

Si based quantum processors For Large Scale Quantum Computation

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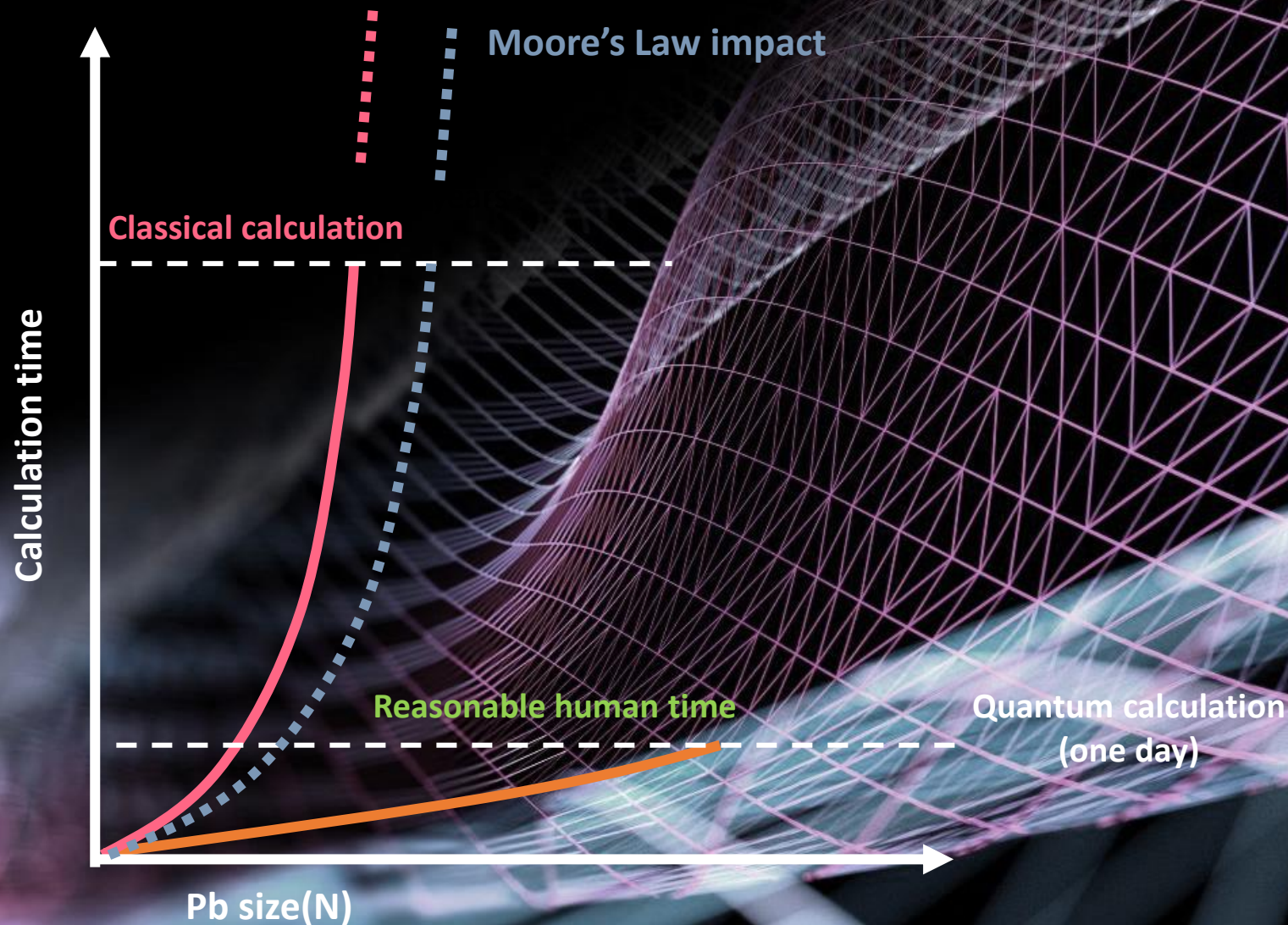
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QUANTUM COMPUTING PROMISE

› Provides access to uncharted computation territories



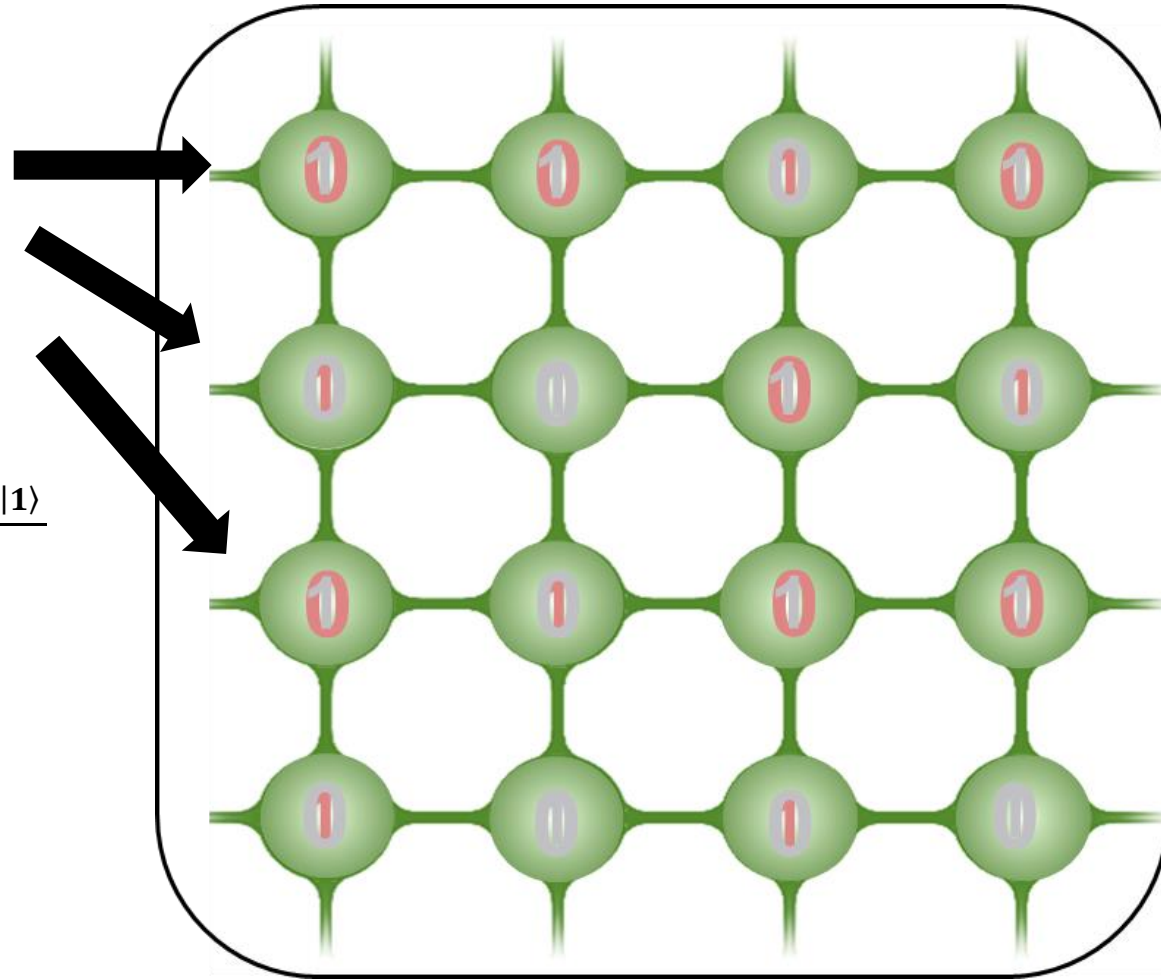
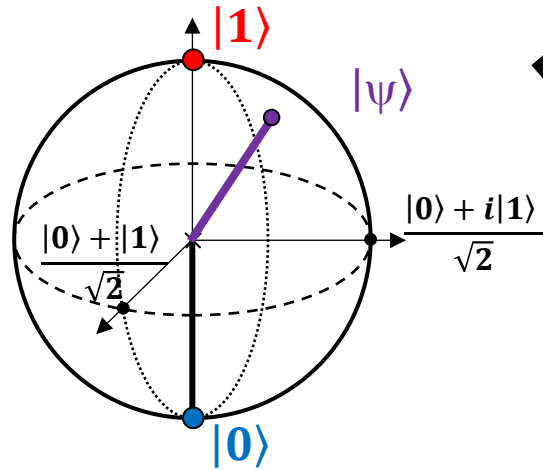
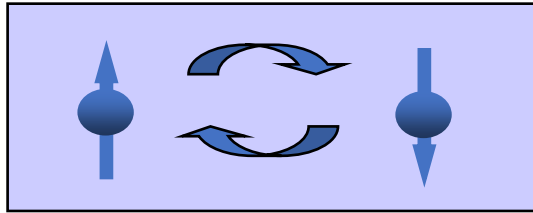
~ nb of qubits > 100

WHAT IS NEEDED TO BUILD A (QUANTUM) COMPUTER

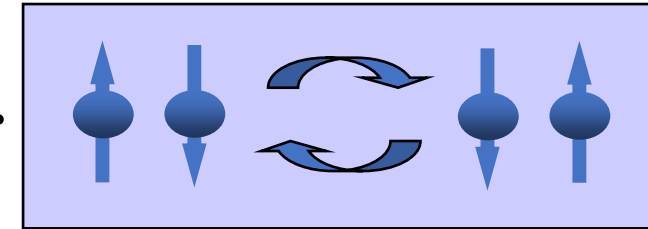
- Quality (yield and robustness)
- Scalability (control and technology)
- Energy, computing and cost efficiency
- Software stack

Topology: 2D arrangement and 4 neighbors

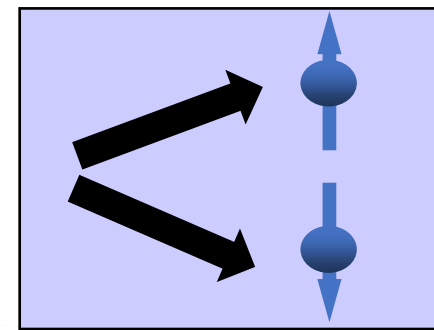
One-qubit gate



Two-qubit gate



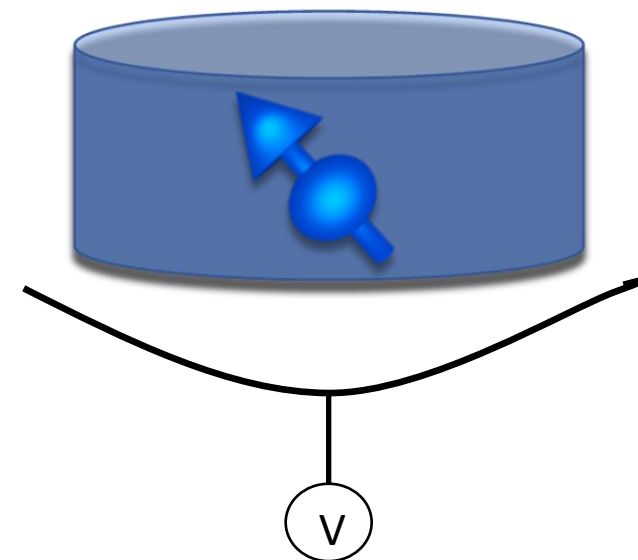
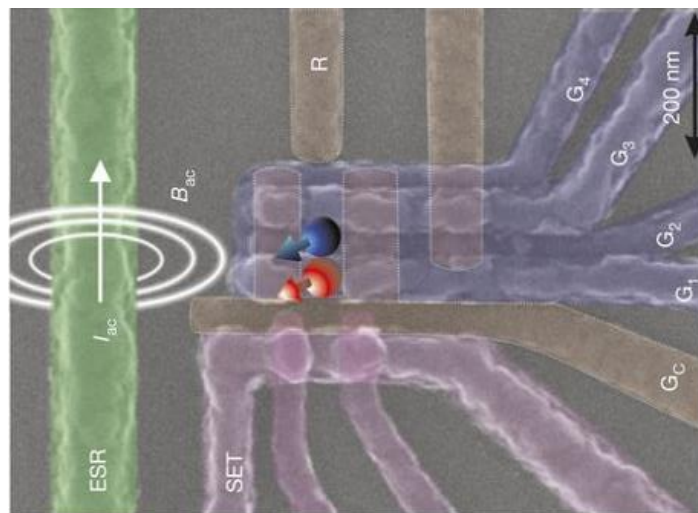
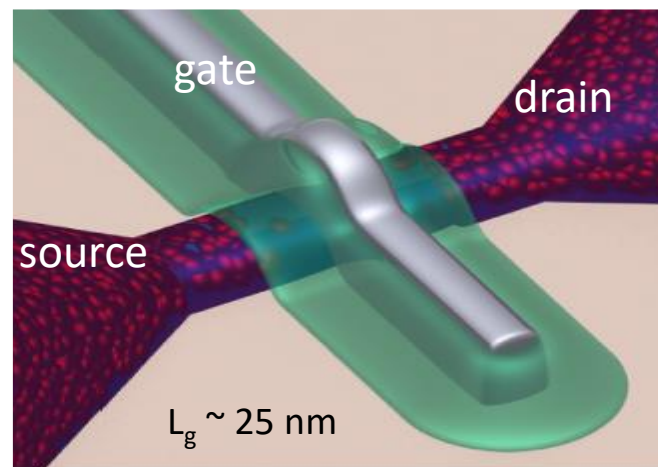
Read-out gate



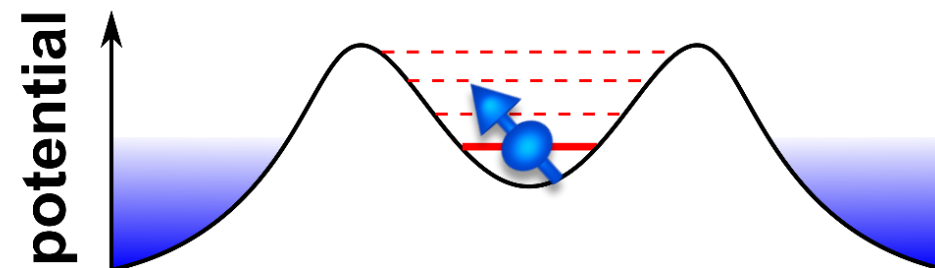
Silicon spin qubits

Si spin

Size	$(100\text{nm})^2$
Fidelity	>99%
Speed	$\sim 1 \mu\text{s}$
Manufacturing	
Qubit Variability	0.1%-0.5%
Operation T°	1K
Connectivity	4
Entangled qubits	12

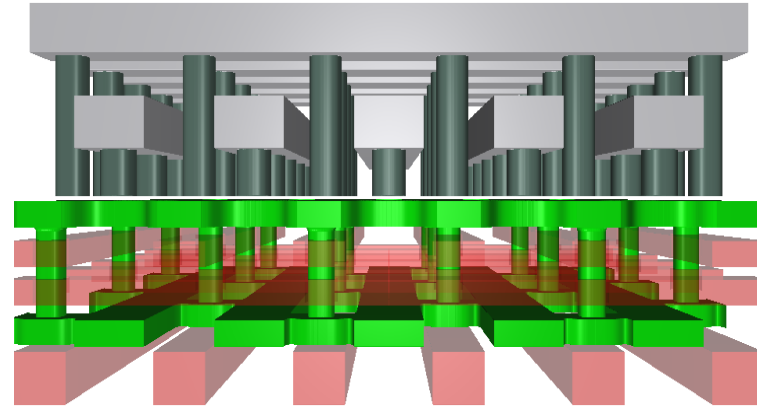


Gate voltage

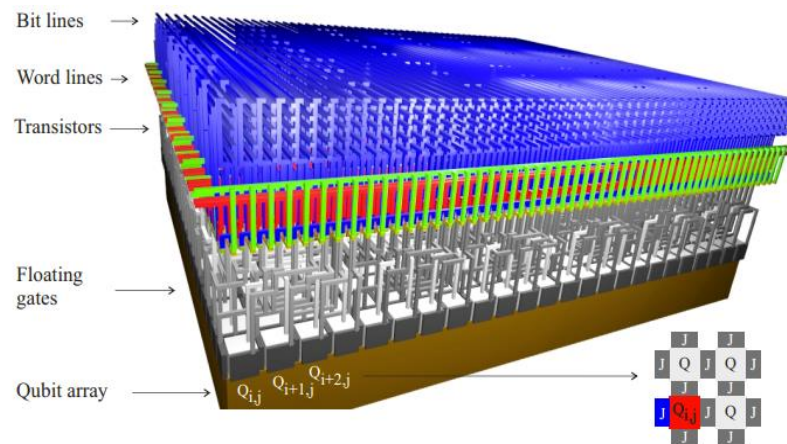


Spin based Quantum computer architectures

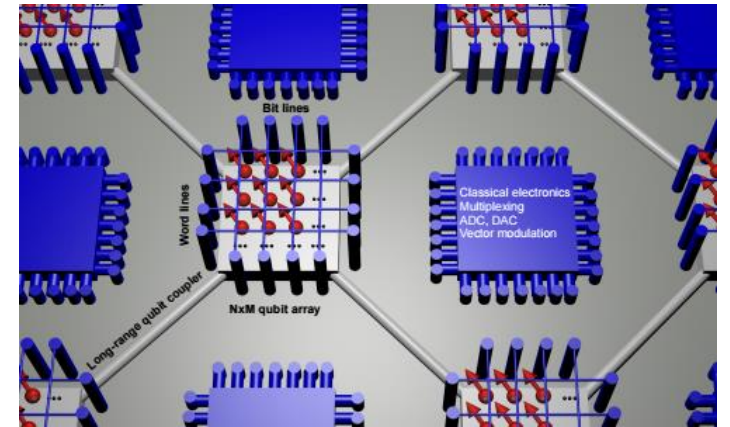
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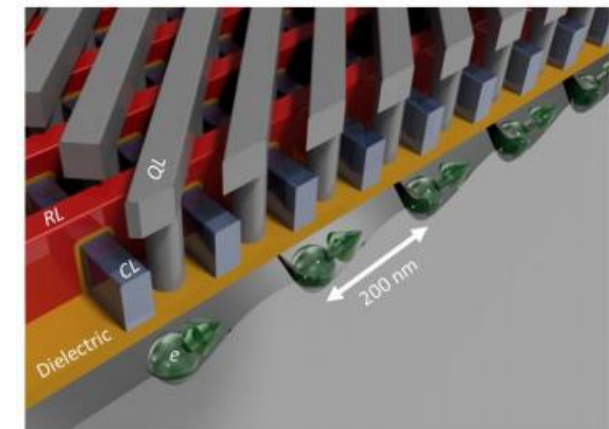
M. Vinet et al et al., IEDM (2018)
3D integration of quantum processor and classical control system



M. Veldhorst et al. (UNSW), Nature Comm. (2017)
10 transistors and 13 control lines per qubit



L.M.K. Vandersypen et al., npj Quant. Inf. (2017)
Monolithic coplanar integration of classical and quantum electronics + long range coupling



R. Li et al., Science express (2017)
Line/column/diagonal addressing of tunnel barriers and QD potentials

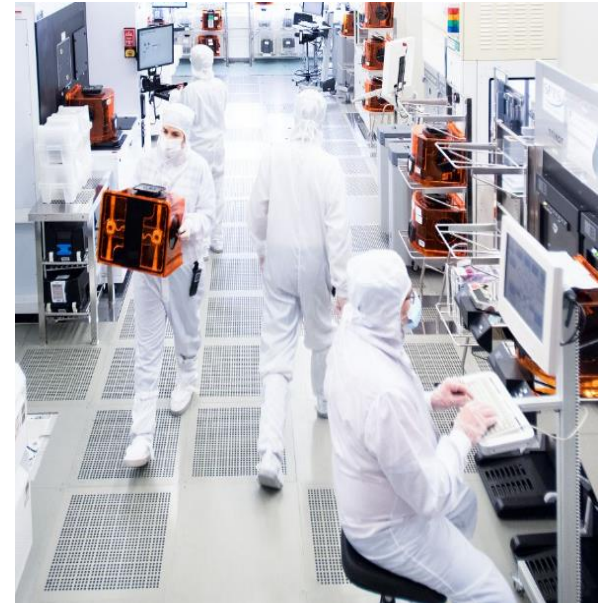
Semiconductor industry potential

Good quality qubits

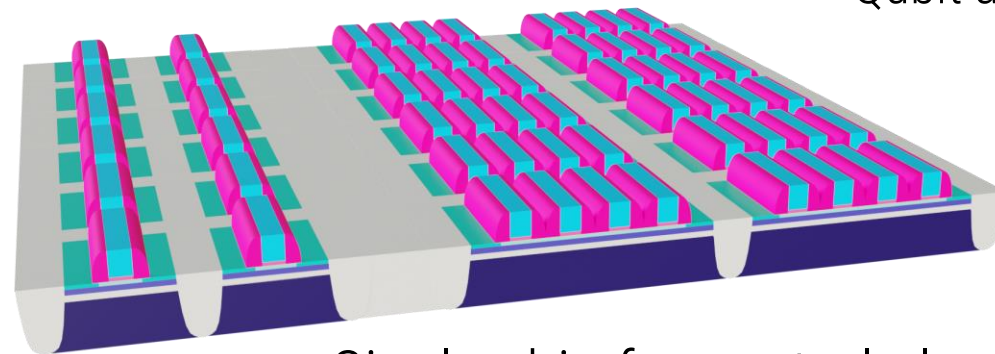
- ✓ $(100\text{nm})^2$
- ✓ Coherence time msec
- ✓ Fidelity >99%
- ✓ Speed of operation ~usec

Effective way to control and program these millions of good qubits

Millions of good qubits



Computer to control the qubit array

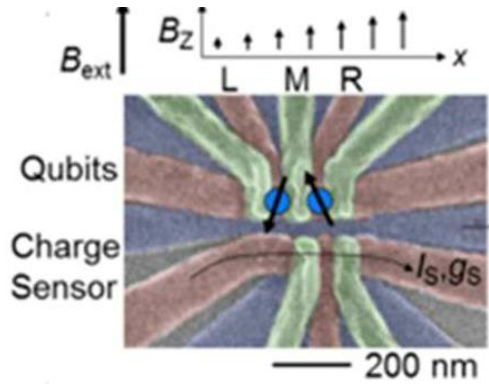


Siquance

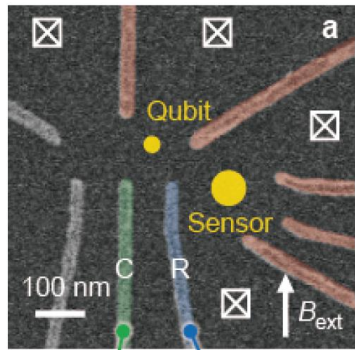
Single chip for control electronics and qubits

Qubit array

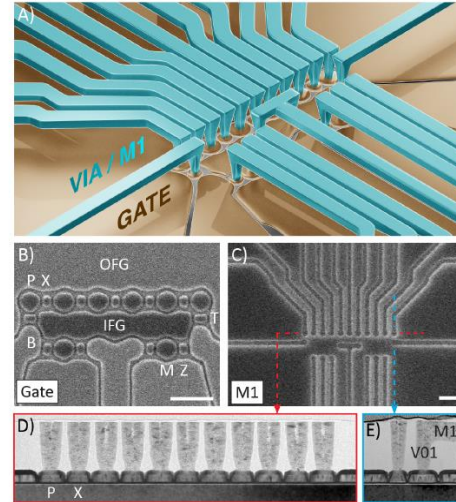
The path towards industrialization



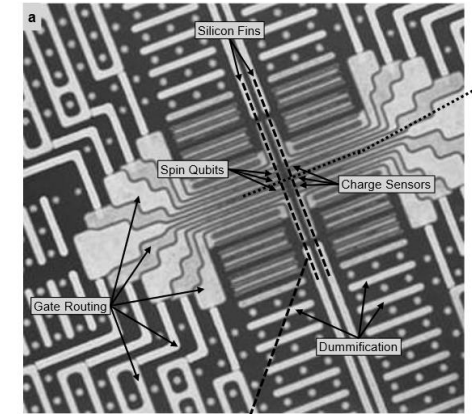
@Princeton



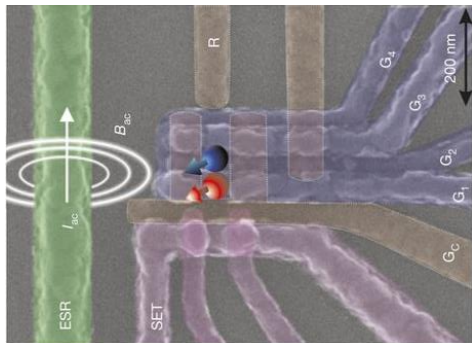
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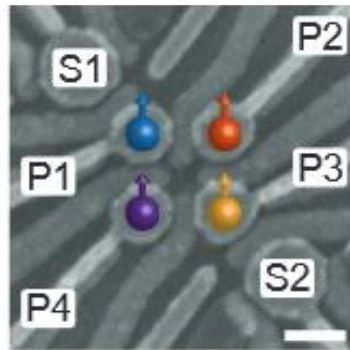
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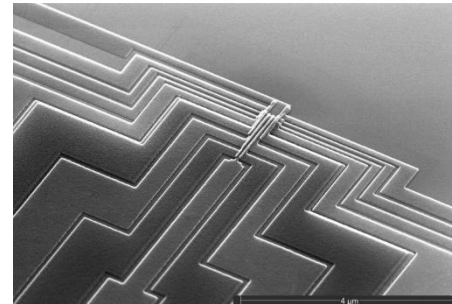
@Intel



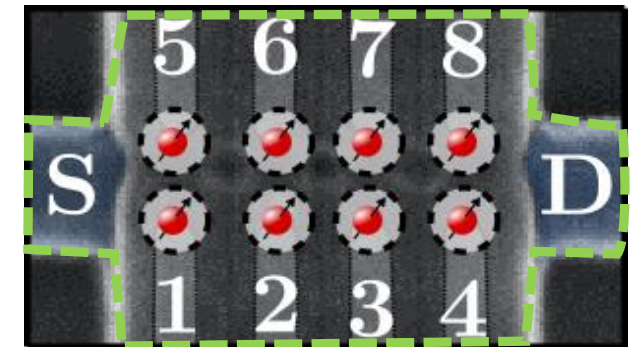
@UNSW



@Delft



@IMEC



@Grenoble

Academic fab line,

Wide range of fab protocols for improving qubit performance (ebeam, lift-off)
 Many materials (Si, SiGe, Ge)
 Many substrates investigated (2DEG, MOS, FinFET, FdSOI)

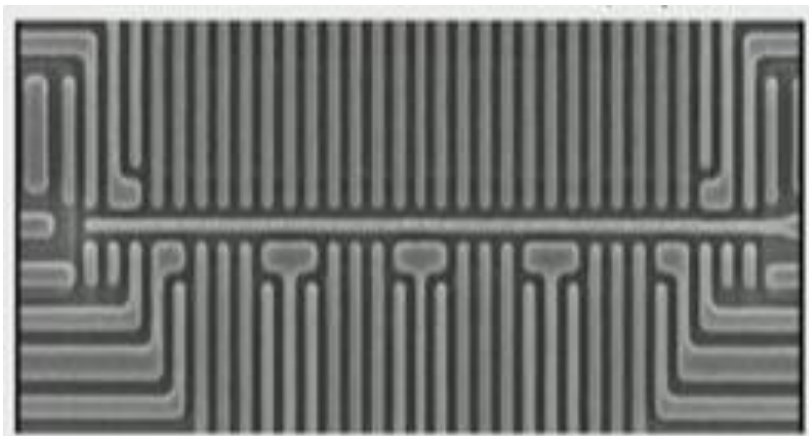
Advanced fab line,

150-300mm tools,
 Wide range of fab protocols for improving qubit performance
 Focus on Si and SiGe technology
 Many substrates investigated (2DEG, MOS, FinFet, FdSOI)

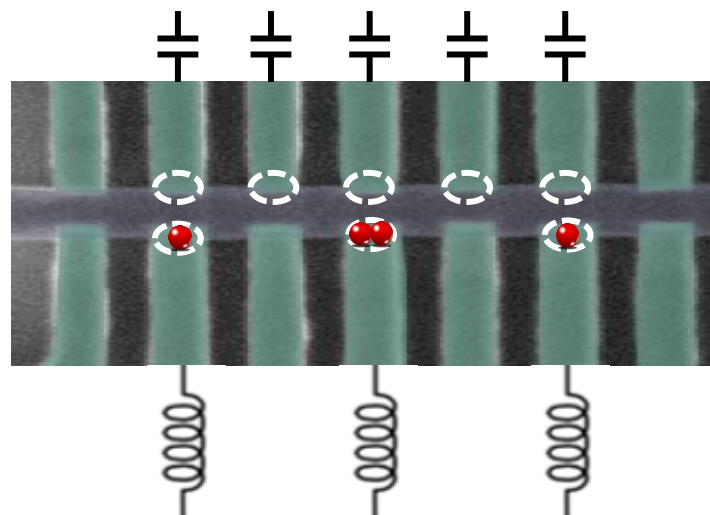
Pre-Industrial fab line,

300mm tools,
 Design and material constrains for high yield
 Industrial technology
 (FdSOI, FinFet only)

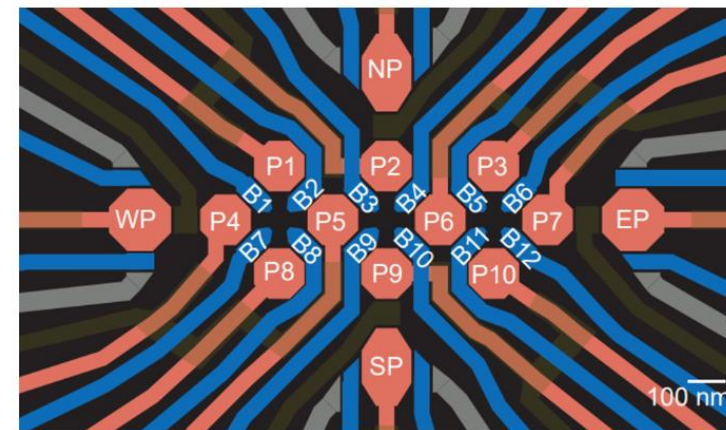
State of art number of qubits



12 qubit linear array (2DEG and Finfet, Tunnel Falls, Intel)

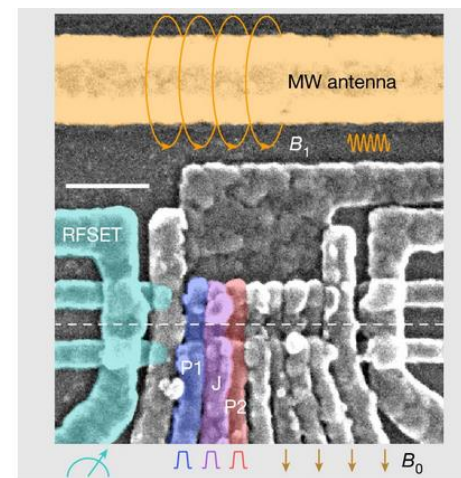


5x2 qubit bilinear array (FDSOI technology, Grenoble)



Legend:
Plunger gates (red)
Barrier gates (blue)
Screening gates (green)
Ohmics (grey)

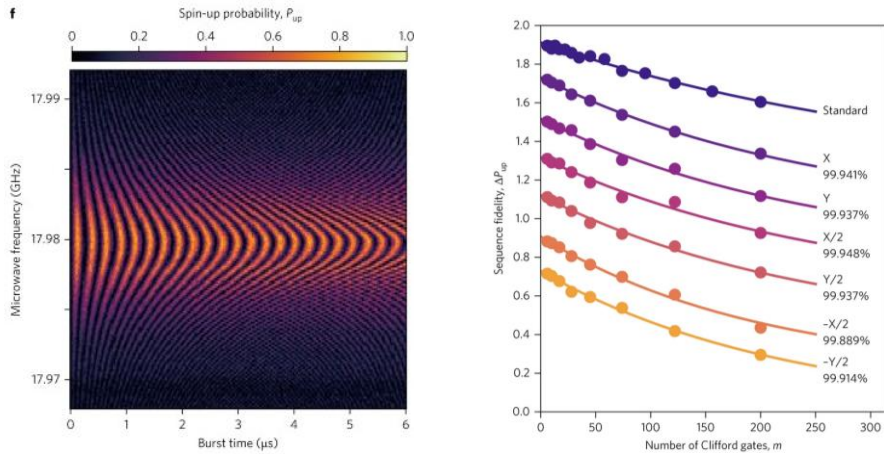
10 qubit trilinear array (2DEG Germanium Delft)



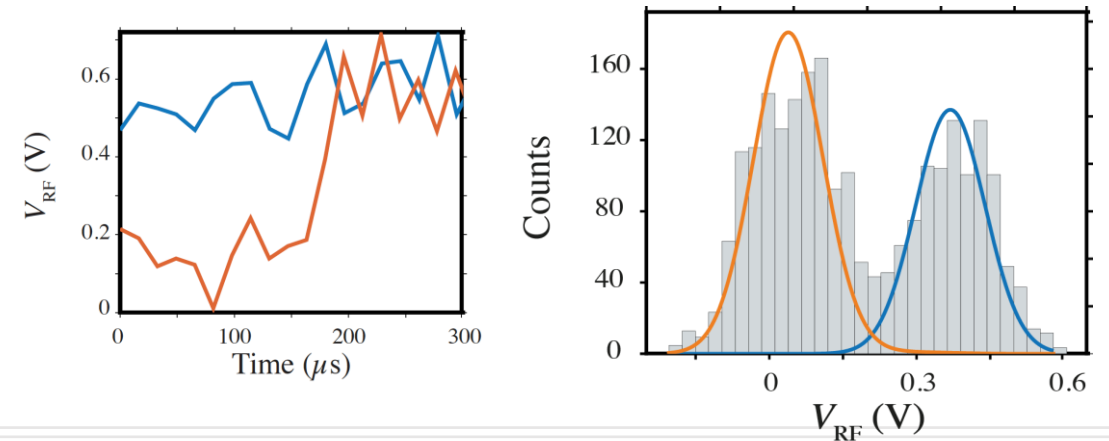
4 qubit linear array (SiMos technology, Sydney)

Few qubit demonstrations

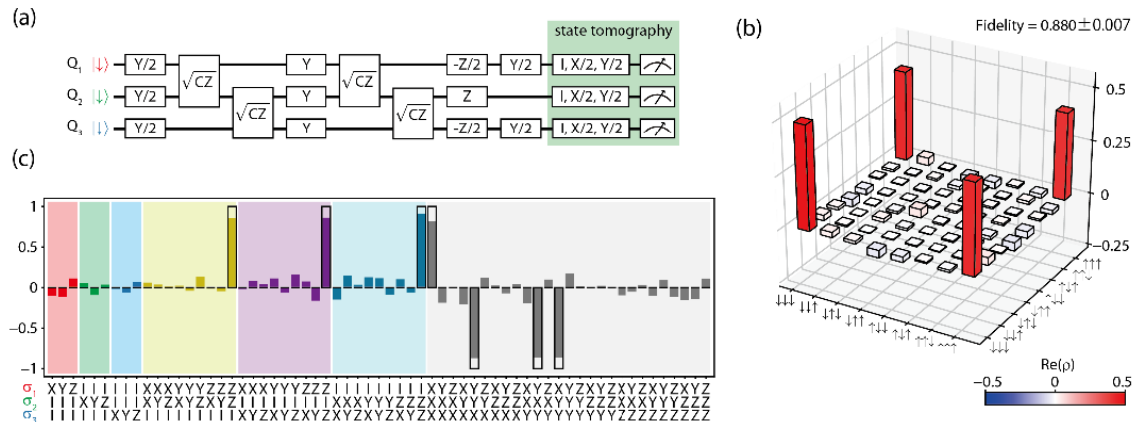
Up to 99.999 one qubit gate below 1 μs (Tokyo)



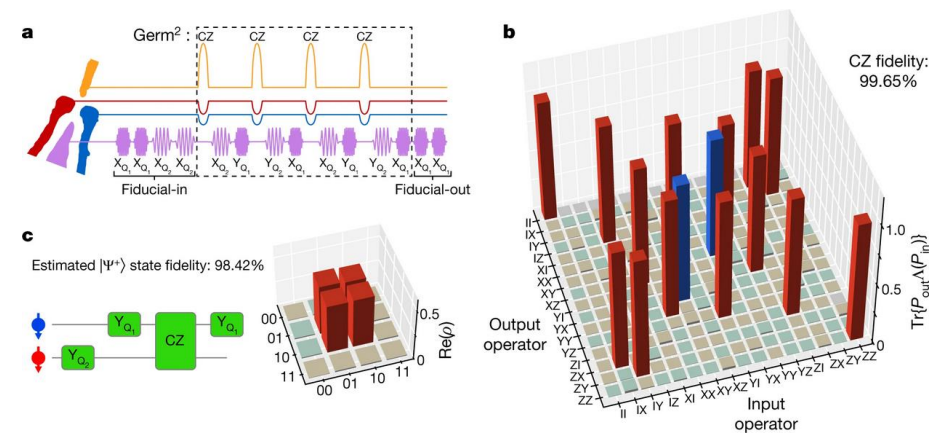
Over 99% single shot spin read-out below 1 μs (Grenoble)



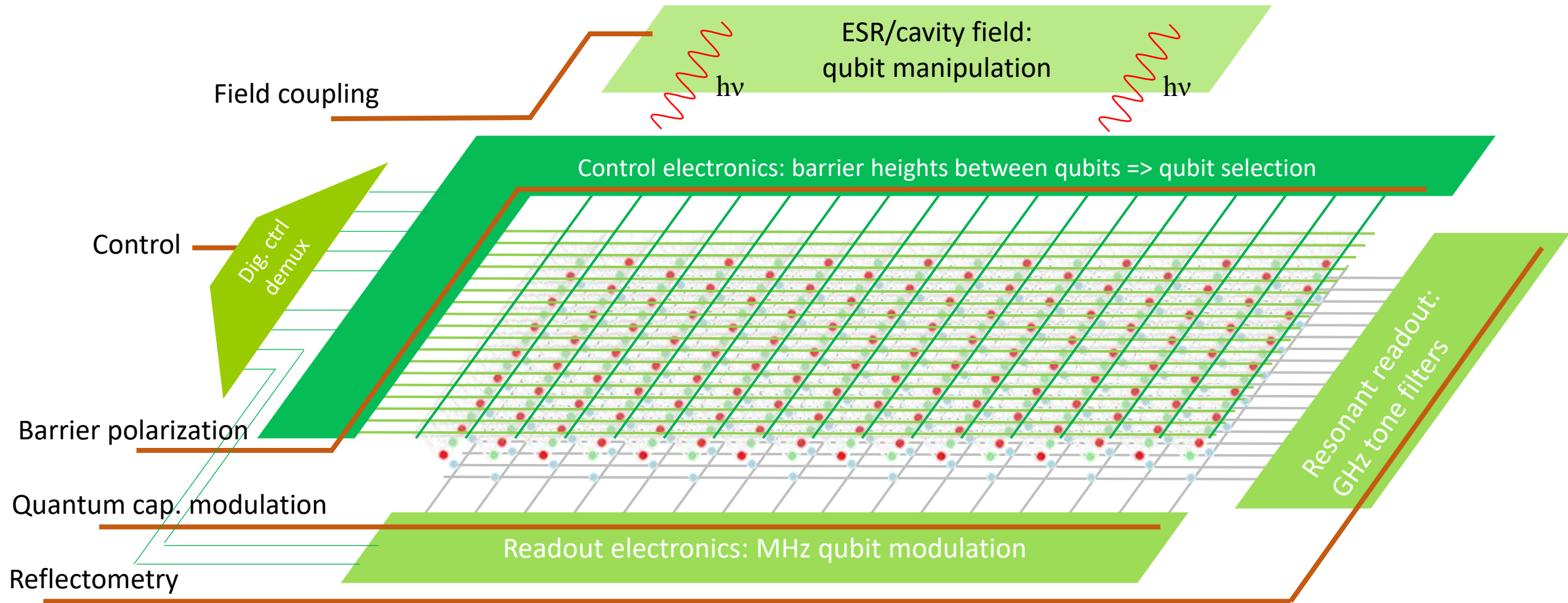
Entanglement up to three qubits (Tokyo)



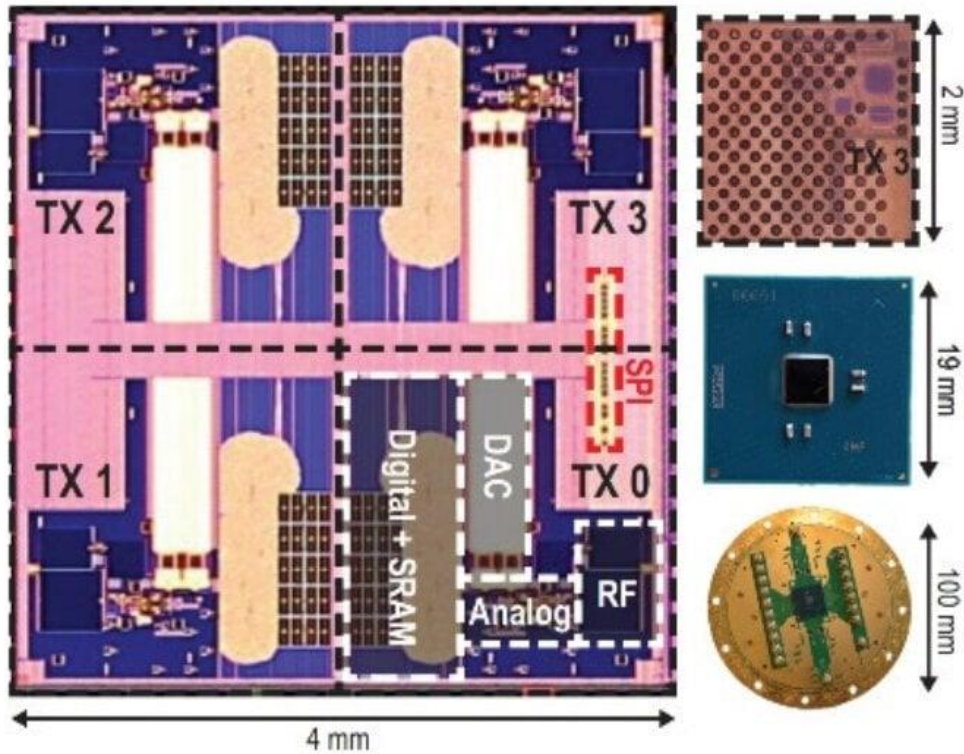
Up to 99.6% fidelity two qubit gate (Delft)



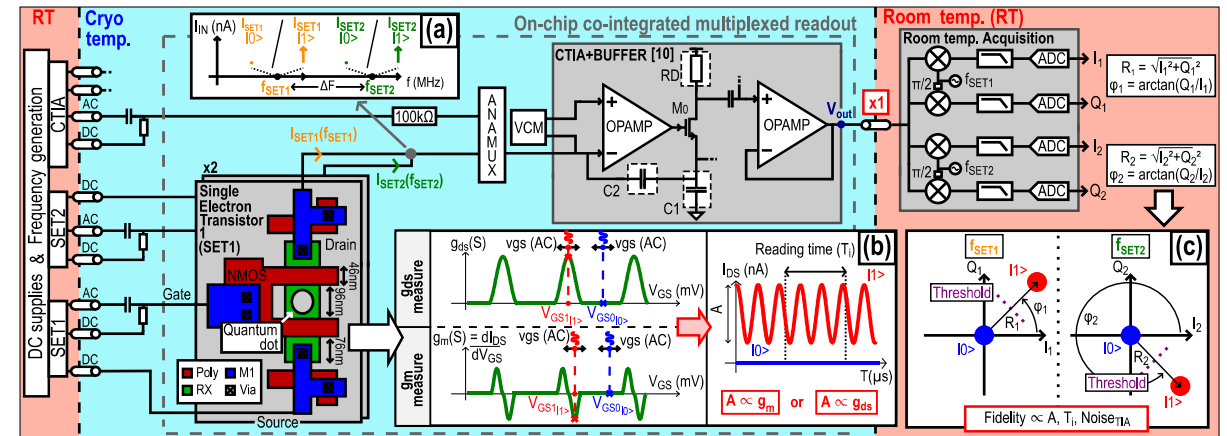
Cryogenic Quantum control architecture



Cryoelectronics developments

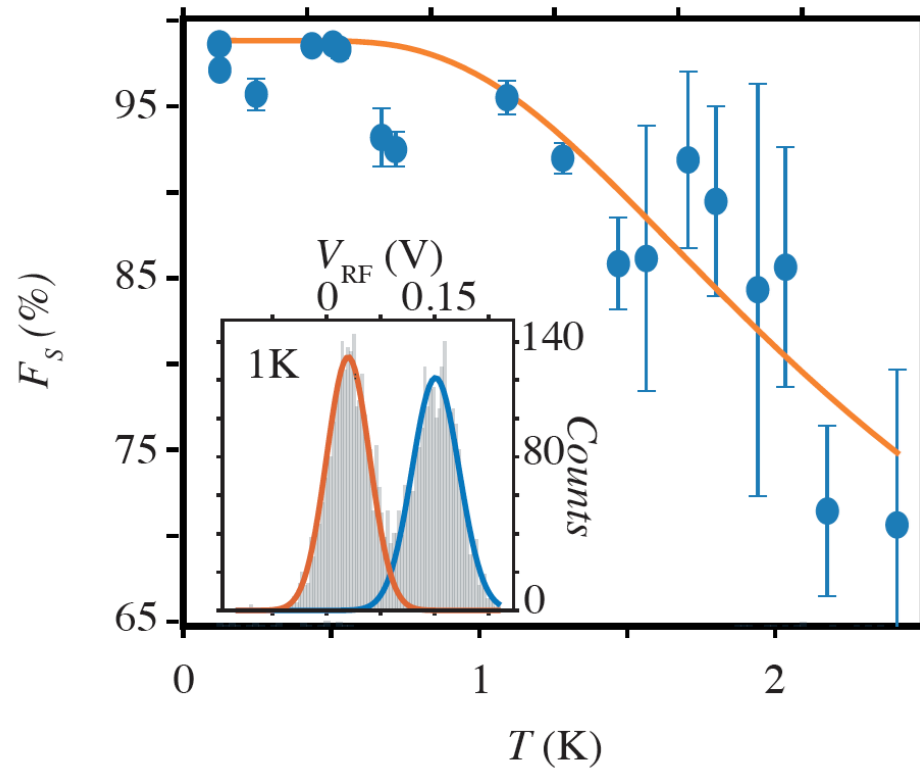


128 qubit control (22nm Intel, Horse ridge, Intel)



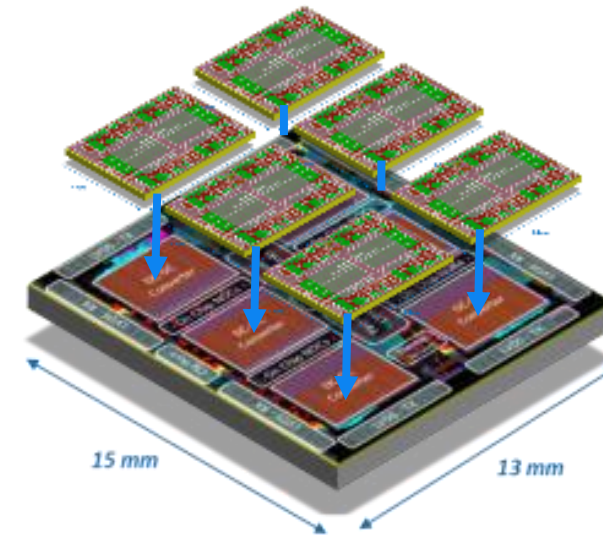
Quantum dot co-integrated with amplifier(22FDX and 28FD, Grenoble)

Fidelity Vs Temperature



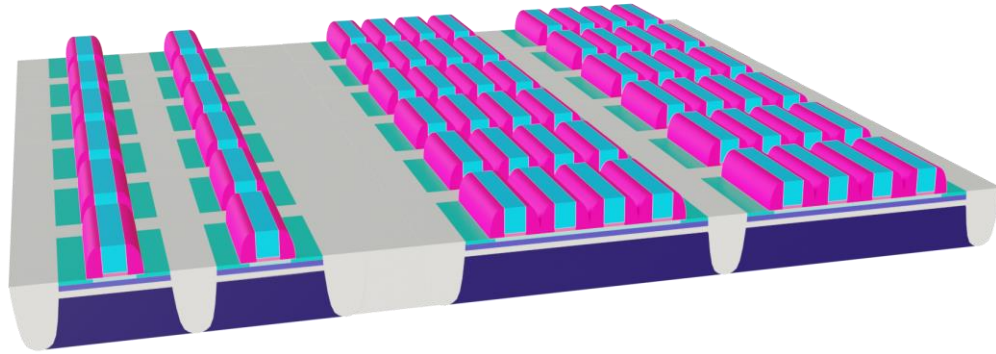
$$\Delta\varphi \propto T^{-1} \cosh(aT^{-1})$$

Urdampilleta et al. Nat. Nanotechnol. (2019).

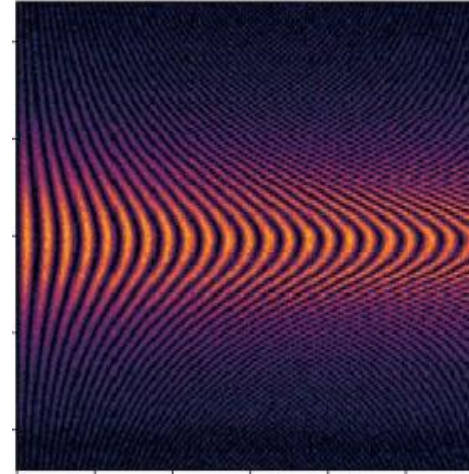


T° of operation	Typical cooling power
30mK	10 μ W
100mK	100 μ W
1K	100mW

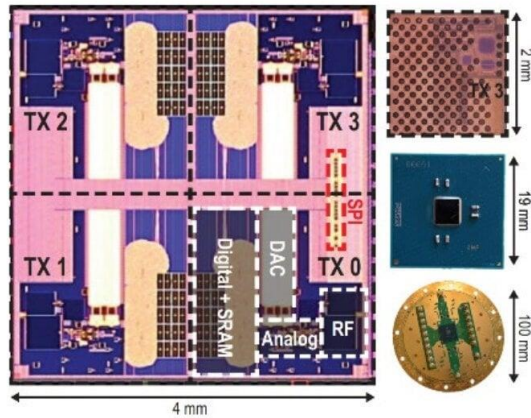
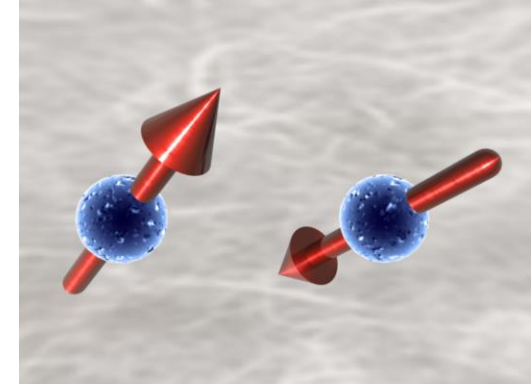
Conclusions and perspectives



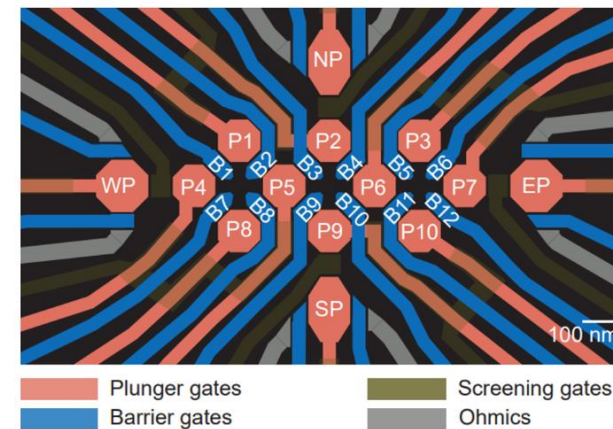
Co integrated Control and quantum hardware



HIFI quantum manipulation



Cryo control



Multi qubit devices