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quantum & neuromorphic computing

Materials and Technologies for Si/SiGe Based Spin Qubits

1 Spin Qubits Based on Si/SiGe

Advantages and Challenges
- long coherence times, CMOS manufacturable

→ 6 qubits in 2022 (Qutech), 12 Qubits in 2024 (Intel)
- material properties influence qubit performance

→ optimization is required

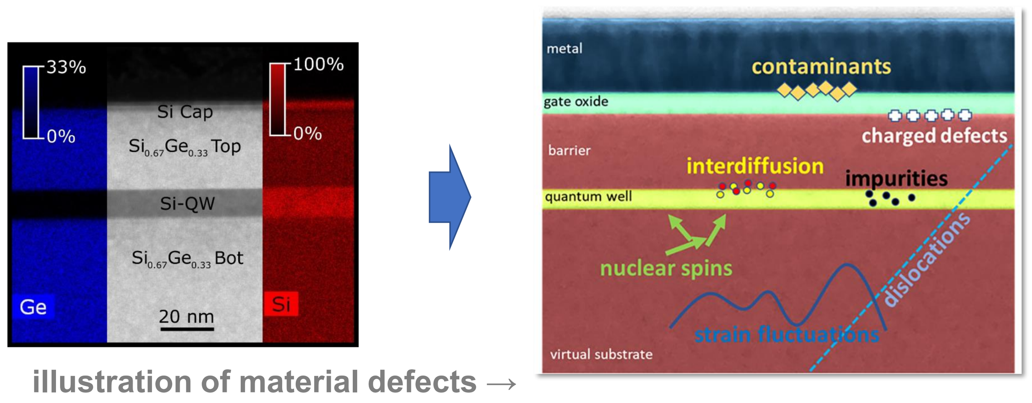


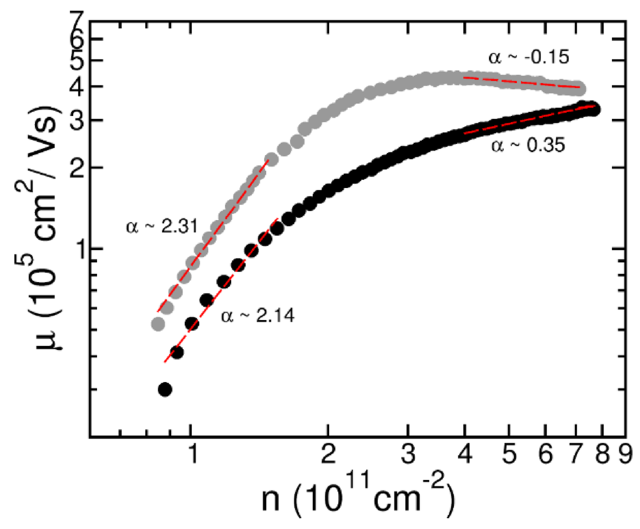
illustration of material defects →

2 Technology 200 mm / 300 mm

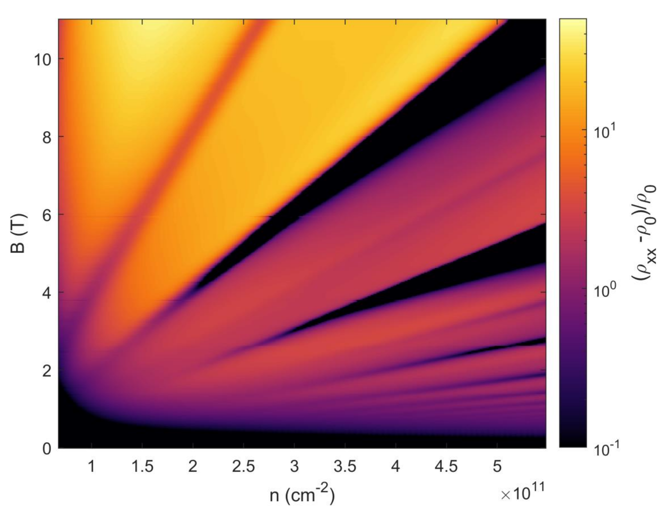
Growth, Fabrication & Components
- Si/SiGe heterostructures
- gate oxide based on PECVD, PVD and ALD
- gate based on PVD and CVD
- electron beam lithography for nanostructuring
- test structures (HB-FETs, MOS dots)
- qubit templates, micromagnets

Characterization
- AFM, XRD, XRR, XPS, SEM, TEM, SIMS
- transport properties (1.5 K, 12 T)
- characterization of gate oxides

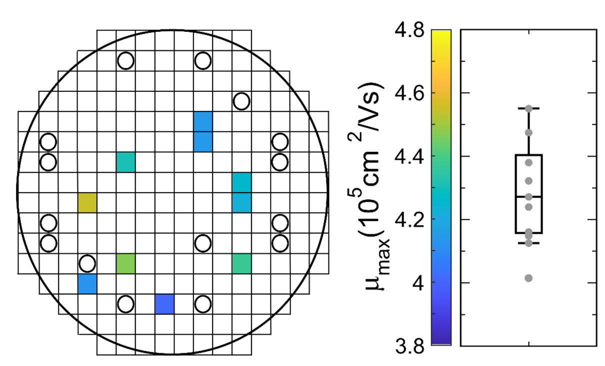
4 Highlights from the QUASAR Project



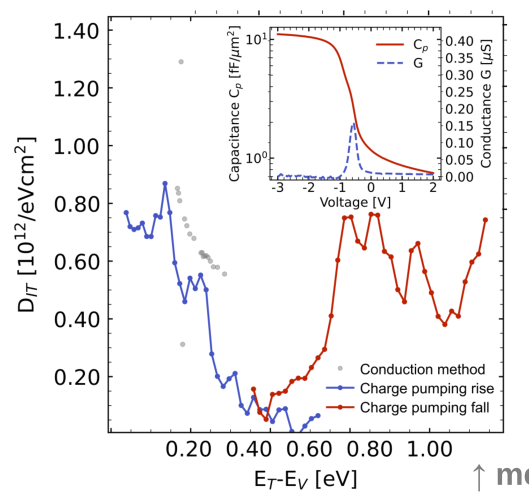
↑mobility vs density comparison of two wafers (grey optimized, black non-optimized)



↑quantum hall effect in IHP HB-FETs


↑wafer scale variation of maximum mobility

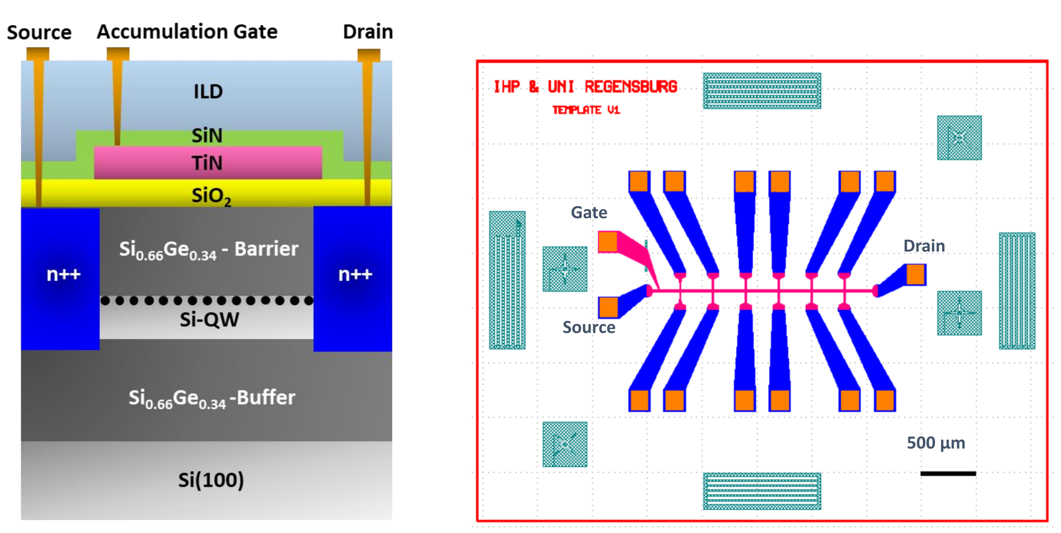
Si/SiGe Technology for Qubits
- improved technology led to increased mobility https://doi.org/10.1149/11402.0109ecst https://doi.org/10.1149/11402.0123ecst
- maximum mobility of over 450,000 cm²/Vs
- percolation density at n = 0.7E11 cm^{-2}
- variance of Hall bar parameters below 5%



Gate Oxide Quality
- energy-resolved defect density D_{it} < 3E10 cm^{-2} eV^{-1}
- fixed charge concentration Q_{fix} < 5E10 cm^{-2}
- determination of hysteresis, permittivity number
- flicker Noise, Charge Pumping, Conduction Method (C/V, G/V)

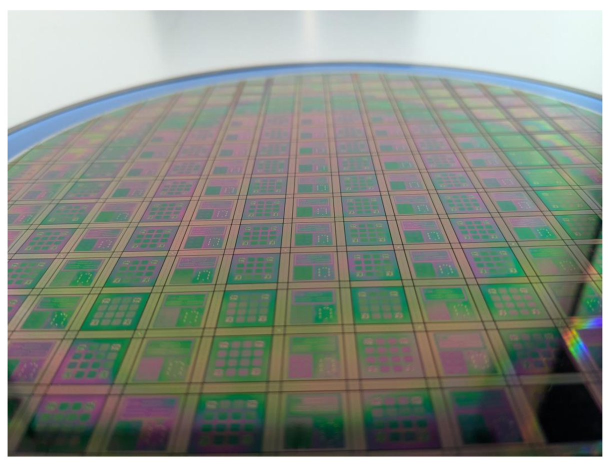
↑ measurement to extract oxide quality https://doi.org/10.1063/5.0147586

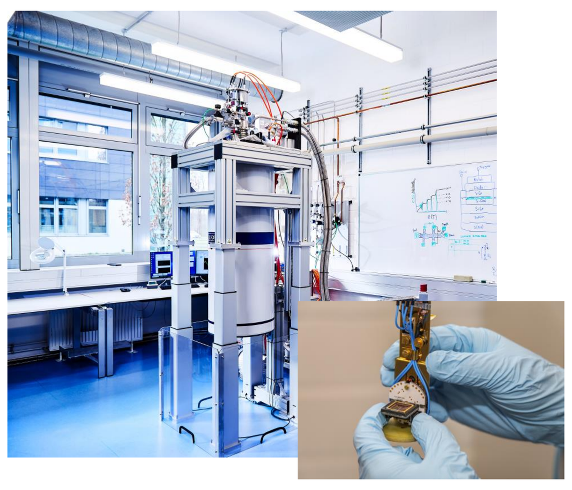
3 Components for Si/SiGe Spin Qubits

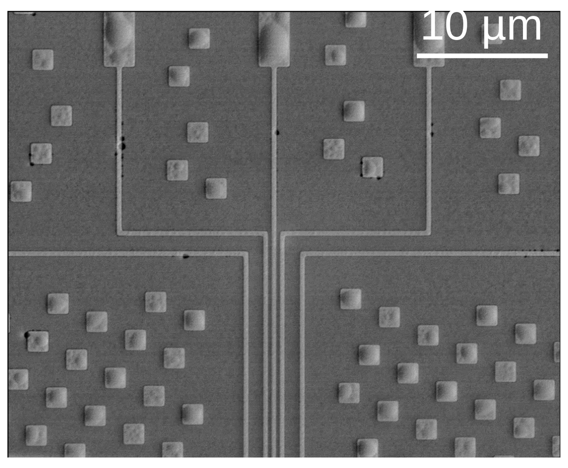


↑HB-FET technology at IHP

- Si/SiGe heterostructure
- Marker
- Ohmic contacts (implantation)
- Mesa Definition
- Gate oxide (SiO_2 , HfO_2 , Al_2O_3)
- Gate (TiN)
- Contact module
- Metal1
- Micromagnets


↑IHP 200 mm wafer with qubit components


↑quantum transport laboratory at IHP



↑reactive ion etched Co for micromagnets

5 Summary

- production of Si/SiGe heterostructures of the highest quality for Si spin qubits
- process development and characterization of suitable gate oxides
- transport measurements at cryogenic temperatures (1.5K)
- manufacturing of nanostructured components
- structured Co micro magnets

6 Outlook

- method development for determination of interface defect density at cryogenic temperatures
- extension of the characterization possibilities: whole wafers at 2 K and chips by 100 mK

For inquiries, email us at experts@module-qnc.de

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