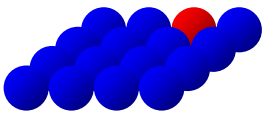
Quantum computing
Supporting slides

the issue: decoherence

the Schroedinger equation expresses a smooth evolution of quantum systems

BUT

in real world no individual quantum state is isolated: you can approximately consider it isolated for a limited time



decoherence in practice

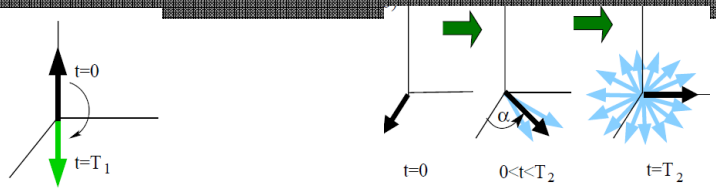
two time scales relevant to establish how long I can use a qubit

T_1: relaxation time – the qubit relaxes to the ground state after ~T_1

T_2: dephasing time, after which the state is affected by wrong precession in the x-y plane on the Bloch sphere

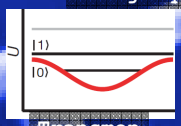
T_2 is usually << than T_1 T_2^* is on the average of many qubits

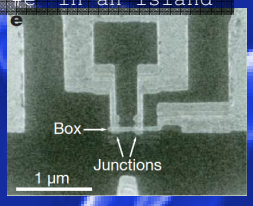
Hu, De Sousa, Das Sarma Decoherence and dephasing in spin-based solid state quantum computers arxiv: 0108339v2



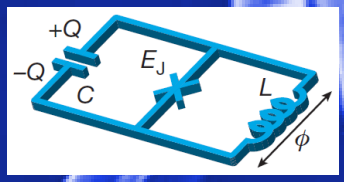
superconducting qubits

Charge qubit: 1e⁻ in an island

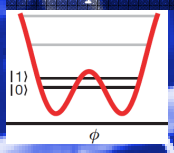




Transmon



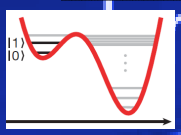
Flux qubit: direction of loop's current

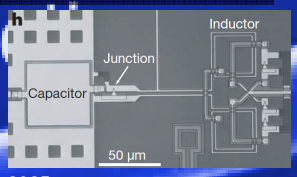


ϕ is the magnetic flux across the inductor

Ladd et al. Quantum Computers Nature 2010
Buluta et al. Natural and artificial atoms for quantum computation Rep. Prog. Phys. 2011

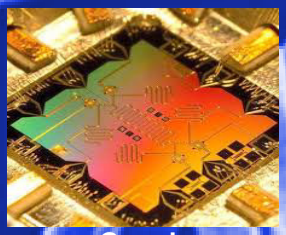
Phase qubit: oscillatory state



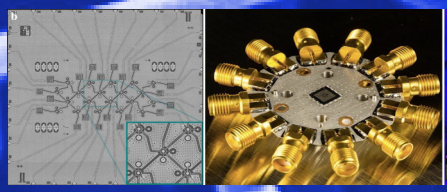


1 μm

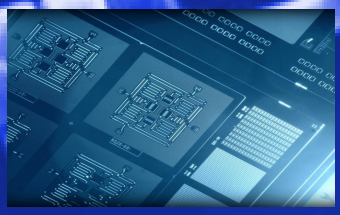
superconducting qubits



Google



Intel

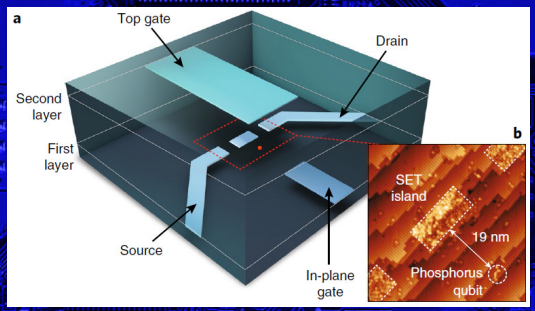


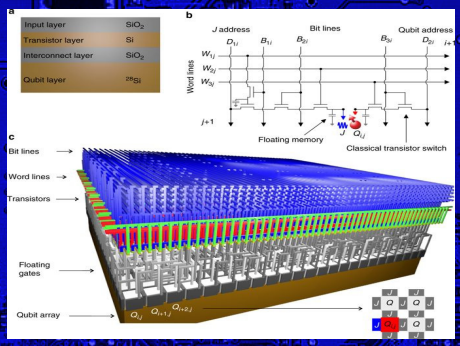
Junctions

IBM

1 μm

spin in silicon qubits

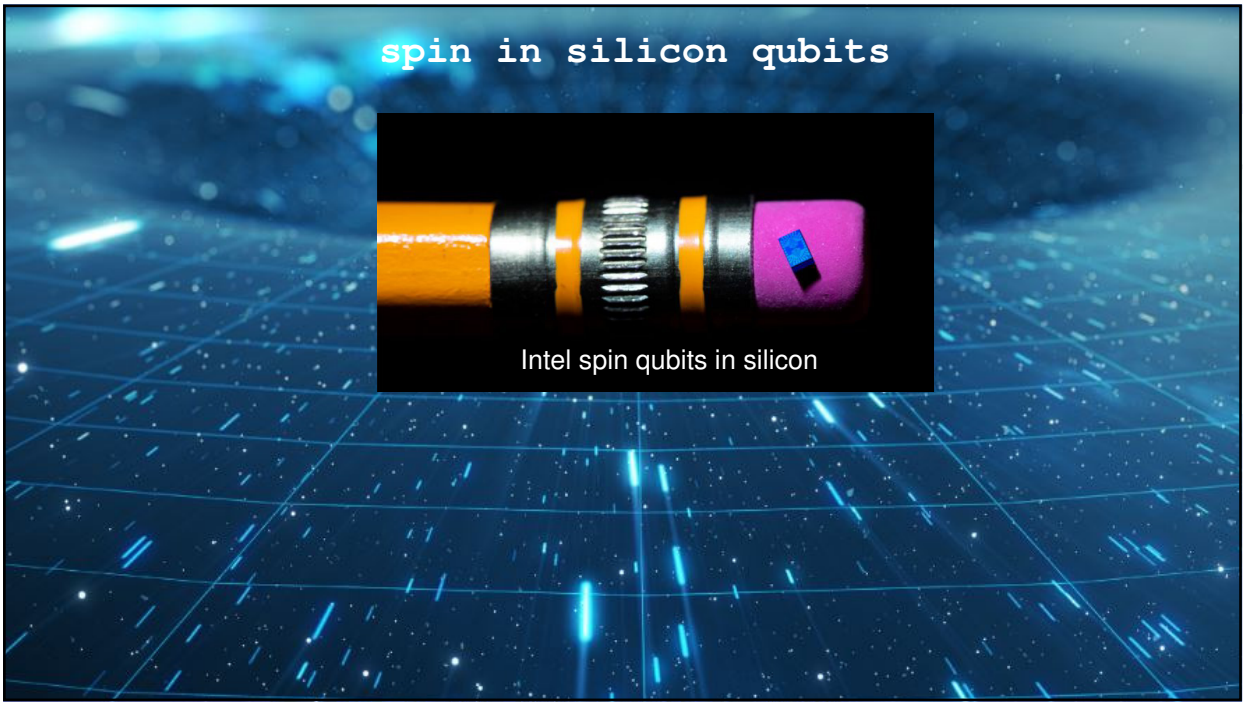


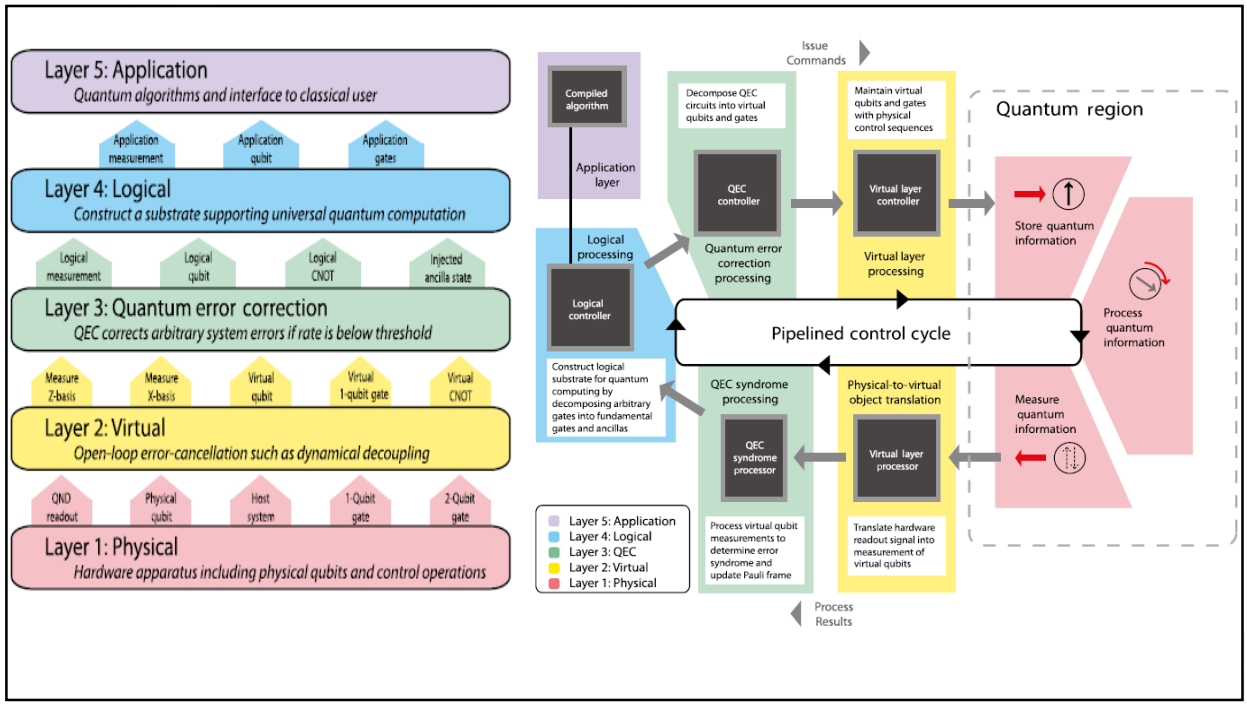


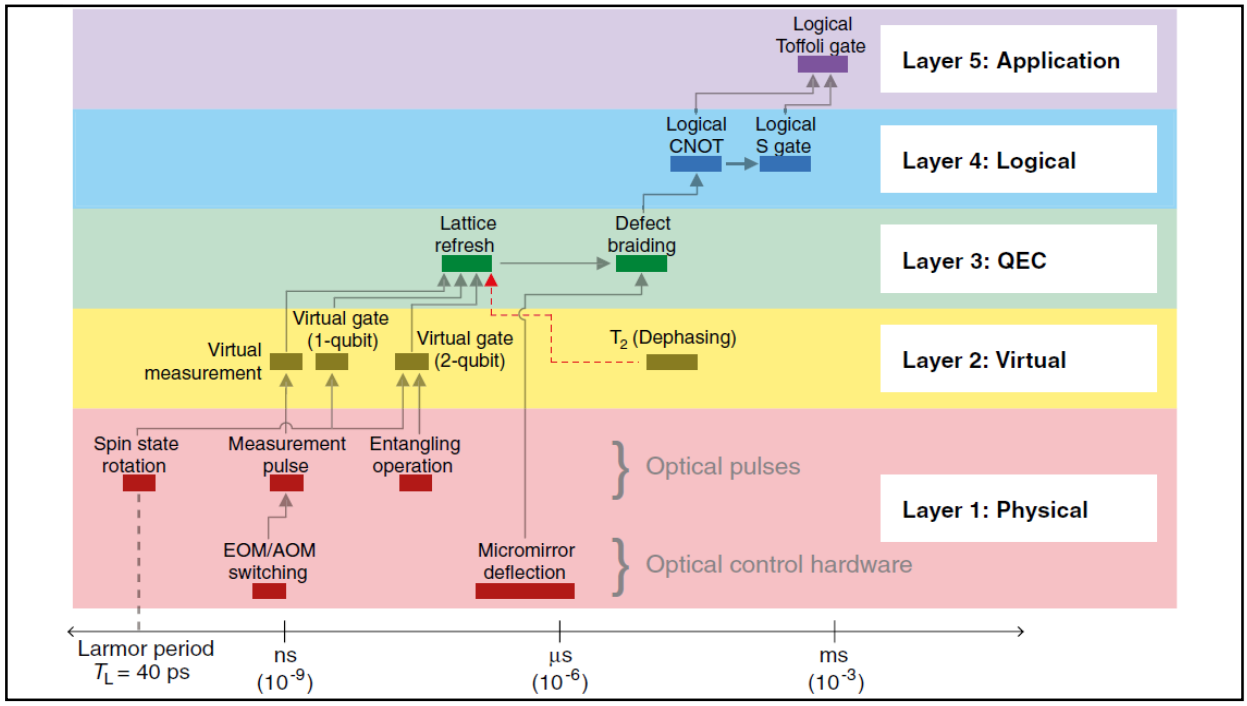
Silicon CMOS architecture for a spin-based quantum computer

M. Veldhorst, H. G. J. Eenink, C. H. Yang & A. S. Dzurak

Nature Communications 8, Article number: 1766 (2017) | Download Citation


spin in silicon qubits
Intel spin qubits in silicon


Layer 5: Application
Quantum algorithms and interface to classical user
Application measurement
Application qubit
Application gates
Layer 4: Logical
Construct a substrate supporting universal quantum computation
Logical measurement
Logical qubit
Logical CNOT
Injected ancilla state
Layer 3: Quantum error correction
QEC corrects arbitrary system errors if rate is below threshold
Measure Z-basis
Measure X-basis
Virtual qubit
Virtual 1-qubit gate
Virtual CNOT
Layer 2: Virtual
Open-loop error-cancellation such as dynamical decoupling
QND readout
Physical qubit
Host system
1-Qubit gate
2-Qubit gate
Layer 1: Physical
Hardware apparatus including physical qubits and control operations
Issue Commands
Compiled algorithm
Application layer
Logical processing
Logical controller
Construct logical substrate for quantum computing by decomposing arbitrary gates into fundamental gates and ancillas
Decompose QEC circuits into virtual qubits and gates
QEC controller
Quantum error correction processing
Maintain virtual qubits and gates with physical control sequences
Virtual layer controller
Virtual layer processing
Pipelined control cycle
QEC syndrome processing
QEC syndrome processor
Process virtual qubit measurements to determine error syndrome and update Pauli frame
Physical-to-virtual object translation
Virtual layer processor
Translate hardware readout signal into measurement of virtual qubits
Quantum region
Store quantum information
Process quantum information
Measure quantum information
Layer 5: Application
Layer 4: Logical
Layer 3: QEC
Layer 2: Virtual
Layer 1: Physical
Process Results


Logical Toffoli gate
Layer 5: Application
Logical CNOT
Logical S gate
Layer 4: Logical
Lattice refresh
Defect braiding
Layer 3: QEC
Virtual measurement
Virtual gate (1-qubit)
Virtual gate (2-qubit)
T2 (Dephasing)
Layer 2: Virtual
Spin state rotation
Measurement pulse
Entangling operation
Optical pulses
Layer 1: Physical
EOM/AOM switching
Micromirror deflection
Optical control hardware
Larmor period
TL = 40 ps
ns
(10-9)
μs
(10-6)
ms
(10-3)