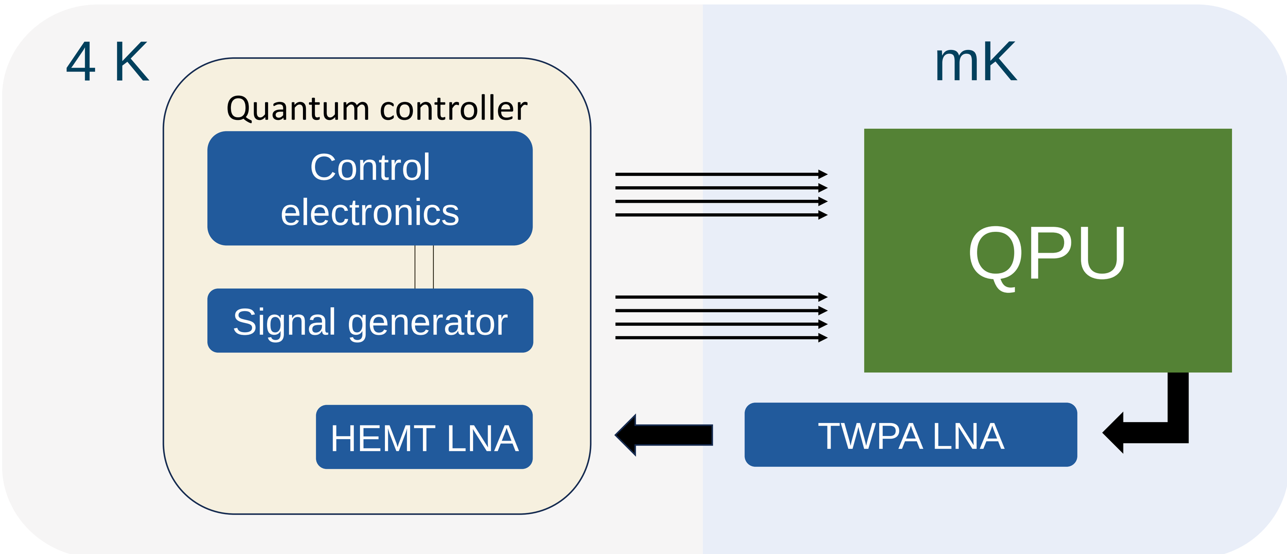
Design and testing of cryogenic electronics

1 Application



Problem:
- Qubit numbers grow towards millions
- Large number of electrical connections required, which take up space and conduct heat into the cryostat
- Weak qubit signals must be pre-amplified in the cryostat

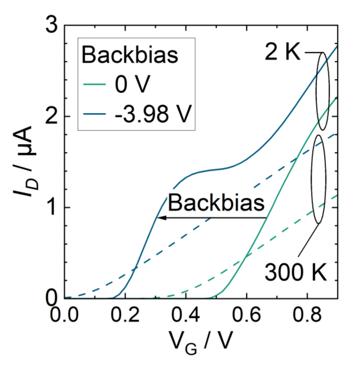
Solution:

➔ Control electronics, amplifier circuits and signal generators placed as close as possible to the quantum computing chip in the cryostat

Challenges:
- Understand behaviour of devices at cryogenic temperatures
- Thermally decouple electronics and QPU for minimisation of qubit disturbance
- Ensure low noise in the readout path

2 Components for cryoelectronics

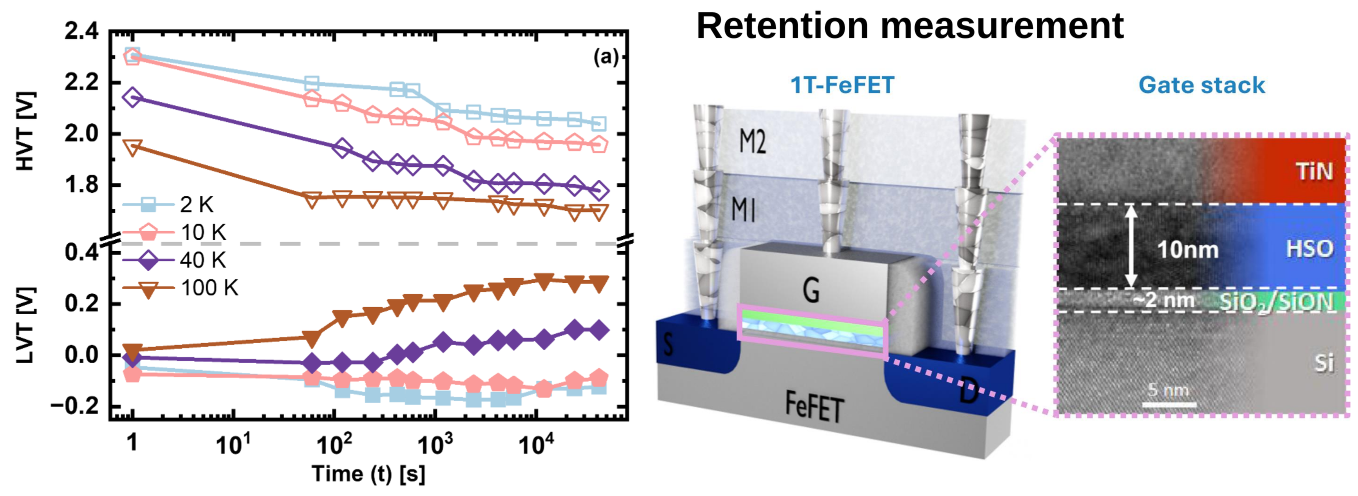
<u>Advantages of components at low temperatures:</u>
- **MOSFET / bipolar**: steeper subthreshold slope, higher transit frequency, greatly reduced thermal noise



Transfer curve of FDSOI NMOS transistor

- **FeFET**: nonvolatile memory with low switching energy in the fJ range, enhanced retention

Retention measurement

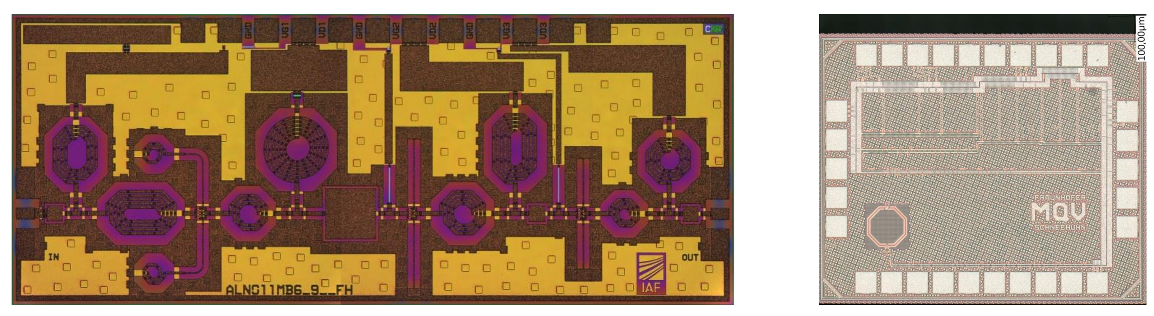


- Metallization can be made **superconducting**, so that heat losses are eliminated
- **HEMT**: lowest transistor noise, increased transit frequencies, high amplification

<u>Further research activities</u>
- Determination of the occupation of defect states at semiconductor-insulator interfaces at cryogenic temperatures
- Design of FDSOI MOSFETs for lower switching voltages

3 Existing design work

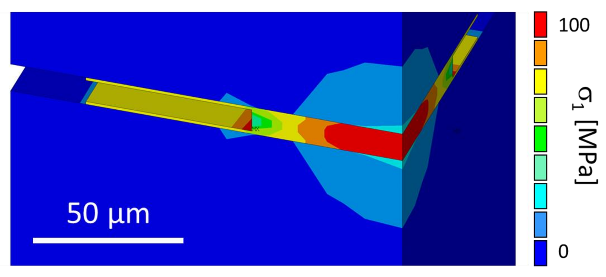
- Integrated **quantum controller** for SC qubits in 22 nm FDSOI and 130 nm BiCMOS technology (MUNIQS-SC, MQV K6)
- **Qubit Control Mixed-Signal** SiGe monolithic microwave IC (MMICs): LNA, signal sources, DAC, dig. 90 nm-CMOS integration
- Integrated phase locked loop **(PLL)** development 22 nm FD-SOI (MUNIQC-SC, MQV K6)
- **Qubit Read-out**: Simulation, design, processing and construction of HEMT LNA MMICs (MUNIQS-SC) based on a 50 nm mHEMT technology



First ASIC prototypes from IIS, IAF and EMFT (MUNIQS-SC and MQV K6)

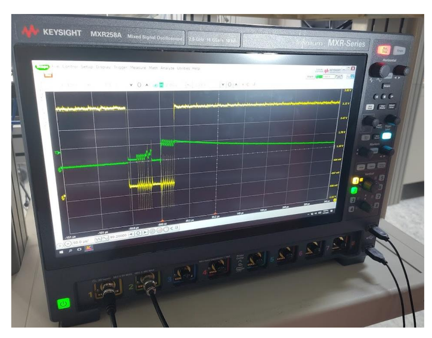
- **Thermal & mechanical co-design** for reliable heterogeneous 3D integration, QC architectures at low temperatures

Stress state Al-Bump in 3D-Cryo-SiP for QC at T = 4 K



4 Cryo measurements of digital electronics

- Measurement infrastructure and know-how available
- Challenges: parasitics from long cables and high connectivity demands
- Successful characterization of SRAM, ADC, ring oscillators within the QNC Space project *CRYSTAL-QC (joint project TUM /EMFT)*
- Capacity to measure analogue signals up to 67GHz with temperature control



5 Summary

- Development of cryo-compatible analog and digital electronics
- Versatile options for electrical cryo-characterization

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

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