FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

PRESS RELEASE

First node for the quantum internet of the future

Just in time for the start of UNESCO's International Year of Quantum Science and Technology 2025, North Rhine-Westphalia is setting up the first node for the quantum internet of the future. A team from the Fraunhofer Institute for Laser Technology ILT brought the system developed with TNO in Delft in the Netherlands to Aachen in mid-January to test it here, develop it further and establish the first regional connections to Jülich and Bonn. The project is a milestone on the way to the "Quantum Technology State of NRW."

Quantum computers will not replace conventional PCs in the foreseeable future as today's quantum platforms are simply too expensive to operate. However, an international team led by QuTech in Delft, the Netherlands, is driving forward the development of so-called "metropolitan scale quantum networks" – to provide many users from industry and science with access to the powerful computers, to connect different quantum computer platforms with each other, or to make entangled qubits usable for the secure encryption of sensitive data. For technical reasons, these networks can only be implemented locally or regionally so far but are considered to be the nuclei of the quantum internet of the future. For long-distance connections, there is a lack of repeaters to amplify the signals transmitted by individual photons without breaking the quantum entanglement. Photons cannot be simply cloned, as is the case in conventional transmission networks, due to the laws of quantum physics.

Cutting-edge research on the way to application

Nevertheless, the research team led by Ronald Hanson from QuTech – backed by the research organization TNO and TU Delft – was recently able to report a breakthrough. It has not only connected two quantum computers in Delft and The Hague with 25 km of underground optical fiber but also was able to reproducibly create the state of so-called quantum entanglement along the fiber. Some background: Entangled quanta assume a common quantum state and maintain this state even across spatial separations; Albert Einstein once spoke of a "spooky action at a distance." In Delft, this entanglement is generated with single photons emitted by qubits in the network nodes. The qubits – known as diamond spin qubits – are the spin of individual electrons captured in the crystal lattice of artificial diamonds. More precisely, the spin is trapped in specifically introduced nitrogen vacancies (NV centers), where it is controlled with microwave signals and magnetic fields and can be read out using lasers. The readout

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results in the emission of a photon with a wavelength of 637 nm, which carries and can transport information about the state of the qubit.

One of the key challenges is to guide the photons emitted in all directions into the optical fiber – efficiently, with low noise and beyond the usual telecom wavelengths. To accomplish this, Fraunhofer ILT developed not only a virtually noise-free quantum frequency converter but also a specifically shaped optical system integrated directly into the diamond chip. But there were many other challenges. For example, establishing a stable connection, which must maintain accuracies in the order of one wavelength of the photons over the 25 km glass fiber; this is comparable to keeping the distance between the earth and the moon constant to within a few millimeters. All of this could only be solved through the interaction of research and applied technology. In addition to QuTech and Fraunhofer ILT, several companies were also involved in the project: OPNT B.V., the Dutch timing hardware specialist; Element6, a supplier of synthetic diamonds and qubit chip substrates; and TOPTICA Photonics AG, a specialist for highly stable lasers.

First German quantum internet node to be built in Aachen

In addition to the connection between The Hague and Delft, the cooperation has now constructed a further quantum internet node optimized using the experience gained with funds from the North Rhine-Westphalian funding project N-QUIK. Together, TNO and Fraunhofer ILT have revised the design so that individual components are now easier to replace during testing. The Aachen-based institute also contributed various optical assemblies. After assembly and a test operation phase including its characterization at TNO in Delft, the new node found its way to Aachen in mid-January. Researchers from Fraunhofer ILT were already actively involved during the assembly and test phase and trained by their TNO-colleagues to operate the system as part of the Dutch-German technology transfer. The dismantling and assembly in Aachen will deepen the know-how they have gained. On this basis, the German engineers will operate the network node in Aachen, systematically develop it further, optimize its photonic components and gradually establish the first "metropolitan scale quantum networks" in NRW.

"This project gives us a practical test field where we want to develop this technology to market maturity together with partners from industry and science," explains Dr. Bernd Jungbluth, who heads the Quantum Technologies strategic program at Fraunhofer ILT. He is also the coordinator of the Quantum Roadmap NRW, which attaches great strategic importance to the development of quantum networks. According to Jungbluth, their potential goes far beyond encryption via quantum key distribution (QKD). "We envision that metropolitan scale quantum networks will enable very powerful, secure connections between quantum computers and between quantum sensors," he says. Applications such as distributed quantum computing are conceivable, which interconnects several computers to form a quantum system to quickly scale their capacity and performance. Quantum networks are also important with regard to secure remote access to quantum computers, which are initially only available to a limited extent. Both could soon become a reality in the form of a connection from the Aachen node to the Helmholtz Quantum Center on the Jülich quantum campus. According to Jungbluth, a connection to the backbone of a central German test network in Bonn is also being considered.

A milestone for the "Quantum Technology State of NRW"

Gradually, further research and industrial sites could be connected in the region, throughout North Rhine-Westphalia and, as technology matures, nationwide. To achieve this, the repeater problem caused by the "no cloning theorem" must be solved. It stands in the way of an extensive cross-border quantum internet of the future. "We want to promote this future technology in NRW and make use of our locational advantages: There is an outstanding specialist community from science and industry in the state, a broad base of potential users and short distances to the metropolitan regions – and let us not forget our central location in Europe. The quantum internet can grow in all directions from here," explains Jungbluth.

This is also one of the core messages of a current position paper drawn up by around 200 experts as part of the NRW roadmapping process. In numerous workshops and discussions over the course of 2024, they have defined a position that is based directly on scientific and industrial practice, and that provides policymakers with feasible visions for a new dawn in the "Quantum Technology State of NRW." Jungbluth, who coordinated the process, draws an optimistic conclusion: "We agree that jointly used infrastructures and test fields are needed so that players from industry and research can together advance the development, testing and concrete application of quantum technology hardware and software. Thanks to its central location in Europe and the densely populated metropolitan regions that are located close to each other, NRW holds all the trump cards," he explains. With the establishment of the quantum internet node in Aachen, a first milestone in the outlined roadmap has already been reached.

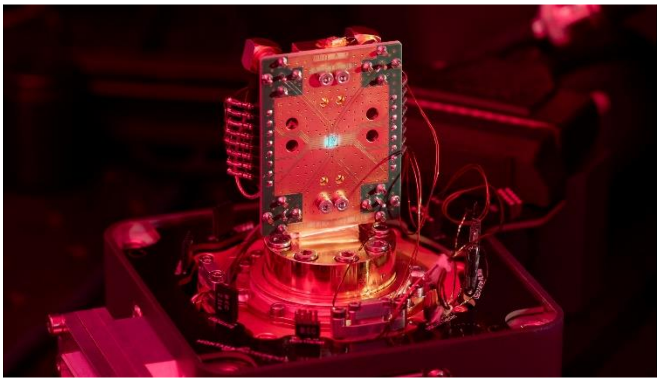

Image 1:
The heart of the quantum internet node is a cultured diamond with specifically introduced nitrogen vacancies (NV centers). It emits single photons that can carry and transport information about the state of the qubit.
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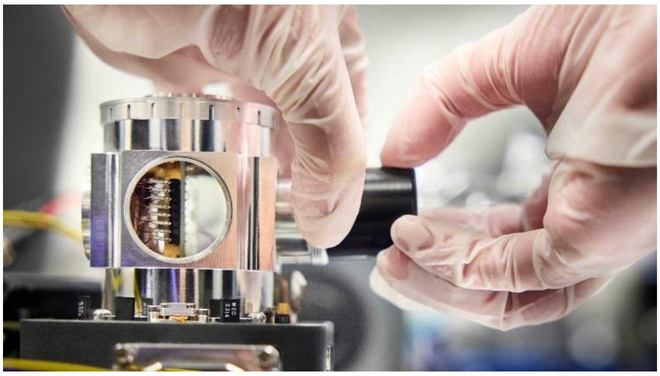

Image 2:
For the joint disassembly of the node in Delft, the teams from TNO and Fraunhofer ILT needed detailed knowledge of the system – and a and a steady hand.
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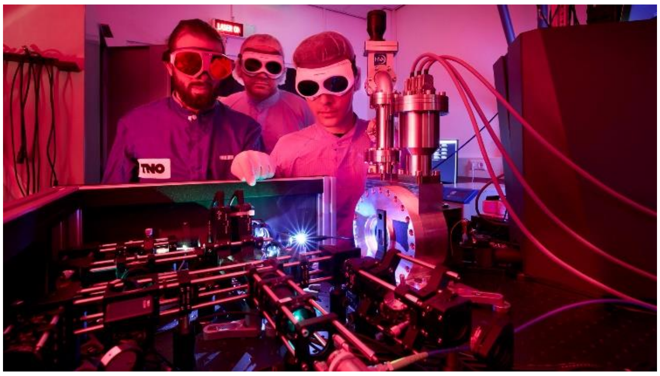

Image 3:
TNO and Fraunhofer ILT have intensified their close collaboration in the NRW-funded project N-QUIK. Their optimized network node for the quantum internet of the future will serve as a test field and node for the first “metropolitan scale quantum networks” in Aachen.
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