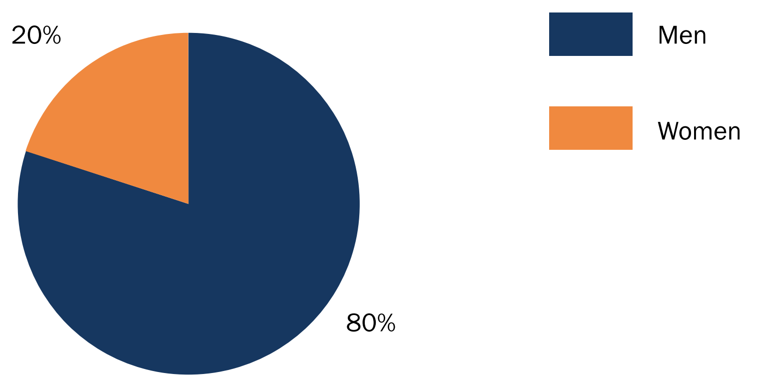


Figure 3: Organogram QuTech 2017

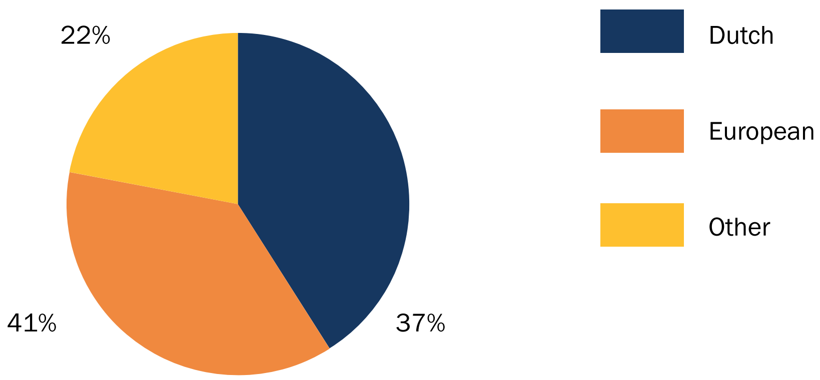
Statistics/graphics

In December 2017, 180 people worked for QuTech. This number is expected to increase over the coming years to about 340.

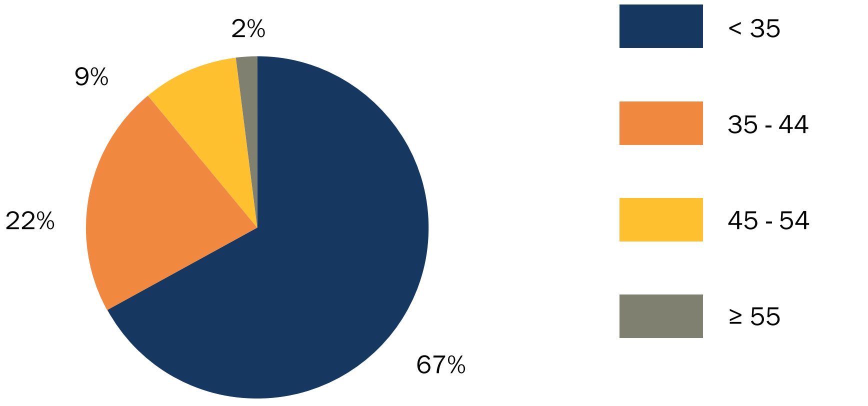
Gender



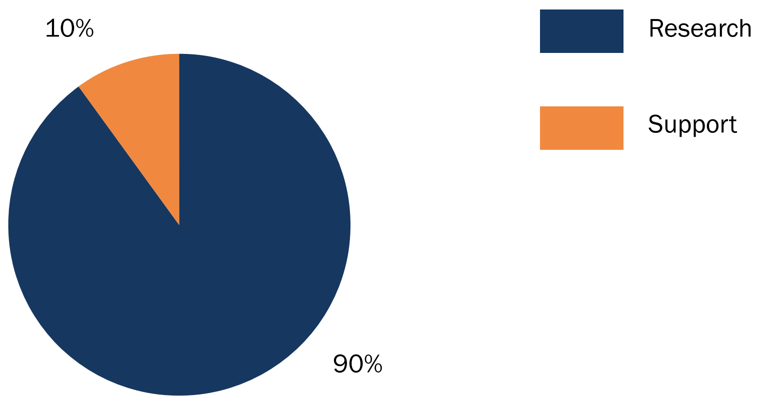
Nationality



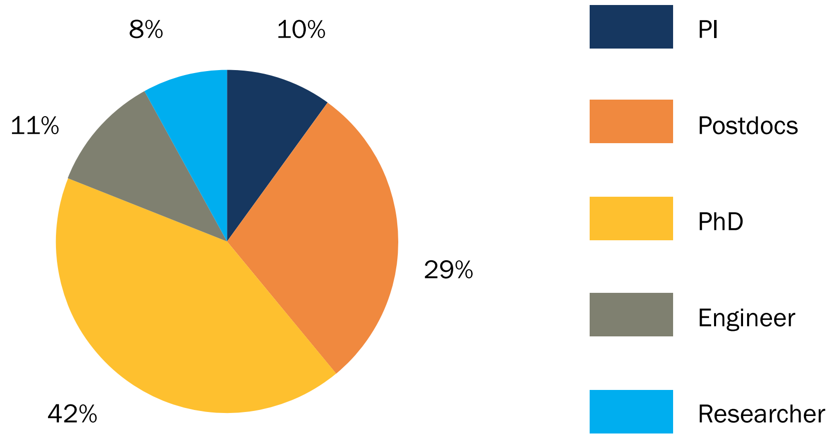
Age structure



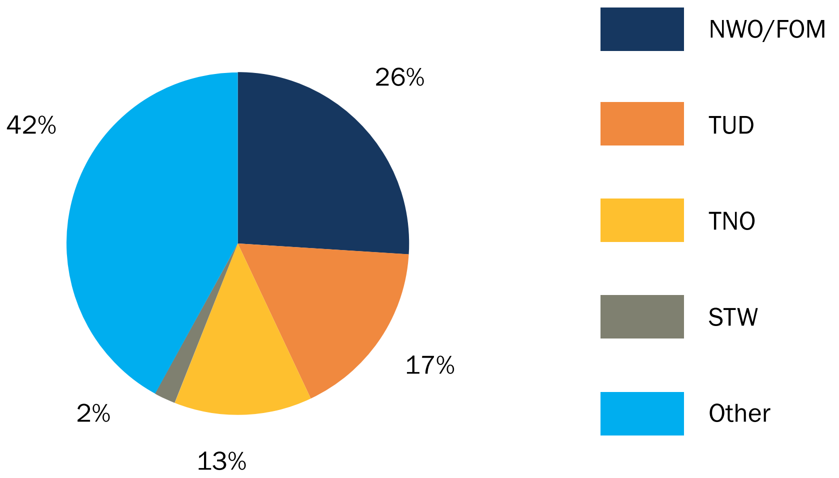
Ratio Research / Support staff



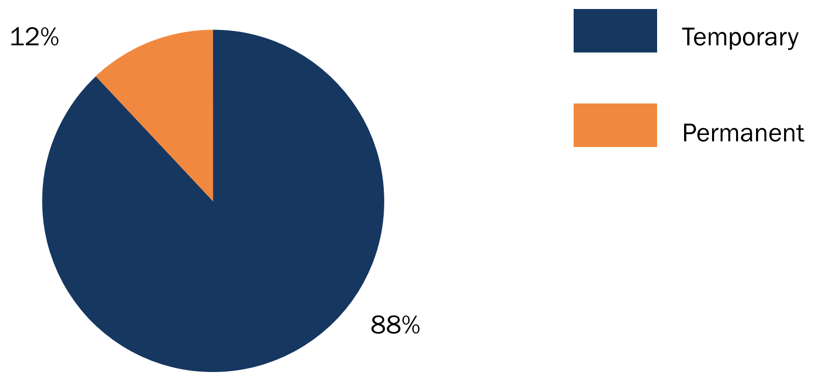
Type of research staff



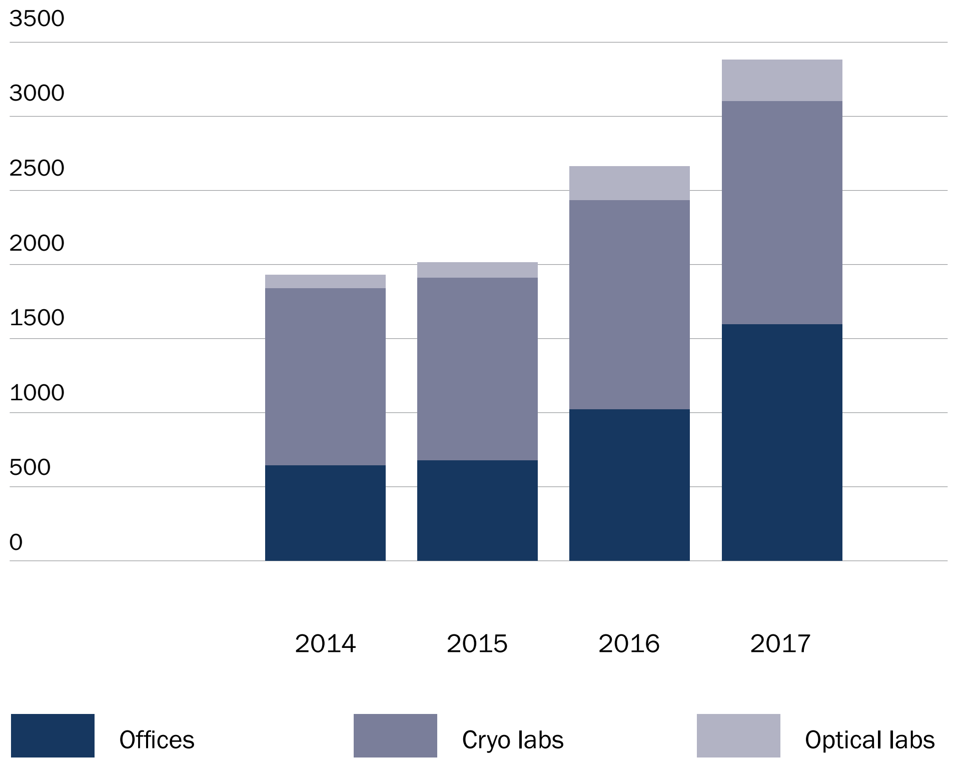
Staff funding source



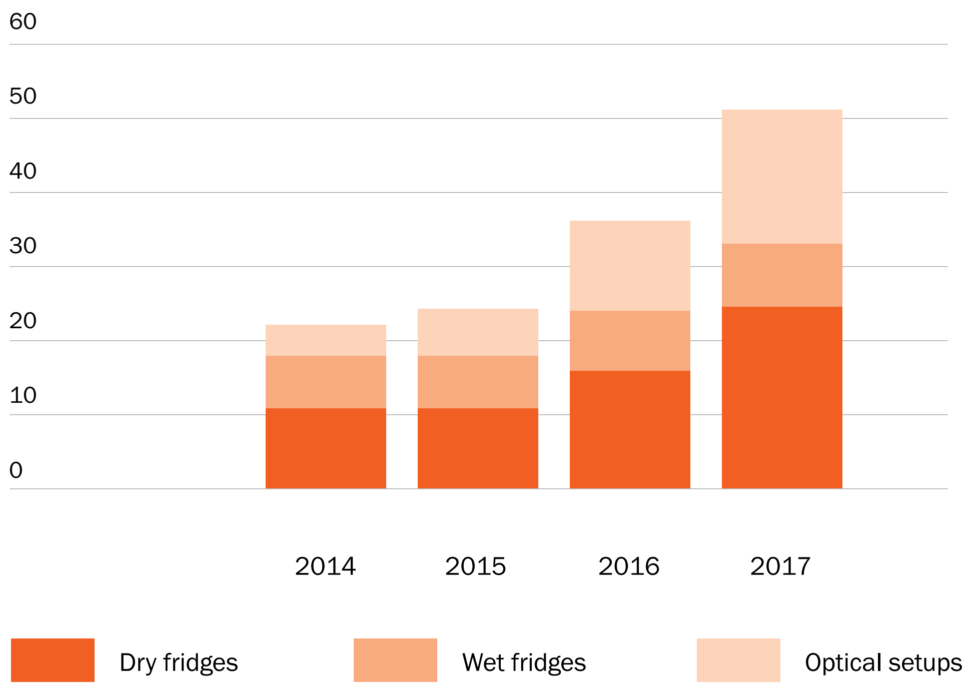
Temporary/ Permanent contract



Growth (m²) in lab and office spaces



Number of experimental setups



Financial overview

FUNDING AND EXPENSES

Photo credit:
Kim van Dam

This section provides further information regarding QuTech's finances, based on the framework of a partnerconvenant established in 2015. It includes the following partners:

- The Ministry of Economic Affairs (EZ)
- The Ministry of Education, Culture and Science (OCW)
- The Netherlands Organization for Applied Scientific Research (TNO)
- Delft University of Technology (TU Delft)
- The Netherlands Organisation for Scientific Research (NWO, including former FOM
- organisation)
- NWO Applied and Engineering Sciences (formerly technology foundation STW)
- TKI Holland High Tech (formerly the Foundation TKI High Tech Systems and Materials)

The partners agreed to financially support QuTech for the 10-year period June 2015 – June 2025. Allocation of the 2020-2025 budgets take place after evaluation in 2018.

This financial overview does not take funding from other grant providers or partners (Microsoft, Intel) into account.

Funding from the Partnerconvenant supports the QuTech goals: to develop the knowledge and technology for quantum computers and quantum internet and build a multiform ecosystem in the Netherlands with national and international partners.

Scientific, engineering and support staff at QuTech, as well as all operating budgets and investments, are currently funded through four primary sources:

1. TU Delft
2. TNO
3. Industry funding
4. EZ, HTSM TKI, NWO/FOM and NWO/TTW (formerly STW).

In addition to funding from the above contributing parties, QuTech researchers receive funding for PhD students, postdocs, running budgets and investments via research grants applied for through the NWO, European Union (ERC grants, FP7 and H2020 grants), IARPA, ARO, etc.

The 10-year budget established in 2015 included the following in-kind and in-cash contributions by partners:

TU Delft in-kind	29	M€
TU Delft in-cash	20	M€
TNO in-cash*	50.75	M€
NWO/FOM*	36.18	M€
STW in-cash	9.6	M€
Total	**145.53**	**M€**

**The HTSM TKI allowance is included in the budgets of TNO and NWO/FOM.*

TU Delft budget

The 10-year commitment of TU Delft includes the following contributions:

- In-kind contribution (29 M€)
  - Provided for housing, energy, clean-room, infrastructure and the professors/ researchers/ personnel of the faculties TNW and EWI.
- In-cash contribution (20M€)
  - Provided from the TU Delft strategy funds.

The budgeted in-cash contribution of TU Delft for 2017 (2 million euros) was allocated according to QuTech purposes (scientific and support staff, equipment). As foreseen in our 2016 annual report, the in-kind contribution for 2017 increased (13 million euros). Therefore, it is once again higher than the 3 million euros per year originally agreed upon in the Partnerconvenant (in 2016 the in-kind contribution had already increased to 8.9 million euros).

TNO budget

The 10-year TNO budget consists of:

- TNO strategic funds (29.75 million euros)
  - SMO (Samenwerkings Middelen Onderzoek) from the High Tech Systems and Materials roadmap and ICT roadmap
  - Early Research Programme
- EZ via TNO (11.75 million euros)
  - This is the EZ fund allocated for TNO for QuTech purposes
- TKI-allowance via TNO (9.25 million euros)
  - This is based on the contribution of 1 million euros/year from private companies

The budgeted contribution of TNO for 2017 was spent according to QuTech purposes within the 'Shared Development' roadmap. TNO personnel mainly contributed to the other roadmaps' goals.

NWO/FOM budget

The 10-year NWO/FOM budget consists of:

- NWO FOM (3.75 million euros plus a further 3.75 million euro intended).
  This budget is and will be largely spent on startups for three QuTech PIs (two senior researchers and one full professor).
- NWO FOM IPP (3.75 million euros plus a further 3.75 million euro intended)
  - This reflects the Industrial Partnership Programme with Microsoft, explicitly included in the Partnerconvenant according to the stipulation of EZ and HTSM partners for a private contribution exceeding 2 million euros/year in order to participate in QuTech. This budget is and will continue to be, used for 6 PhD positions, 6 postdoctoral years, one 5-year technician position and one senior researcher position, as

well as for materials and equipment required for the research within the programme. The private contribution funds another 8 PhD positions, 16 postdoctoral years, 10 technician years and a senior researcher year, as well as materials and equipment required for the research within the programme.

- TKI-allowance via NWO/FOM
  The TKI-allowance generated from the IPP project collaboration Microsoft-TU Delft-FOM, was intended to be routed via NWO/FOM. In 2017 QuTech, NWO/FOM and TKI HTSM agreed to grant the allowance directly to QuTech, where it will be spent on PhD and postdoctoral positions and running budgets as described in the research programme approved by TKI HTSM.

NWO-TTW budget (STW budget)

The 10-year NWO-TTW budget consists of:

- For the period 2014-2019 NWO TTW (STW) has granted 2.6 million euros. The budgeted costs (PhD's, materials, equipment, cleanroom, engineers) are partially spent. The remaining budget will be spent according to the plan on open research positions (PhD/PostDoc) and materials.
- Allocation of the 2020-2025 NWO-TTW budget takes places after (positive) evaluation in 2018.

TKIs explained

The Top Consortium for Knowledge and Innovation (TKI) facilitates the collaboration of 'Holland High Tech' (formerly 'High Tech Systems and Materials'), knowledge institutions and industrial organisations on a multi annual TKI programme based on public and private funding. A TKI programme includes fundamental research, industrial research, and experimental development, or a combination of these types of research. The Dutch Ministry of Economic Affairs stimulates the private-public collaboration between research organizations and industrial companies with TKI allowances. The basic principle is simple: for every euro that a private company invests in R&D at a knowledge institution, the Top Consortium for Knowledge and Innovation receives € 0,25 from the ministry. The TKI uses these revenues for new public-private research.

Appendices

Photo credit:
Ernst de Groot | Haalbeeld

List of peer-reviewed publications 2017

JANUARY

5 January 2017

Giant spin-orbit splitting in inverted InAs/GaSb double quantum wells

F. Nichele, M. Kjaergaard, H.J. Suominen, R. Skolasinski, M. Wimmer, B.-M. Nguyen, A.A. Kiselev, W. Yi, M. Sokolich, M.J. Manfra, F. Qu, A.J.A. Beukman, L.P. Kouwenhoven and C.M. Marcus

Physical Review Letters, 118, 016801 (2017)

10 January 2017

Side gate tunable Josephson junctions at the LaAlO 3/SrTiO 3 interface

A.M.R.V.L. Monteiro, D.J. Groenendijk, N. Manca, E. Mulazimoglu, S. Goswami, L.M.K. Vandersypen, A.D. Caviglia

Nanoletters 17, 715-72- (2017)

FEBRUARY

2 February 2017

An electrically-driven spin qubit based on valley mixing

W. Huang, M. Veldhorst, N.M. Zimmerman, A.S. Dzurak, and D. Culcer

Physical Review B 95, 075403 (2017)

8 February 2017

Entropic uncertainty relations and their applications

Patrick J. Coles, Mario Berta, Marco Tomamichel, and Stephanie Wehner

American Physical Society, Rev. Mod. Phys. 89, 015002 (2017)

20 February 2017

Quantum preparation uncertainty and lack of information

Filip Rozpędek, Jędrzej Kaniewski, Patrick Coles and Stephanie Wehner

New Journal of Physics, February 2017

MARCH

3 March 2017

Demonstration of an ac Josephson junction laser

M.C. Cassidy, A. Bruno, S. Rubbert, M. Irfan, J. Kammhuber, R.N. Schouten, A.R. Akhmerov, L.P. Kouwenhoven

Science 355, 939–942 (2017)

29 March 2017

Hard superconducting gap in InSb nanowires

Ö. Gül, H. Zhang, F.K. de Vries, J. van Veen, K. Zuo, V. Mourik, S. Conesa-Boj, M.P. Nowak, D.J. van Woerkom, M. Quintero-Pérez, M.C. Cassidy, A. Geresdi, S. Kölling, D. Car, S.R. Plissard, E.P.A.M. Bakkers and L.P. Kouwenhoven

Nano Letters 17, 2690-2696 (2017), DOI:10.1021/acs/nanolett.7b00540

APRIL

11 April 2017

Spin-orbit interaction in a dual gated InAs/GaSb quantum well

A.J.A. Beukman, F.K. de Vries, J. van Veen, R. Skolasinski, M. Wimmer, F. Qu, D.T. de Vries, B.-M. Nguyen, W. Yi, A.A. Kiselev, M. Sokolich, M.J. Manfra, F. Nichele, C.M. Marcus, L.P. Kouwenhoven

Phys. Rev. B 96, 241401 (2017)

24 April 2017

Design and low-temperature characterization of a tunable microcavity for diamond-based quantum networks

Stefan Bogdanović, Suzanne B. van Dam, Cristian Bonato, Lisanne C. Coenen, Anne-Marije J. Zwerver, Bas Hensen, Madelaine S. Z. Liddy, Thomas Fink, Andreas Reiserer, Marko Lončar, and Ronald Hanson

Appl. Phys. Lett. 110, 171103 (2017)

24 April 2017

Restless tuneup of high-fidelity qubit gates

M.A. Rol, C.C. Bultink, T.E. O'Brien, S.R. de Jong, L.S. Theis, X.Fu, F.Luthi, R.F.L. Vermeulen, J.C. de Sterke, A. Bruno, D. Deurloo, R.N. Schouten, F.K. Wilhelm, and L. DiCarlo,

Physical Review Applied, 7, 041001 (2017)

MAY

5 May 2017

Current-phase relation of ballistic graphene Josephson junctions

G.Nanda, J.L. Aguilera-Servin, P. Rakyta, A. Kormanyos, R. Kleiner, D. Koelle, K. Wtanabe, T. Taniguchi, L.M.K. Vandersypen, S. Goswami

Nano Letter 17, 3396 (2017)

17 May 2017

High-fidelity hot gates of generic spin-resonator systems

Martin.J.A. Schuetz, Geza Giedke, Lieven M.K. Vandersypen, J. Ignacio Cirac

Phys Review A 95, 052335 (2017)

18 May 2017

Dressed photon-orbital states in a quantum dot: Intervalley spin resonance

P. Scarlino, E. Kawakami, T. Jullien, D. R. Ward, D. E. Savage, M. G. Lagally, Mark Friesen, S. N. Coppersmith, M. A. Eriksson, and L. M. K. Vandersypen

Physical Review B 95, 165429 (2017)

JUNE

2 June 2017

Entanglement distillation between solid-state quantum network nodes

Norbert Kalb, Andreas A. Reiserer, Peter C. Humphreys, Jacob J. W. Bakermans, Sten J. Kamerling, Naomi H. Nickerson, Simon C. Benjamin, Daniel J. Twitchen, Matthew Markham, Ronald Hanson

Science 356, 928 (2017)

5 June 2017

Microwave spectroscopy of spinful Andreev bound states in ballistic semiconductor Josephson junctions

D.J. van Woerkom, A. Proutski, B. van Heck, D. Bouman, J.I. Väyrynen, L.I. Glazman, P. Krogstrup, J. Nygård, L.P. Kouwenhoven and A. Geresdi

Nature Physics, 13, 876-881 (2017), DOI: 10.1038/NPHYS4150

9 June 2017

Orbital contributions to the electron g-factor in semiconductor nanowires

G. W. Winkler, D. Varjas, R. Skolasinski, A. A. Soluyanov, M. Troyer, and M. Wimmer

Phys. Rev. Lett. 119, 037701 (2017)

12 June 2017

Coherent shuttle of electron-spin states

Fujita, T. A. Baart, C. Reichl, W. Wegscheider, L. M. K. Vandersypen

Nature PJ Quantum Informatics 3:22 (2017)

20 June 2017

Multiplexed entanglement generation over quantum networks using multi-qubit nodes

Suzanne B. van Dam, Peter C. Humphreys, Filip Rozpędek, Stephanie Wehner, Ronald Hanson

IOP Science Quantum Science and Technology, Volume 2, Number 3

30 June 2017

Observation of conductance quantization in InSb nanowire networks

E.M.T. Fadaly, H. Zhang, S. Conesa-Boj, D. Car, Ö. Gül, S.R. Plissard, R.L.M. Veld, S. Kölling, L.P. Kouwenhoven, E.P.A.M. Bakkers

Nano Letters 17, 6511-6515 (2017)

JULY

5 July 2017

Impact of g-factors and valleys on spin qubits in a silicon double quantum dot

J.C.C. Hwang, C.H. Yang, M. Veldhorst, N. Hendrickx, M.A. Fogarty, W. Huang, F.E. Hudson, A. Morello, and A.S. Dzurak

Physical Review B 96, 045302 (2017)

6 July 2017

Ballistic superconductivity in semiconductor nanowires

H. Zhang, Ö. Gül, S. Conesa-Boj, K. Zuo, M.P. Nowak, M. Wimmer, K. Zuo, V. Mourik, F.K. de Vries, J. van Veen, M.W.A. de Moor, J.D.S. Bommer, D.J. van Woerkom, D. Car, S.R. Plissard, E.P.A.M. Bakkers, M. Quintero-Pérez, M.J. Cassidy, S. Koelling, S. Goswami, K. Watanabe, T. Taniguchi and L.P. Kouwenhoven

Nature Communications, 8, (16025), 1-7 (2017), DOI: 10.1038/ncomms16025

AUGUST

2 August 2017

Quantum simulation of a Fermi-Hubbard model using a semiconductor quantum dot array

T. Hensgens, T. Fujita, L. Janssen, Xiao Li, C.J. van Diepen, C. Reichl, W. Wegscheider, S. Das Sarma, L.M.K. Vandersypen

Nature 548, 70–73 (2017)

16 August 2017

Multiplexed entanglement generation over quantum networks using multi-qubit nodes

Suzanne B. van Dam, Peter C. Humphreys, Filip Rozpędek, Stephanie Wehner, Ronald Hanson

Quantum Sci. Technol. 2, 034002 (2017)

23 August 2017

Epitaxy of advanced nanowire quantum devices

S. Gazibegovic, D. Car, H. Zhang, S.C. Balk, J.A. Logan, M.W.A. de Moor, M.C. Cassidy, R. Schmits, D. Xu, G. Wang, P. Krogstrup, R.L.M. Op het Veld, K. Zuo, Y. Vos, J. Shen, D. Bouman, B. Shojaei, D. Pennachio, J.S. Lee, P.J. van Veldhoven, S. Koelling, M.A. Verheijen, L.P. Kouwenhoven, C.J. Palmstrom and E.P.A.M. Bakkers

Nature, 548, 434-438 (2017)

24 August 2017

Robust nano-fabrication of an integrated platform for spin control in a tunable microcavity

Stefan Bogdanović, Madelaine S. Z. Liddy, Suzanne B. van Dam, Lisanne C. Coenen, Thomas Fink, Marko Lončar, Ronald Hanson

APL Photonics 2, 126101 (2017)

SEPTEMBER

6 September 2017

Interfacing spin qubits in quantum dots and donors – hot, dense and coherent

L.M.K. Vandersypen, H. Bluhm, J.S. Clarke, A.S. Dzurak, R. Ishihara, A. Morello, D.J. Reilly, L.R. Schreiber, and M. Veldhorst,

NPJ Quantum Information 3, 34 (2017)

7 September 2017

Conductance through a helical state in an InSb nanowire

J. Kammhuber, M.C. Cassidy, F. Pei, M.P. Nowak, A. Vuik, D. Car, S.R. Plissard, E.P.A.M. Bakkers, M. Wimmer, L.P. Kouwenhoven

Nature Communications 8, (478), 1-6 (2017), DOI:10.1038/s41467-017-00315-y

11 September 2017

Josephson radiation and shot noise of a semiconductor nanowire junction

D.J. van Woerkom, A. Proutski, R.J.J. van Gulik, T. Kriváchy, D. Car, S.R. Plissard, E.P.A.M. Bakkers, L.P. Kouwenhoven and A. Geresdi

Physical Review B, 96, 094508 (2017), DOI: 10.1103/PhysRevB.96.094508

18 September 2017

h=e superconducting quantum interference through trivial edge states in InAs

F.K. de Vries, T. Timmerman, V.P. Ostroukh, J. van Veen, A.J.A. Beukman, F. Qu, M. Wimmer, B.-M. Nguyen, A.A. Kiselev, W. Yi, M. Sokolich, M.J. Manfra, C.M. Marcus and L.P. Kouwenhoven

Phys. Rev. Lett. 120, 047702 (2018)

25 September 2017

Density-matrix simulation of small surface codes under current and projected experimental noise

T.E. O'Brien, B. Tarasinski, and L. DiCarlo

NPJ Quantum Information 3, 39 (2017)

25 September 2017

Scalable quantum circuit and control for a superconducting surface code

R. Versluis, S. Poletto, N. Khammassi, B. Tarasinski, N. Haider, D.J. Michalak, A. Bruno, K. Bertels, and L. DiCarlo

Phys. Rev. Applied 8, 034021

OCTOBER

18 October 2017

An experimental microarchitecture for a superconducting quantum processor

X. Fu*, M. A. Rol, C. C. Bultink, J. van Someren, N. Khammassi, I. Ashraf, R. F. L. Vermeulen, J. C. de Sterke, W. J. Vlothuizen, R. N. Schouten, C. G. Almudever, L. DiCarlo, and K. Bertels,

Proceedings of the 50th Annual IEEE/ACM International Symposium on Microarchitecture, pp. 813-825 (2017)

** winner Best Paper Award at Best Paper award at MICRO-50 Conference and winner Paper Award from the HiPEAC FP7 Network of Excellence by Xiang Fu*

25 October 2017

Acoustic traps and lattices for electrons in semiconductors

Martin J.A. Scheutz, Johannes Knörzer, Geza Giedke, Lieven M.K. Vandersypen, Mikhail D. Lukin, J. Ignacio Cirac

Phys. Rev. X 7, 041019 (2017)

NOVEMBER

3 November 2017

Supercurrent interference in few-mode nanowire Josephson junctions

K. Zuo, V. Mourik, D.B. Szombati, B. Nijholt, D.J. van Woerkom, A. Geresdi, J. Chen, V.P. Ostroukh, A.R. Akhmerov, S.R. Plissard, D. Car, E.P.A.M. Bakkers, D.I. Pikulin, L.P. Kouwenhoven, S.M. Frolov

Physical Review Letters 119 (18), 187704 (2017)

23 November 2017

Experimentally simulating the dynamics of quantum light and matter at ultrastrong coupling

N.K. Langford, R. Sagastizabal, M. Kounalakis, C. Dickel, A. Bruno, F. Luthi, D. J. Thoen, A. Endo, and L. DiCarlo,

Nature Communications, 8, 1715 (2017)

DECEMBER

15 December 2017

Silicon CMOS architecture for a spin-based quantum computer

M. Veldhorst, H.G.J. Eenink, C.H. Yang, and A.S. Dzurak,

Nature Communications 8, 1766 (2017)

29 December 2017

Smoothed generalized free energies for thermodynamics

Remco van der Meer, Nelly Huei Ying Ng, and Stephanie Wehner

Phys. Rev. A 96, 062135, December 2017, Volume 96, Number 6

List of graduated students

We wish to congratulate the following PhD researchers and students on their graduation from QuTech:

Date	PhD defense
March 10	David van Woerkom - Semiconductor Nanowire Josephson junctions
March 24	Daniel Szombati - Superconducting InSb nanowire devices
March 29	Nelly Ng Huei Ying - A theory of thermodynamics for nanoscale quantum systems
June 16	Jakob Kammhuber - Spin Orbit Interaction in Ballistic InSb nanowire devices
October 18	Önder Gül - Ballistic Majorana nanowire devices
November 3	Stefan Bogdanovic - Diamond-based Fabry-Perot microcavities for quantum networks

MSc	
Guanzhong Wang	Zhoumuyan Geng
Bas van t Hooft	Jaap Wesdorp
Yoram Vos	Jesse Slim
Nick van Loo	Sophie Hermans
Martijn Sol	Oscar Enzing
Kian van der Enden	Livio Ciorciaro

BSc
Tim Dikland
Maurits Houck
Gerhard Nordemann
Yves van Montfort
Karima Almouji
Rens Jochemsen
Martijn Papendrecht

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