Spin-2 QPU

Spin-based Quantum Processor Unit

The number of quantum computing use cases in the realm of quantum simulations, optimization and machine learning is steadily growing. At QuTech we are convinced that offering the public broad access to technologies such as quantum computing hardware as well as a quantum computing simulator tool will further stimulate this growth. Therefore, Quantum Inspire (QI) was launched in the cloud on 20. April 2020. QI is a platform with a high degree of modularity and offers the public cloud-based access to QuTech quantum technologies and includes the world's first spin-based quantum processor: our Spin-2 Quantum Processor Unit (QPU).

Our Spin-2 QPU is a 2-qubit programmable quantum processor based on spin qubits in Silicon, which are kept at a temperature of 10 to 20 mK inside a dilution refrigerator. Conventional DC-carrying cables and high frequency transmission lines will bring the signals to and from the Spin-2 QPU. The two electron spins trapped in semiconductor quantum dots, are particularly promising building blocks of a quantum processor [2-4]. These devices can be manufactured and tailored by standard lithographic techniques, which is a considerable advantage for potential future large-scale integration of a large number of qubits. In addition, they are controlled and read out by current-state electronics. Spin qubits, are very promising from the point of view of very large-scale integration, thanks to their small size and similarity to classical transistor technology.

Developing a Spin-2 QPU

The Spin-2 QPU was developed at QuTech and consists of two single electron spin qubits hosted in a double quantum dot in isotopically purified Si-28, and allows for arbitrary single-qubit rotations and two-qubit gates. Fast readout of the quantum dot states is performed with a nearby single electron transistor. Carefully tuned voltages applied to 14 metallic electrodes on the device, define the confinement potential for the qubit electrons and the single electron transistor. Single- and two-qubit gates are implemented by applying fast microwave and DC pulses to the same electrodes. More details on the functional requirements and the device lifecycle including materials, fabrication and electrical screening can be found in Figure 1 and in reference [1]. The key performance parameters of our Spin-2 QPU is in table 1.

Table 1 Key performance parameters of the Spin-2 QPU.

Key performance parameters	*Spin-2*
Material	Si-28 QW in SiGe
Single qubit gate control	EDSR microwave pulsing
Two-qubit gate control	Exchange interaction
Read-out	Spin-selective tunneling
Energy relaxation time T1	> 20 ms (similar device)
*Phase coherence time T2**	> 6 µs
Single-qubit gate fidelity (RB)	~ 99.0% (average)
Two-qubit gate fidelity	> 90% (estimate - under validation)
Initialization+readout fidelity	~ 85% (average)
Single-qubit gate duration	250 ns (average)
Two-qubit gate duration	150 ns
Readout duration	2 x 300 µs = 600 µs (sequential readout)

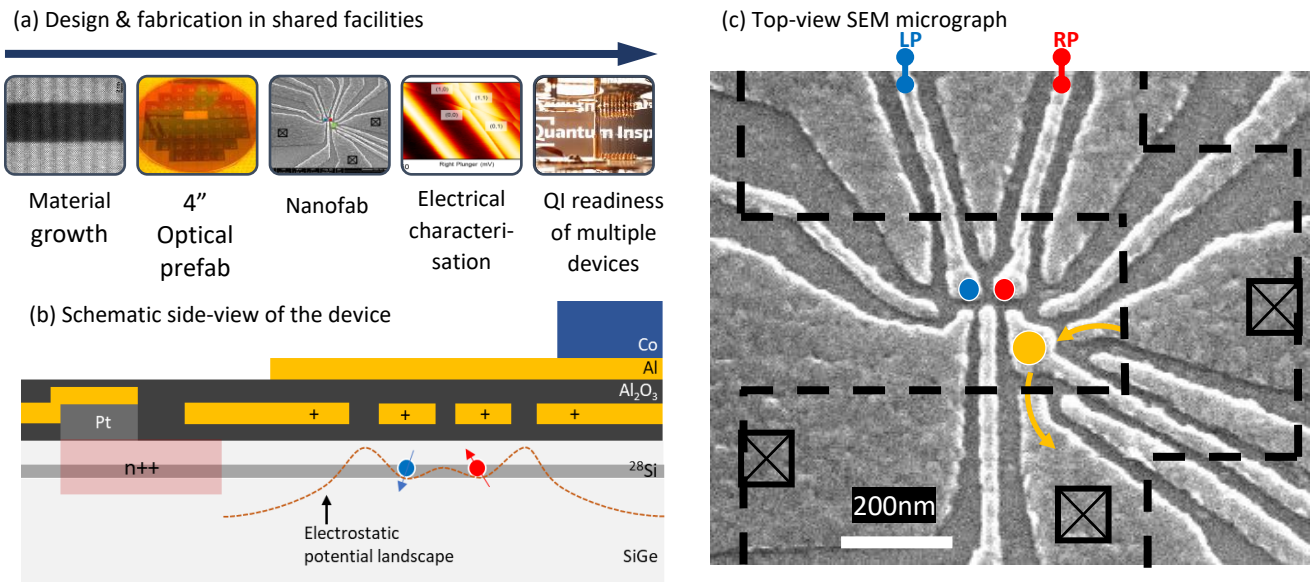

Figure 1 The design and fabrication of the 28Si-based two spin qubit quantum processor: In (a) the device development feedback loop is presented including materials growth, pre- and nanofabrication of the device, with subsequent electrical screening. The optical CMOS-based prefab step for the chip periphery ensures an increased device turn-around and fast process development learning. The nanoscale part of the devices is fabricated with electron beam lithography. Only after thorough electrical screening QI readiness of the chips is determined. (b) A schematic side-view cross-cut of a typical quantum device design. Picture adapted from [1].

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