RESEARCH GROUP

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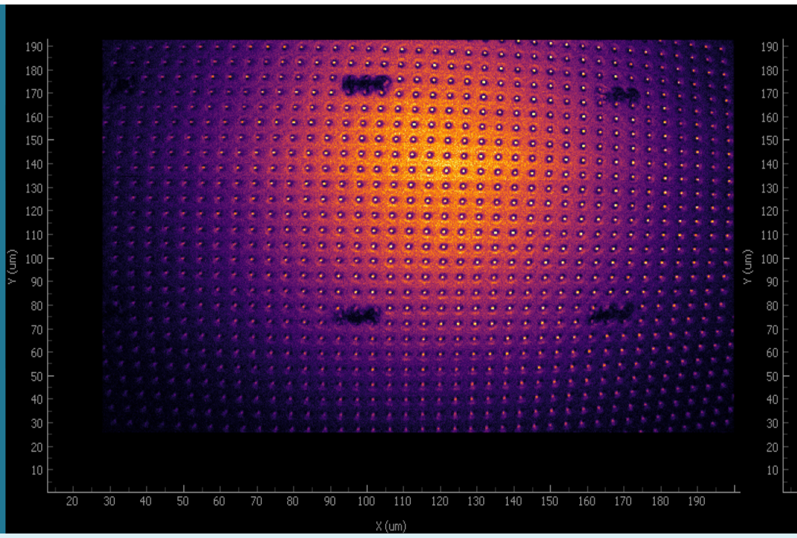
Quantum Materials



The Quantum Materials group focuses on the development of semiconductor quantum hardware for quantum technologies. Our emphasis is set on the semiconductor silicon carbide (SiC), for which synergies with the high-power electronics industry pave the way for industrial-scale quantum-chip fabrication. Our research expands the current fabrication methods to the generation of efficient quantum colour centres, nanofabrication of photonic integrated circuits (PICs), post-fabrication treatments to improve stability and spectral properties, and application-relevant quantum benchmarking.
Our perspective is to use silicon carbide quantum chips for next-gen applications, including quantum communication, quantum computing, and quantum sensing.

Main research fields

Our group focuses on advancing three research lines:

1. Development of a scalable semiconductor quantum hardware platform:
   - SiC-on-insulator bonding
   - Large-scale fabrication of photonic quantum chips
   - Efficient creation of quantum colour centres
   - High-fidelity control of spin-based quantum processors and memories

- Post-fabrication improvements of quantum hardware:
  - Surface charge passivation methods
  - Fermi-level control in photonic nanostructures
  - Optical transducers for maximum photonic efficiency

- Quantum technology applications:
  - Spin-photon interfaces for quantum communication
  - Distributed quantum computing
  - Quantum sensing

Innovation challenges

- Development of high-throughput quantum characterisation platform
- Development of quantum opto-electronic devices
- Increased performance of quantum chips based on spectral and temporal multiplexing

Selected publications

Silicon Carbide Quantum Hardware

- J. Körber, J. Heiler, P. Fuchs, P. Flad, E. Hesselmeier, P. Kuna, J. Ul-Hassan, W. Knolle, C. Becher, F. Kaiser, J. Wrachtrup, Fluorescence Enhancement of Single V2 Centers in a 4H-SiC Cavity Antenna, Nano Lett. 24, 9289 (2024)
- M. Krumrein, R. Nold, F. Davidson-Marquis, A. Bouamra, L. Niechziol, T. Steidl, R. Peng, J. Körber, R. Stöhr, N. Gross, J.H. Smet, J. Ul-Hassan, P. Udvarhelyi, A. Gali, F. Kaiser, J. Wrachtrup, Precise Characterization of a Waveguide Fiber Interface in Silicon Carbide, ACS Photonics 11, 2160 (2024)
- S. Kucera, C. Haen, E. Arenskötter, T. Bauer, J. Meiers, M. Schäfer, R. Boland, M. Yahyapour, M. Lessing, R. Holzwarth, C. Becher, J. Eschner, Demonstration of quantum network protocols over a 14-km urban fiber link, npj Quant. Inf. 10, 88 (2024)
- E. Hesselmeier, P. Kuna, W. Knolle, F. Kaiser, N.T. Son, M. Ghezellou, J. Ul-Hassan, V. Vorobyov, J. Wrachtrup, High-Fidelity Optical Readout of a Nuclear-Spin Qubit in Silicon Carbide, Phys. Rev. Lett. 132, 180804 (2024)
- E. Hesselmeier, P. Kuna, I. Takacs, V. Ivady, W. Knolle, N.T. Son, M. Ghezellou, J. Ul-Hassan, D. Dasari, F. Kaiser, V. Vorobyov, J. Wrachtrup, Qudit-Based Spectroscopy for Measurement and Control of Nuclear-Spin Qubits in Silicon Carbide, Phys. Rev. Lett. 132, 090601 (2024)
- J. Heiler, J. Körber, E. Hesselmeier, P. Kuna, R. Stöhr, P. Fuchs, M. Ghezellou, J. Ul-Hassan, W. Knolle, C. Becher, F. Kaiser, J. Wrachtrup, Spectral stability of V2 centres in sub-micron 4H-SiC membranes, npj Quantum Mater. 9, 34 (2024)
- D. Liu, F. Kaiser, V. Bushmakin, E. Hesselmeier, T. Steidl, T. Ohshima, N.T. Son, J. Ul-Hassan, O.O. Soykal, J. Wrachtrup, The silicon vacancy centers in SiC: determination of intrinsic spin dynamics for integrated quantum photonics, npj Quant. Inf. 10, 72 (2024)
- S.K. Parthasarathy, B. Kallinger, F. Kaiser, P. Berwian, D.B.R. Dasari, J. Friedrich, R. Nagy, Scalable Quantum Memory Nodes Using Nuclear Spins in Silicon Carbide, Phys. Rev. Applied 19, 034026 (2023)
- H. Singh, M.A. Hollberg, M. Ghezellou, J. Ul-Hassan, F. Kaiser, D. Suter, Characterization of single shallow silicon-vacancy centers in 4H-SiC, Phys. Rev. B 107, 134117 (2023)

Partners

Luxembourg National Research Fund (projects: AQuaTSiC, SiCqurTech), Horizon Europe (project: QIA), European Research Council (project: Q-Chip), SnT department at University of Luxembourg , University of Stuttgart (Germany), Delft University of Technology (The Netherlands), Friedrich-Alexander-University Erlangen-Nuremberg (Germany), University of Surrey (UK), Heriot-Watt University (Scotland), University of Science and Technology of China (China), Saarland University (Germany), Technical University of Dortmund (Germany), Helmholtz-Zentrum Dresden-Rossendorf (Germany), Fraunhofer Institute IISB Erlangen (Germany), LinkÃ¶ping University (Sweden), ETH ZÃ¼rich (Switzerland), University of California, Davis (USA), University of California, Stanford (USA)

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