SQUARE

https://square.phi.kit.edu/

Objectives

The results of the SQUARE project will contribute to strengthen the European high-tech industry as it aims to establish a new platform for quantum computing, quantum networking and quantum communication.

The SQUARE project is part of the basic science segment and in particular, aims to show that rare earth ions in solids could serve as a material that allows high-density integration of the elementary building blocks of quantum computers – qubits – and their efficient local and long-range interconnection via light.

To do so, we will demonstrate the basic elements of a multifunctional quantum processor node and develop scalable device elements.

Project Progress & Achievements

Within the first funding period, the SQUARE project has worked towards the detection and control of single rare earth ions as optically addressable spin qubits, developed several device elements required for scalable quantum nodes, and devised theoretical frameworks to describe e.g. optically interconnected quantum nodes.

Specifically, they were able to demonstrate the detection and quantum control of a single Cerium spin and used it to sense nearby Silicon nuclear spins as possible quantum memories. Furthermore, they demonstrated dynamic tuning of strong Purcell enhancement of Erbium ion emission, which is a crucial ingredient for efficient single ion readout, optimized quantum gates, and interconnection of quantum nodes.

Another important breakthrough was the development of a theoretical framework to realistically describe travelling quantum pulses, which is key to understand the features and limitations of quantum networks and the interconnection of quantum nodes. Also, realistic modelling to assess the limits of single qubit gate fidelities was performed.

Another focus was on the technology development of scalable device elements for a rare-earth ion quantum computer, including a cryogenic nanopositioning platform, fiber cavities, rare-earth-ion-doped thin films, a scheme for a scalable laser source that can coherently address up to 100 qubits, and a concept for an all-European closed-cycle cryo-cooler.

Applications

Overall, SQUARE aims at realizing scalable quantum computing nodes, which in the long term may allow for distributed quantum computing and the realization of quantum repeaters for long-distance quantum communication. The project's achievements so far have direct relevance for a variety of technological and scientific applications:

- They have advanced fiber-based microcavities as a general tool for efficient light extraction from quantum emitters for single photon sources, spin-photon interfaces, readout of quantum bits of trapped-ion quantum computers, readout of atoms in optical clocks, and high-quality tailored potentials for photon BECs, as well as for sensing, ultra-sensitive spectroscopy and imaging.
- They have developed a cryogenic nanopositioning setup and a vibration isolation platform with superior performance for cross-sectional use under highest stability needs e.g. in closed-cycle cryostats.
- The novel theoretical formalism for the description of travelling quantum pulses fills a gap for the realistic description of elementary processes in quantum networks and can be generalized to a broad range of questions in various fields of quantum science.
- Dynamical tuning of emission enhancement represents a novel capability to optically address also large numbers of qubits separated in frequency space, and could thus become a central element for scalable quantum nodes.
- The investigated laser source could become relevant for advanced spectroscopy and signal processing.
- The investigated cryo cooler could become a blueprint for an all-European closed-cycle cryostat.

SQUARE in the Media

Placing Single Impurities into a Crystal
https://physics.aps.org/articles/v12/s101

Researchers can now place single ions into solids
https://www.sciencedaily.com/releases/2019/09/190924112113.htm

Sensing Single Spins in Dense Spin Baths
https://physics.aps.org/articles/v13/s56

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