2nd EU-Japan Digital Week 2026
Semiconductor WS: “Japan-EU Cooperation on Advanced Computing, Advanced Functionalities and Semiconductor Value Chain”
24 March, 2026, University of Tokyo, Japan

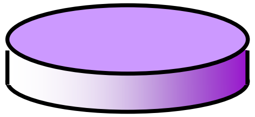
High-fidelity Qubit Devices in Silicon

Seigo Tarucha

RIKEN Center for Emergent Matter Science
& Quantum Computing

Spin Qubits in Silicon

Si



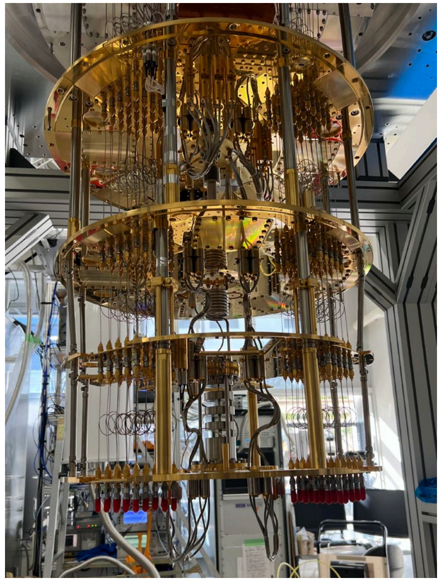
100nm

Small footprint

Small foot print

Compatibility with CMOS based manufacturing techniques

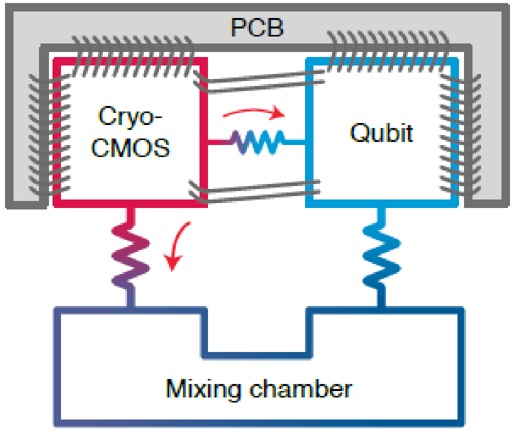
Possible integration with cryo-electronics at > 0.1 K



← > 1K

← < 0.1 K

Quantum processor



S.J.Pauka et al.
Nat. Electron. 4, 64 (2021)

Industrial Technology of 300mm Process Line

intel

imec

leti
cea tech

Startups & Spin-offs

Silicon Quantum Computing
(2017)

QUANTUM MOTION
(2017)

equal1
(2017)

QUANTUM MACHINES
(2018)

QuEL, Inc.
(2021)

diraq
(2021)

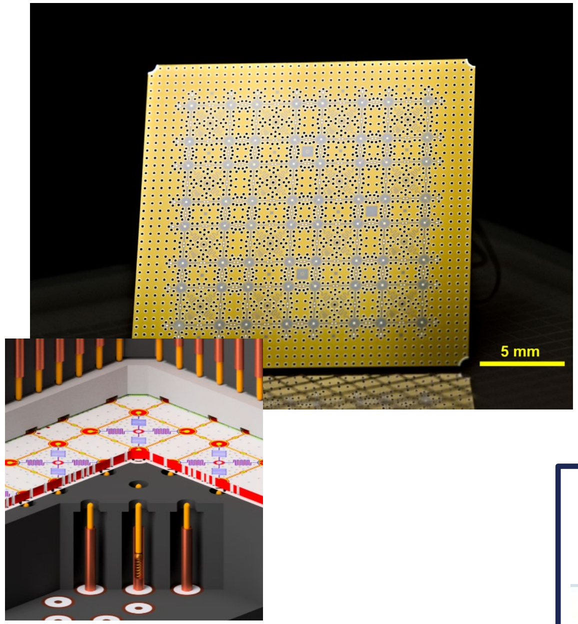
quobly
(2022)

Groove Quantum
(2024)

…and more!

RIKEN Research Center for Quantum Computing

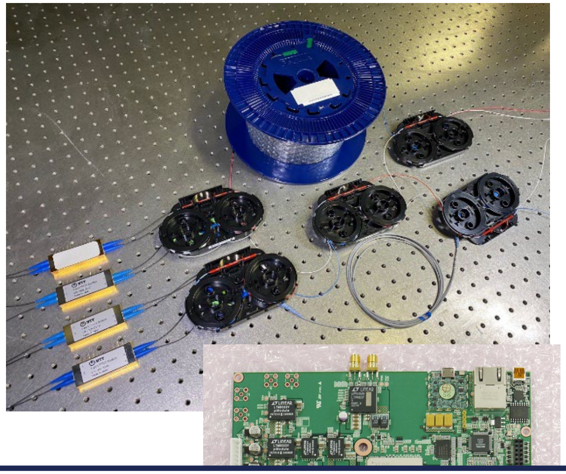
SC



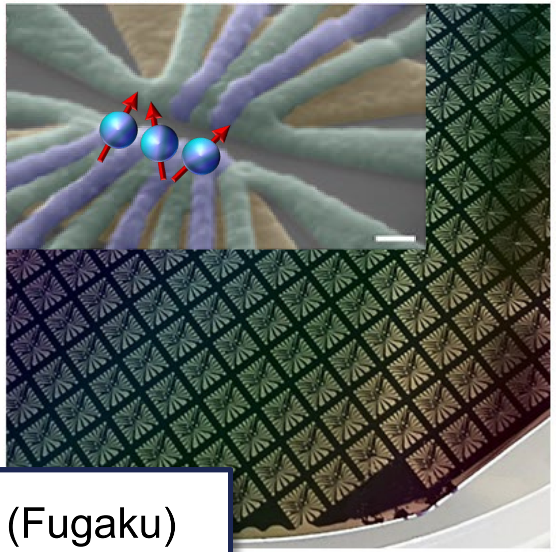
RIKEN/FUJITSU

- 3x64 qubits QC for crowd services

Optical

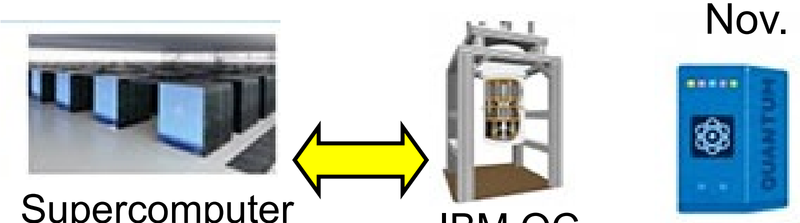


Semiconductor



A project to hybridize QC and HPC (Fugaku)

Nov. 2023



Supercomputer

IBM QC

Quantinuum QC

Pioneer a new calculation regime which enables to apply for designing new materials and medicines and calculating many-body states.

Moonshot R&D Program

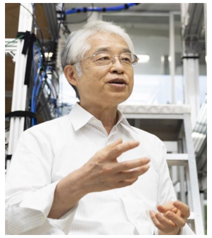
Japan Science and Technology Agency (JST):
Funding of **10 Moonshot goals** until 2050
Fields: AI, quantum technologies, robotics, and sustainability

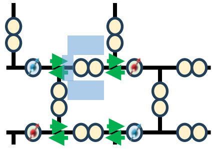
Moonshot Goal 6

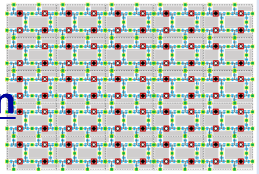
Realization of a fault-tolerant universal quantum computer that will revolutionize economy, industry, and security by 2050.

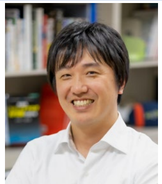

Program Director for QC
Prof. Masahiro Kitagawa

R&D Project Development of fault-tolerant Silicon quantum computer technology


Project Manager:
Prof. Seigo Tarucha, RIKEN

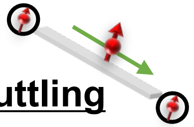

Scalable Spin Qubit unit cell with QEC
T. Nakajima, RIKEN



Scale-up & QEC System integration
H. Mizuno, Hitachi



Wiring & Packaging
T. Miki, Kobe-U


Scalable readout
T. Kodera, TS-U


New qubits
J. Yoneda, Tokyo-U


Qubit shuttling
T. Fujita, Osaka-U


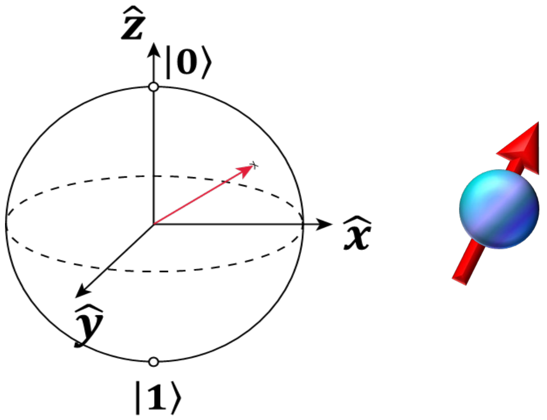

28Si/SiGe Substrate
S. Miyamoto, AIST

Agenda

- High qubit fidelity > 99.99 % by optimizing the qubit drive
- Simultaneous operation of multiple qubits, critical for mitigating problems of qubit decoherence and scale up
- Integration and shuttling technologies for scaling up qubit arrays

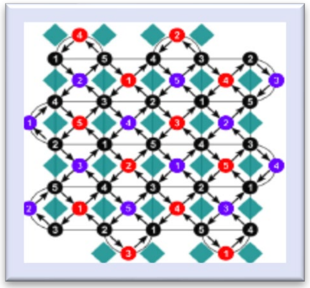
Challenges in Semiconductor QC

- **High fidelity qubit control (> FTQC threshold 99%)**
  to reduce physical qubit overhead for making a logical qubit



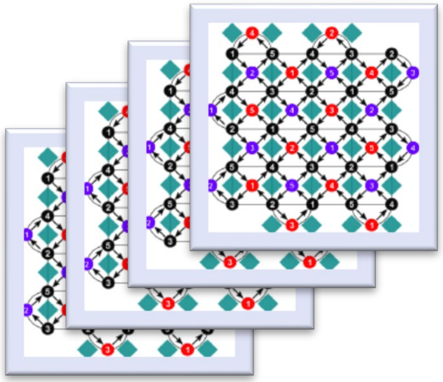
- **QEC**
  to implement logical qubits

Logical qubit



Gambetta *et al.*, NPJ QI (2017).

- **Scale-up > 10^6 qubits**
  to implement large-scale FTQC

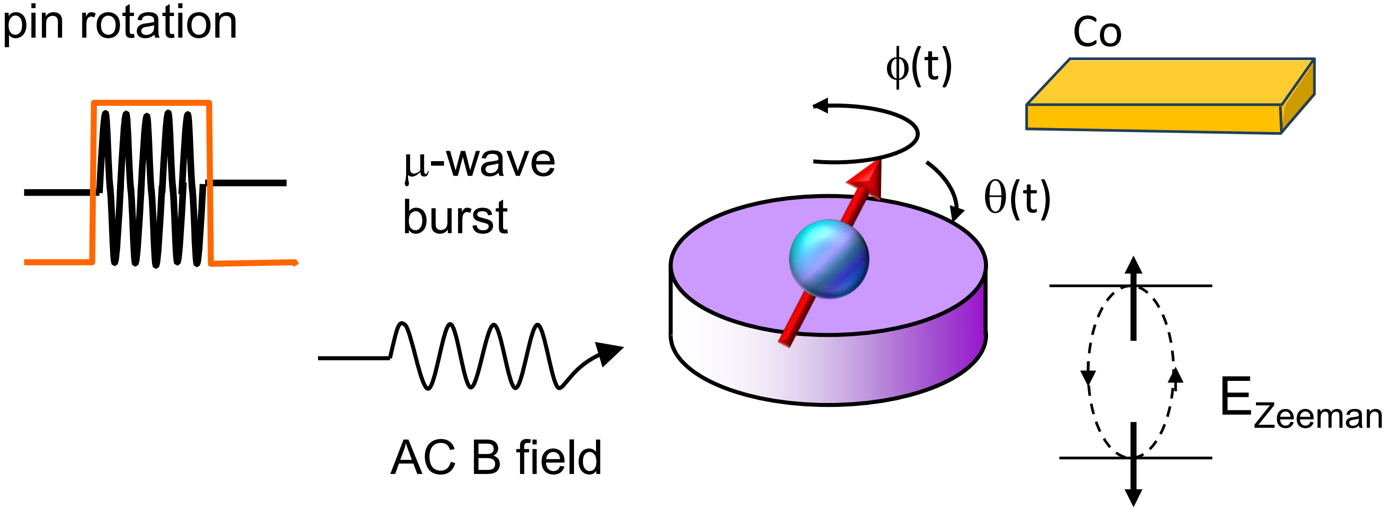


Gidneyand Ekerå,Quantum (2021).

Implementation of Semiconductor Spin Qubits

Time window of MW to control spin rotation

Spin resonance occurs to flip the spin when MW frequency $\omega = E_{Zeeman.}$



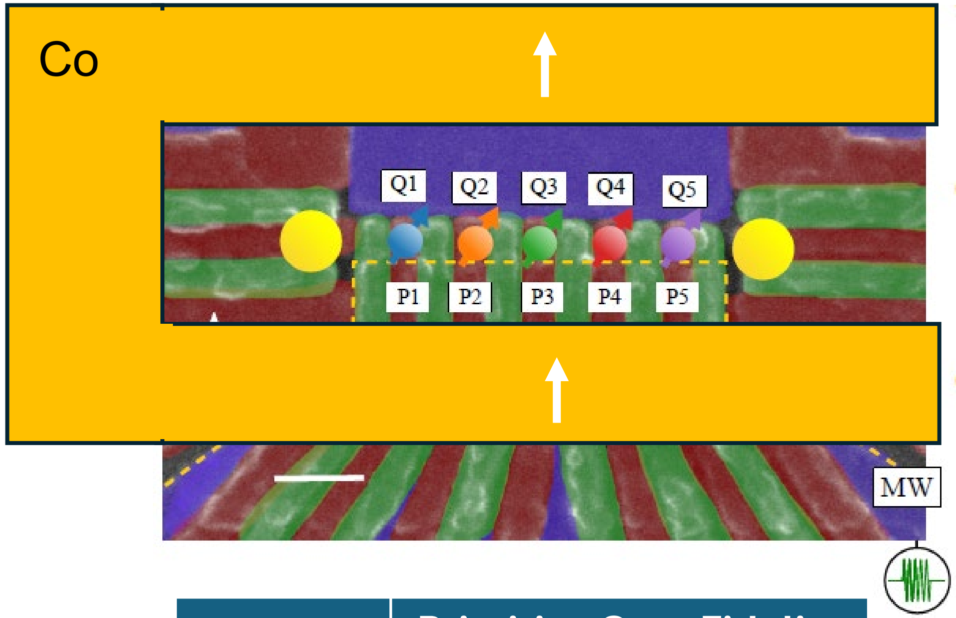
Co MM used to convert MW electric field to magnetic field to generate spin resonance

Others: MW antenna, spin-orbit effect,….

High-fidelity (> 99.99%) Five Qubit Device

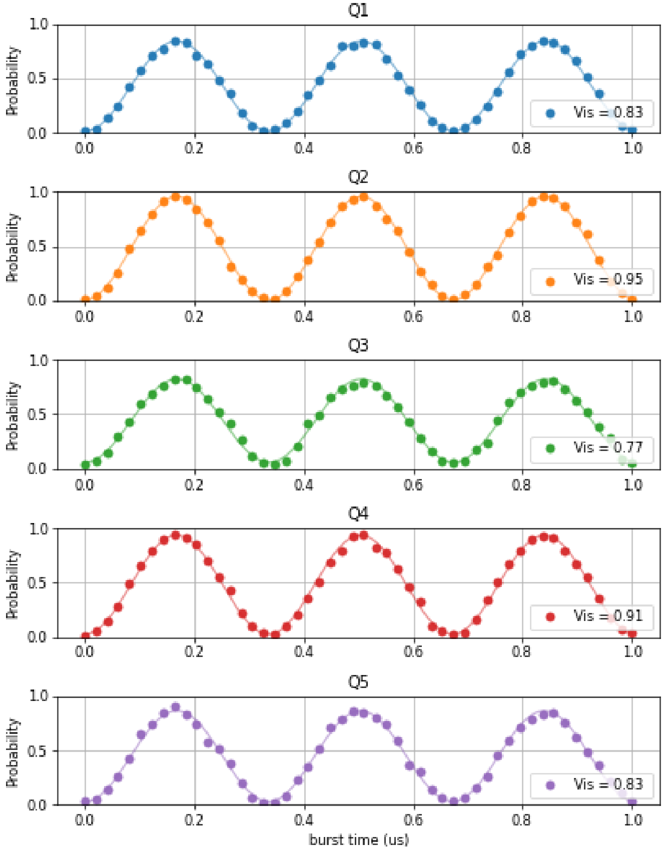
28Si/SiGe
(G.Scappucci)

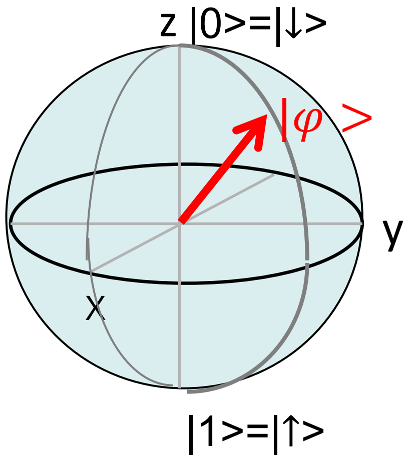
Wu , Camenzind et al.,
arXiv:2507.11918v1

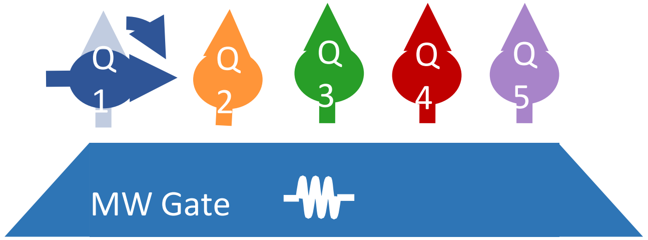


	Primitive Gate Fidelity
Q1	99.996(2) %
Q2	99.998(1) %
Q3	99.998(1) %
Q4	99.996(1) %
Q5	99.990(1) %

set $f_{Rabi} = 3$ MHz for all qubits

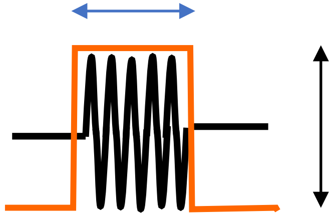




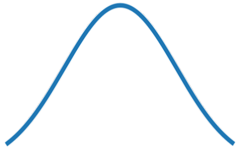


Ways to Improve Qubit Control Fidelity

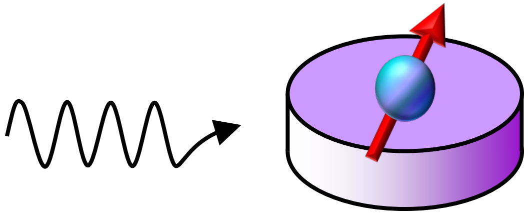
- Calibration of MW window pulse in width, amplitude and phase



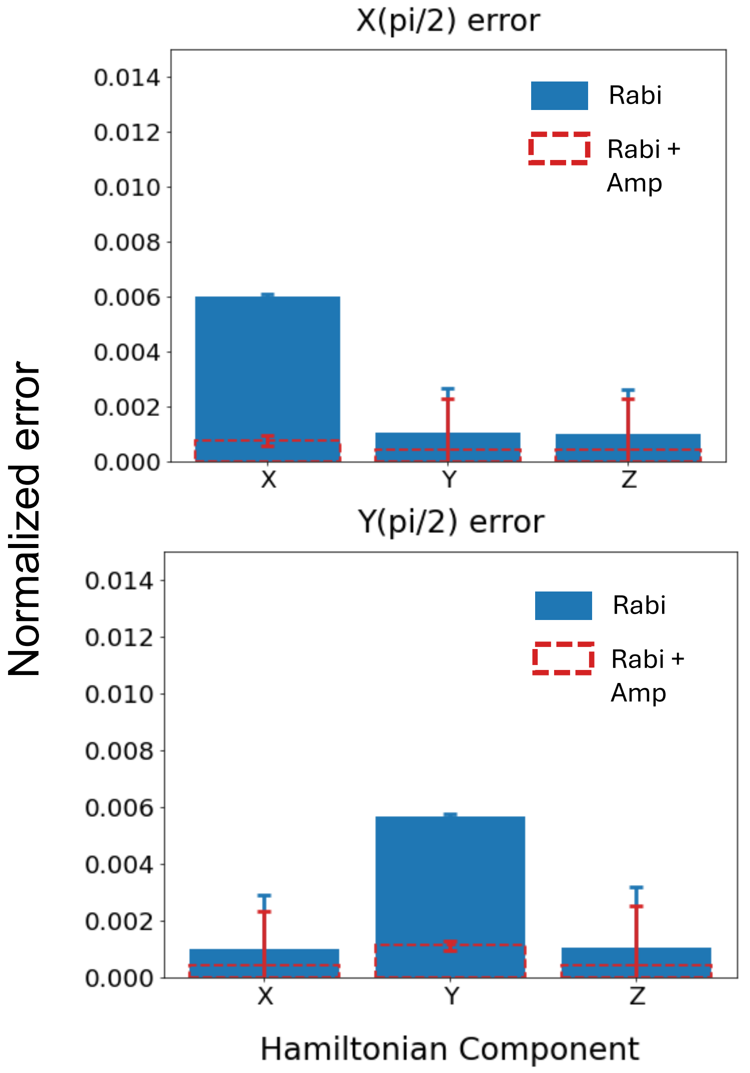
- Tailoring of MW window pulse

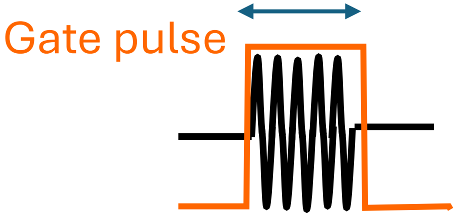


- Optimization of qubit drive condition of MW power vs heating

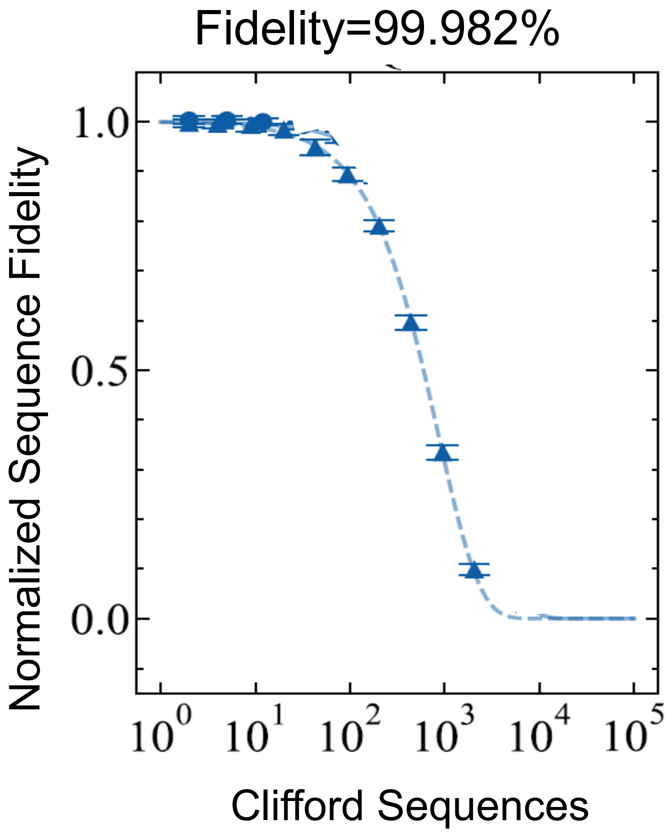


Gate Pulse Calibration of Qubit Rotations in Gate Set Tomography





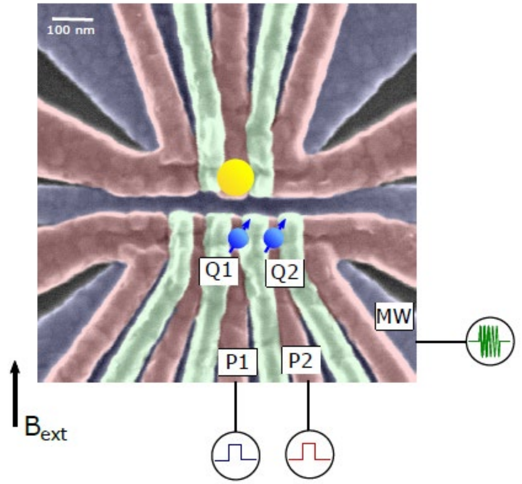
Fine amplitude calibration reduces systematic rotation error


Fidelity=99.982%

Y-H. Wu *et al.*, npj Quantum Information (2024)

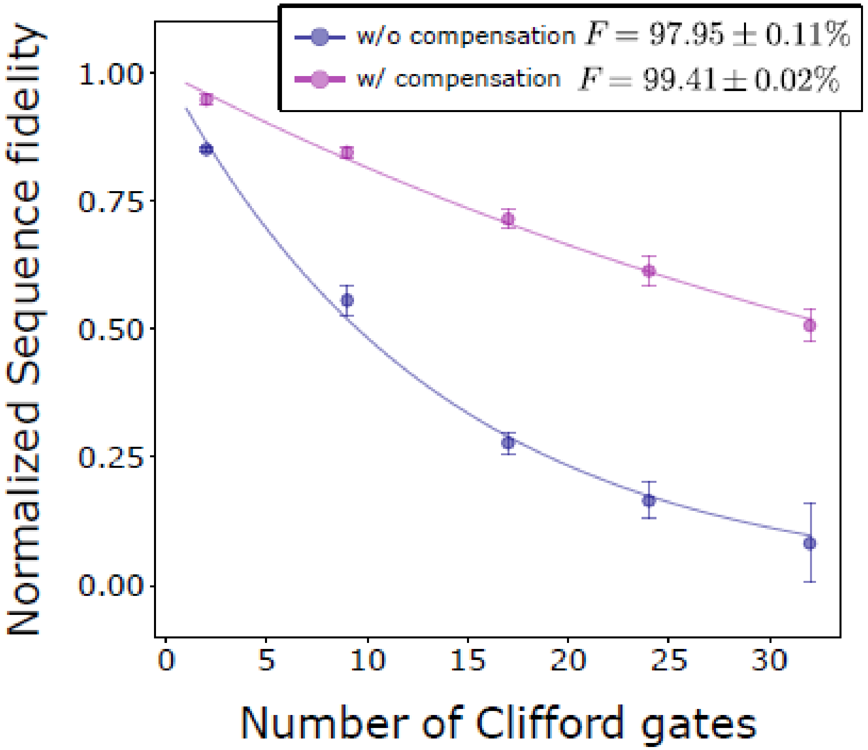
Error Compensation in Two-qubit Gate (CNOT)

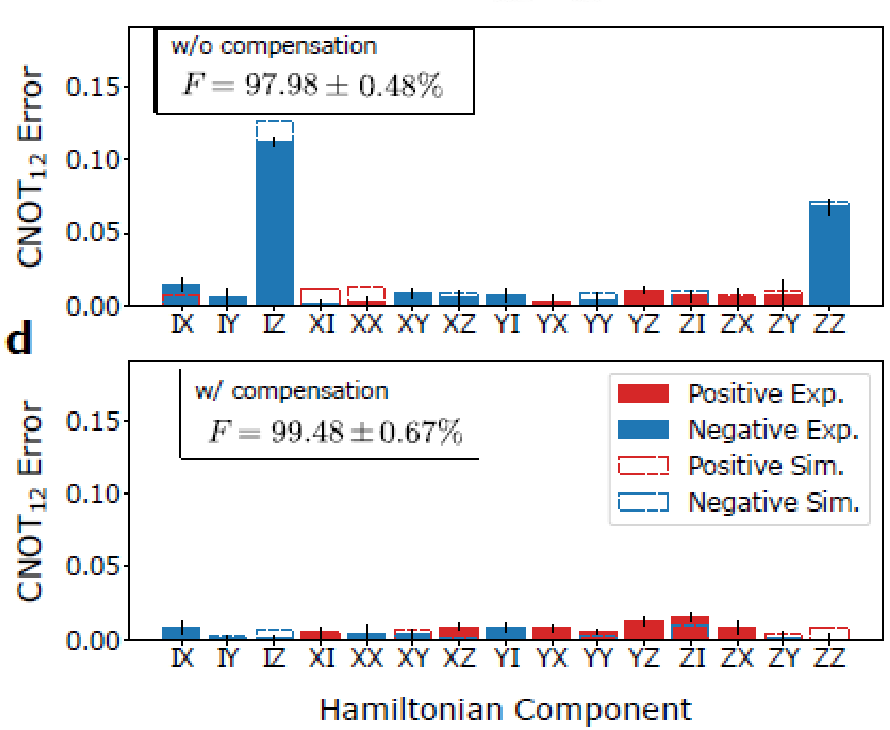
28Si/SiGe
(G.Scappucci)



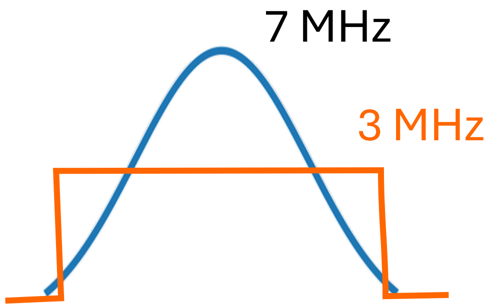
A. Noiri et al. Nature (2022)
Y-H. Wu *et al.*, npj Quantum Information (2024)

F=99.5%





Tailored-MW Window (Kaiser, Gaussian) pulse



Smooth shape :
Reduction of stochastic noise and leakage into off-resonant qubit excitation

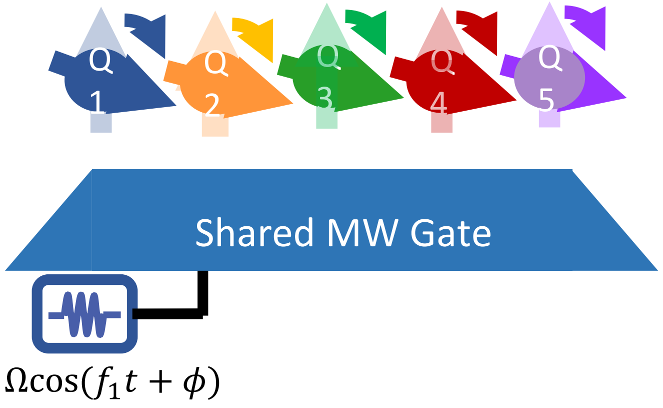
Suppression of random MW phase, which occurs due to the abrupt onset in the window pulse

Suppression of crosstalk between qubits in multiple qubit operation

Simultaneous Operation of Multiple Qubits

Advantages:

- Mitigate fast dephasing of idling qubits with $T_2^* \ll T_2^{Rabi}$, $T_{1\rho}$
- Reduce the number of impedance-controlled MW lines by sharing the MW gate

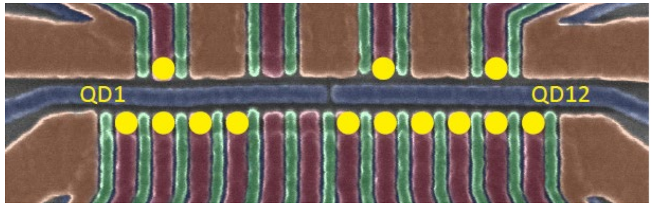


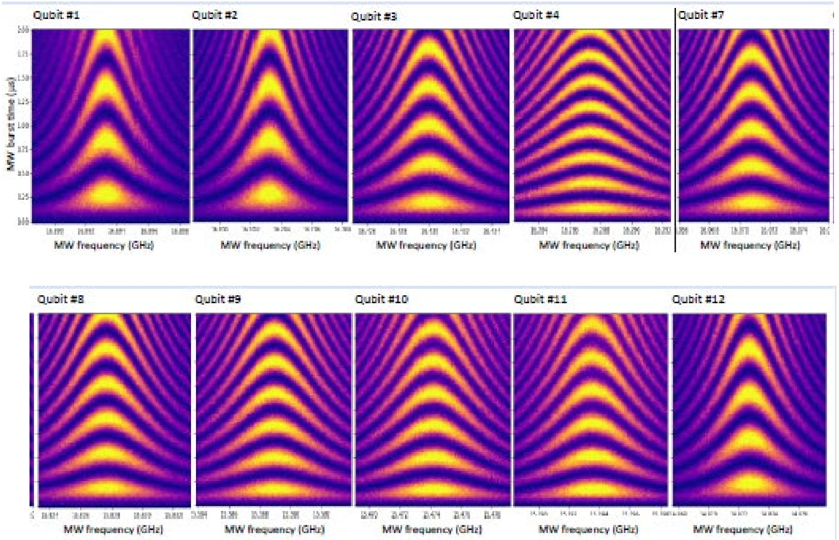
Crosstalk problems :

- AC Stark shift: Frequency and phase shifts in neigbours
  ← Fine calibration
- Heating due to MW multiplexing
  ← Tradeoff between number of qubits and fidelity

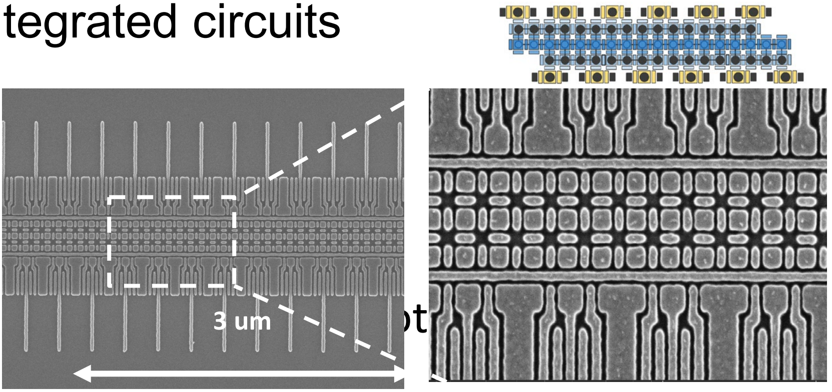
From 1D to 2D Qubit Array

Introduction of integration technology





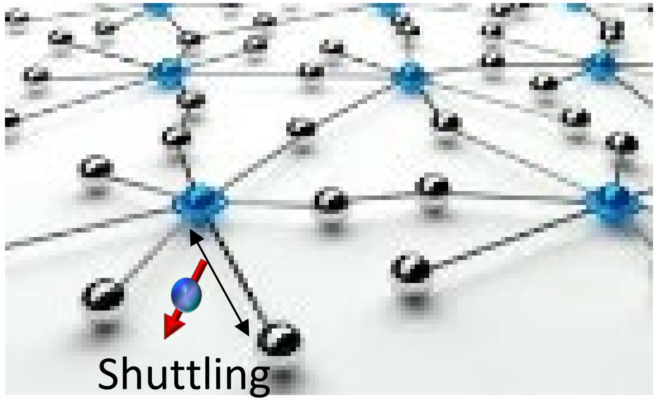
Integrated circuits



Large-scale trilinear array

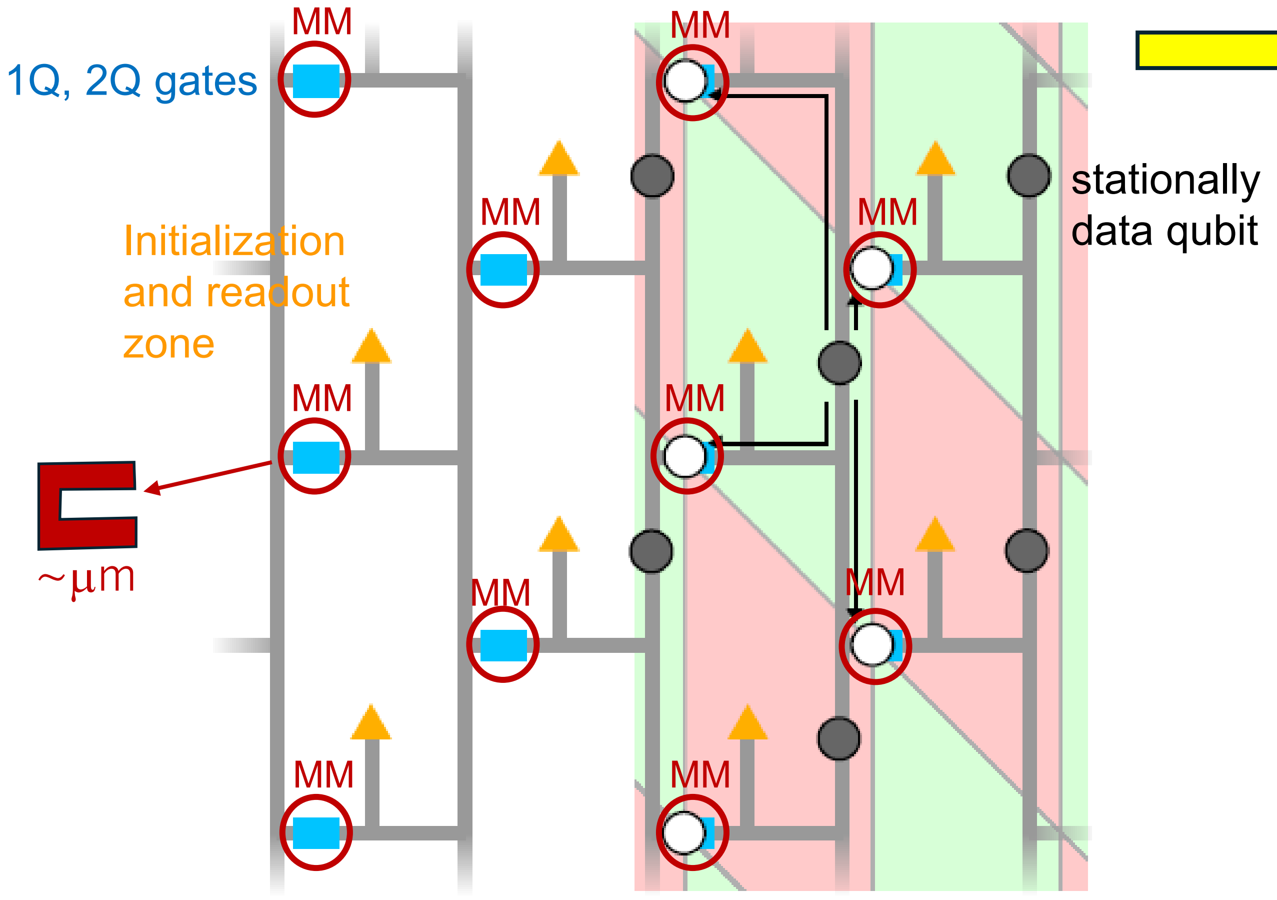
From imec

Quantum link



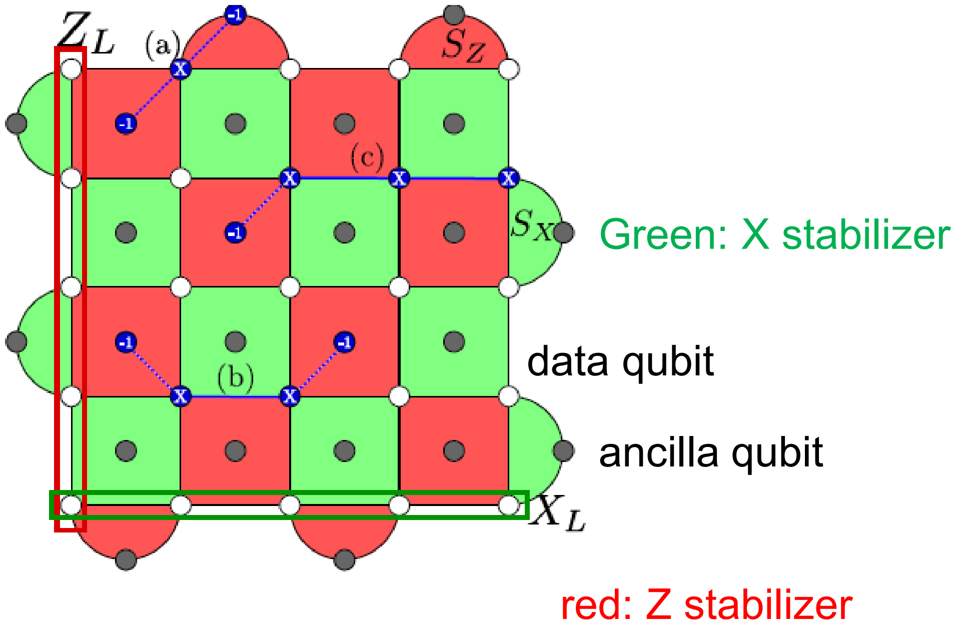
Performance of the spin qubit shuttling architecture for a surface code implementation

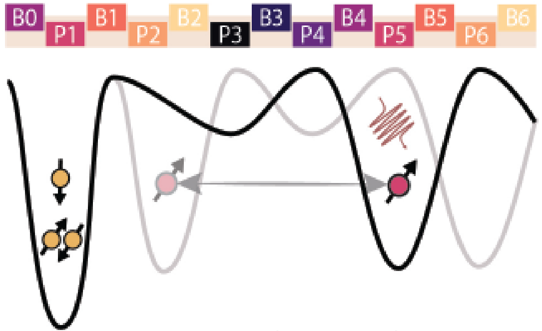
B. Yenilen et al. arXiv: 2503.10602v2



SpinBus architecture: Nature Commun. 15:4977 (2024)

Map to surface code



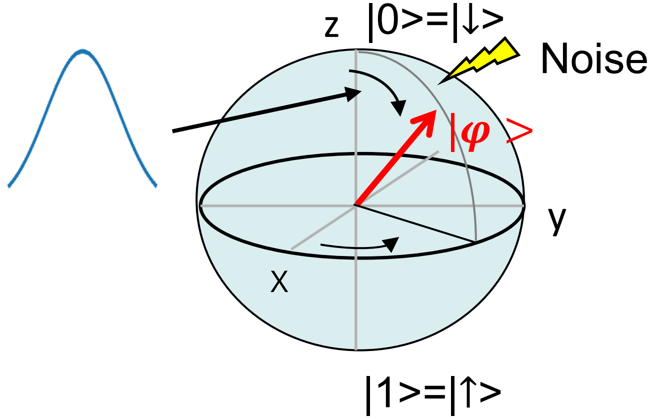


F > 99 %, > 10 μm

S. De Smet et al. Nat. Nanotechnol. 2025

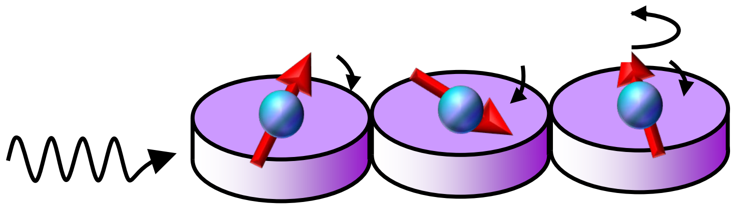
Problems to be considered:
Crosstalk, shared MW, Heating, ….

Summary



- Achieved high-fidelity (> 99.99%) of qubit gates by calibrating gate errors, tailoring (Kaiser, Gaussian) gate pulses and optimizing the MW drive in a 5 qubit device

- Performed simultaneous qubit operation with fidelity > 99.99% for 3 qubits and > 99.9% for 5 qubits



- Addressed scalable 2D qubit arrays with shuttling links and local two-qubit manipulation