Projects as part of the Quantum Transitional Call
Participation by SNI members

The second half of 2023 saw the launch of four quantum research projects with the participation of SNI members. These projects had been announced as part of the Quantum Transitional Call by the Swiss National Science Foundation (SNSF). For researchers from the Department of Physics at the University of Basel, the support will allow them to continue with their various lines of research, which were previously part-supported by EU funding programs. Although the funding is no substitute for participation in the European programs, it goes some way toward mitigating the impact of exclusion for Swiss research groups.

On the road to quantum networks
Numerous research groups worldwide are investigating quantum networks with a view to the wide-ranging applications they promise, such as the interlinking of quantum computers or quantum sensors, secure quantum communication, or the investigation of many-particle systems. The construction of complex quantum networks, however, represents a major technological challenge that is yet to be overcome.

Combined expertise
A powerful platform for such quantum networks is being developed by researchers led by Basel professors Philipp Treutlein and Richard Warburton together with colleagues from the Swiss Center for Electronics and Microtechnology (CSEM) in Neuchâtel.

The researchers are using a platform that appears to offer feasible upscaling from a technological perspective. For each node point in the network, the platform allows researchers to combine a source of single photons, which transport information, with a single-photon memory. The photons are placed in a quantum mechanical superposition state, with one part being stored in the memory while the other part relays quantum information to the next node points, in order to generate entanglement within the network.

Quantum dots and atomic vapor cells
Richard Warburton's group has already shown that semiconductor quantum dots can emit single photons at a high rate and with excellent spectral purity. In the SQnet project launched in September 2023, the researchers will now use novel quantum dots that emit photons of a specific wavelength that is compatible with rubidium atoms. For the quantum memory, the researchers are using atomic vapor cells developed by the Treutlein team. "These are glass bulbs filled with rubidium gas that, unlike other quantum memories, also work at room temperature and don't need to be intensely cooled in a cryostat. This is vital when it comes to upscaling the technology for a complex network," explains Treutlein.

The researchers have already performed a proof-of-principle demonstration with a quantum memory, but they will need to miniaturize the technology in order to build a more complex network. The glass cylinders used so far are a few centimeters in size and are individually produced by a glassblower. Thanks to the expertise of CSEM colleagues in miniaturization, nanofabrication and nanophotonics, it will be possible to produce quantum memories of a significantly smaller size and to automate the production process.

Background information

Within the international research program known as Horizon Europe, Switzerland is currently classed as a non-associated third country, meaning that researchers from Swiss research institutions have been excluded from many EU research programs. Switzerland's State Secretariat for Education, Research and Innovation has therefore mandated the Swiss National Science Foundation to develop a transitional solution, leading to the announcement of the Quantum Transitional Call in 2022 with a view to allowing researchers involved in quantum research programs under Horizon Europe to continue pursuing their research projects. Five SNI members from the Department of Physics at the University of Basel are involved in successful projects that began in the second half of 2023 and are set to receive funding over a period of four years.

Further information:

Interview with the successful professors from the University of Basel:
https://www.unibas.ch/de/Universitaet/Administration-Services/Vizerektorat-Forschung/Grants-Office/Grants-Office-News/Grants-Office-Newsletter-2023-7/Quantum.html

Research group Philipp Treutlein
https://atom.physik.unibas.ch/en/research/

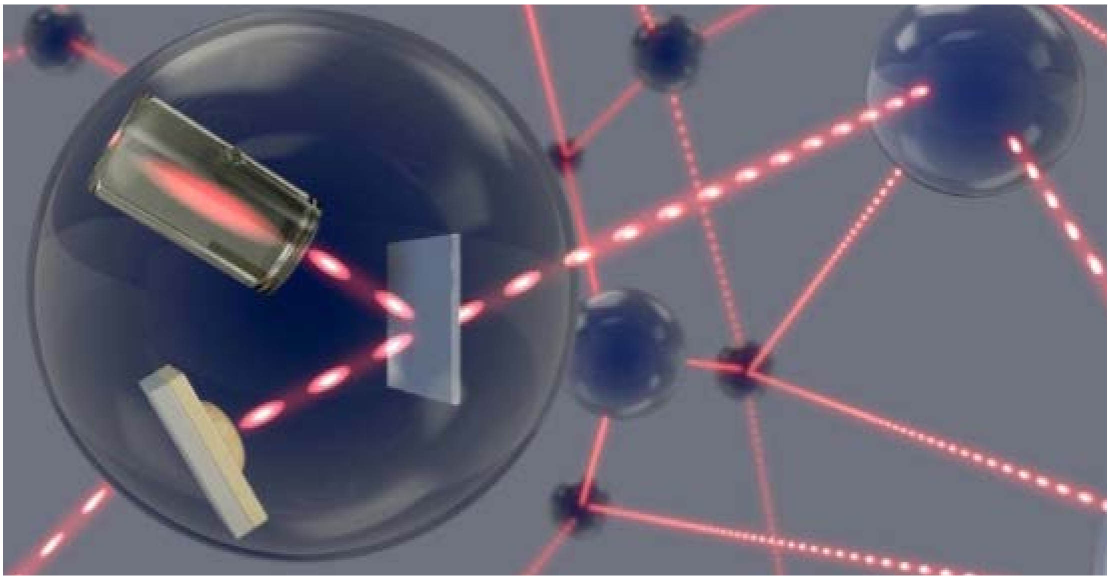
Research group Richard Warburton
https://nano-photonics.unibas.ch

Contribution *Physics World*
https://physicsworld.com/a/rubidium-vapour-makes-a-good-quantum-memory/

Research group Martino Poggio
https://poggiolab.unibas.ch

Research group Patrick Maletinsky
https://quantum-sensing.physik.unibas.ch/en/

Research group Andrea Hofmann
https://hofmannlab.physik.unibas.ch/en/



At each node point in the quantum network, the aim is to link a photon source with a quantum memory. The information is then transmitted using entangled photons. (Image: Department of Physics, University of Basel)

"Our partners at CSEM have managed to produce 700 of these vapor cells on a wafer," says Treutlein. "We can use these tiny quantum memories to make the individual nodes of the network significantly smaller, so that we can potentially build larger networks. It may also be possible to equip individual nodes with multiple vapor cells and thus to increase the processed data volume – but there's a lot of research to do before we reach that stage." Two doctoral students and one postdoc will push ahead with this work at the Department of Physics.

Wavelength adjustment

Another challenge facing the researchers are the glass fibers that connect the nodes. Transmitting data over large distances will require the wavelength of the photons to be within the range used by existing telecoms fiber – which is not the case for the spectral lines studied so far. In the scalable system, the researchers must therefore incorporate a photonic chip that allows them to convert the wavelength. This then combines the red photons of the existing system with an infrared pump laser so that they generate photons suitable for telecom networks. Every single photon is converted into exactly one photon of the required wavelength.

Sensors for superconducting quantum bits

For Professor Martino Poggio's group, the funding received will allow the continuation of research in the field of quantum sensors for superconducting quantum bits. Starting in December 2023, two PhD students and one postdoc will advance the Poggio Lab's promising research into scanning probe microscope imaging.

The researchers will study superconducting qubits – as these are being used as a promising platform for realizing a quantum computer by large companies such as Google and IBM. Working designs with tens to hundreds of qubits already exist, but the much larger numbers needed for a working quantum computer require a better understanding of defects and vulnerabilities – in terms of both the material and the design of the superconducting circuits.

Tracking down defects

The superconducting qubits studied by the Poggio team are largely fabricated by colleagues at ETH Zurich from thin layers of aluminum and niobium or tantalum. The Poggio group uses highly sensitive scanning probe imaging with superconducting quantum interference devices (SQUIDs) at the probe's tip to identify, localize and ultimately contribute to solving problems that arise when the number of qubits is scaled up.

Currently, researchers from the Department of Physics study the qubits in a cryostat at 300 millikelvin. "With the help of the SuperSQUID project, we will be able to upgrade our cooling system so that we can cool them down to temperatures of 10 millikelvin," reports Dr. Floris Braakman, who is responsible for the project in the Poggio team.

"The superconducting qubits normally operate at these low temperatures. So, it's important for us to be able to work with our scanning SQUID microscope in these conditions." In addition, the researchers plan to implement a high-speed microscope that can capture rapid changes.

Over the next four years, the researchers will use these methods to create spatial maps of material defects and to map magnetic fields as well as current flow and losses in the superconducting circuits. The data will help to better understand the mechanisms for the loss of quantum properties, known as decoherence, and to provide recommendations for improved circuit design and the quantum bit fabrication process.

Rotation and temperature measurements using diamonds

In recent years, tiny diamonds with defects known as nitrogen-vacancy centers have become an established tool for the development of powerful, highly sensitive quantum sensors for electric and magnetic fields. Accurate temperature measurements can be obtained via the spin of individual electrons orbiting within the vacancy centers, while rotation can be measured by analyzing the angular momentum of the atomic nuclei.

In the ensQsens project, researchers from the University of Basel, the Swiss Center for Electronics and Microtechnology (CSEM) in Neuchâtel and the Laboratoire des Sciences des Procédés et des Matériaux (CNRS) will develop quantum thermometers and rotation sensors of this kind. The researchers will also initiate the miniaturization and integration of these sensors into housings on the centimeter scale. Launched in October 2023, the project will further promote the applicability and distribution of quantum sensors.

The research will be carried out by two doctoral students and one postdoc in the group working under principal investigator Professor Patrick Maletinsky from the Department of Physics. Teaming up with CSEM and the CNRS, the researchers will pursue the use of ensembles of nitrogen-vacancy centers (NV centers) as sensors in complementary lines of research. On the one hand, they are using nuclear spin ensembles in diamonds to develop a novel rotation measurement device that could be used in portable navigation systems and could operate more accurately and more robustly than existing rotation sensors. On the other hand, their research aims to produce a tiny thermometer based on electron spin ensembles. This could have applications in areas such as electronics.

Use of electron and nuclear spins

The researchers believe that the spins in diamonds are particularly promising, for they operate at room temperature and have already proven themselves to be robust sensors. Each of the NV centers contains six orbiting electrons, whose intrinsic angular momenta (spins) react very sensitively to electric and magnetic fields in their environment, and which together behave like a tiny magnet. The electrons are excited and then emit individual photons, which deliver information about the spin state and therefore about the electric and magnetic fields.

For the envisaged temperature measurements, the researchers are planning to use probes featuring a conical diamond tip with a diameter of only around 10 nanometers at the point and numerous NV centers at the base. Since diamond is an excellent conductor of heat, the temperature "felt" by the tiny tip influences the interactions between electrons of the NV centers. The individual NV centers are not particularly affected by these interactions – which is what makes them so robust in other applications. If numerous NV centers are combined, however, the thermal expansion of the diamond crystal can be used for temperature determination. Using the planned setup, the researchers expect to achieve a spatial resolution of some 10 to 20 nm.

Electron spins offer only limited suitability for the accurate detection of rotation. This is because they respond too sensitively to magnetic fields, whereas the spins of atomic nuclei (nuclear spins) are much better suited to this application. Not only are these spins less sensitive to external magnetic fields, but they can also be addressed optically – as Maletinsky's group was able to demonstrate for the first time last year. With that in mind, the group is working with the project partners to explore the use of diamond nuclear spins as rotation sensors in another subarea of the project. The aim is to integrate these sensors into a compact housing in collaboration with the project partners at CSEM. In the future, this may lead to applications in the navigation and stabilization of self-driving vehicles or drones.

Qubits made of graphene

Professor Andrea Hofmann was a successful co-applicant in the GraQuaDotQb project. Led by Professor Thomas Ihn (ETH Zurich), this project will see Hofmann and her group investigate how quantum dots can be formed in coupled graphene layers. In collaboration with the researchers from ETH Zurich, Hofmann's team will then study these bilayer graphene quantum dots as substrates for spin, valley or spin-valley qubits.

Currently, however, Andrea Hofmann is immersed in an even more exciting project, having become a mother in mid-October. Our congratulations and best wishes to her and her family!