Quantum MBE for the Information Age

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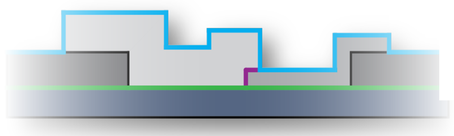
'Materials for Quantum'

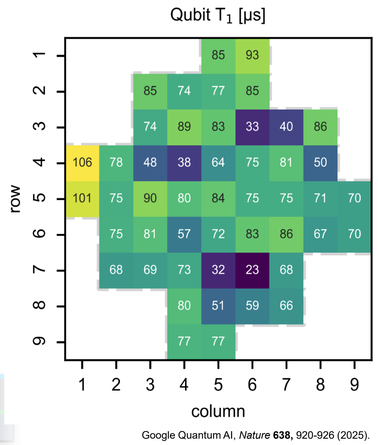
Superconducting qubits have a coherence problem

- Targeting challenges
- Chip- and wafer-scale uniformity

Loss sources are tricky!

- Interface losses:
  - M-A, M-S, M-Ox, …
- Two-level systems (TLS)





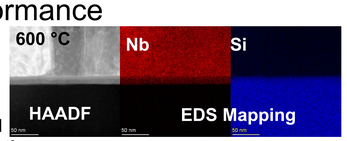
Google Quantum AI, *Nature* **638,** 920-926 (2025).

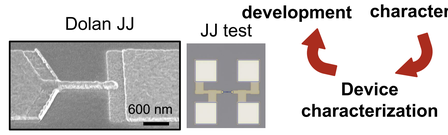
What are the fundamental material factors in microwave dissipation?

Our Approach: MBE cluster tool @ MIT.nano

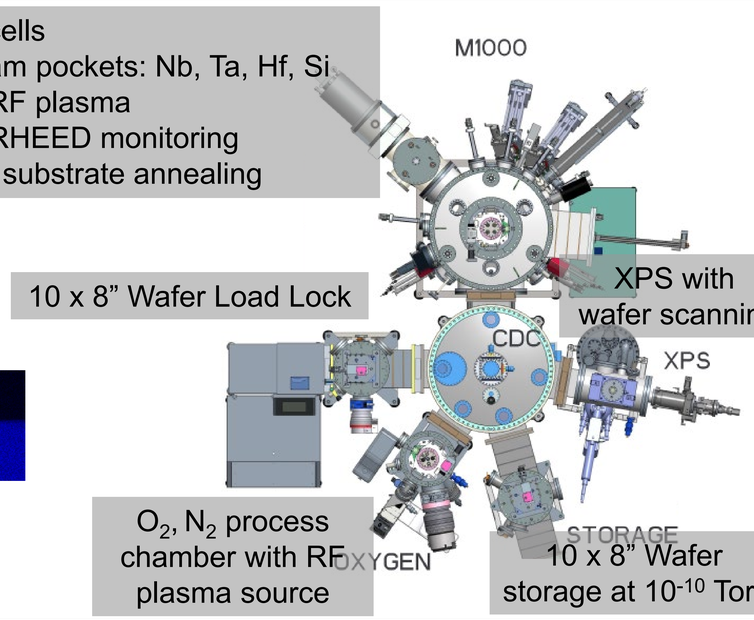
MBE cluster designed to study interfaces

- System installed March 2026
- Positioned within the Class 100/1000 cleanroom space at MIT.nano
- Materials development in tandem with state-of-the-art superconducting qubit fabrication
- Wafer-scale metrology and fabrication, correlating process variables to end-of-line performance metrics





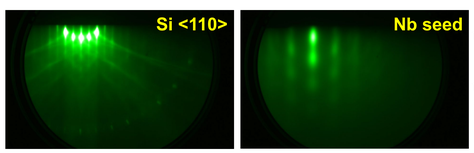
2 Al K-cells
8 E-beam pockets: Nb, Ta, Hf, Si
O_2, N_2 RF plasma
In-situ RHEED monitoring
1600 C substrate annealing

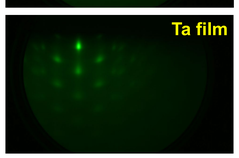


Establishing Cluster Baseline

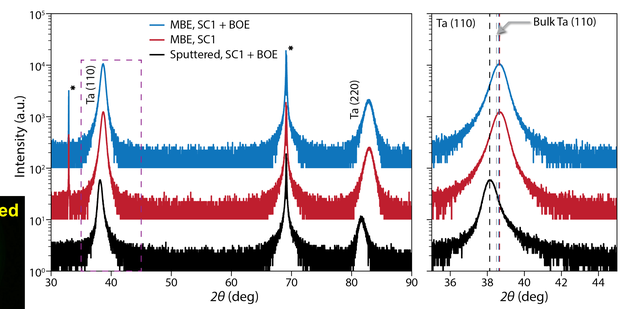
Preliminary Metallization via MBE Cluster Tool

- Nb + Nb-seed Ta Metallization
- Films nominally α-Ta





Nb/Ta crystallizes (110), strong fiber texture



Sample	Substrate Prep	a_{Ta110} (Å)	Strain
MBE, Nb/Ta	SC1	3.29	0.4% (T)
MBE, Nb/Ta	SC1 + BOE	3.29	0.4% (T)
Sputter, Nb/Ta	SC1 + BOE	3.33	-0.8% (C)

MBE imparts different internal strain state

- Role of strain on microwave dissipation needs further study

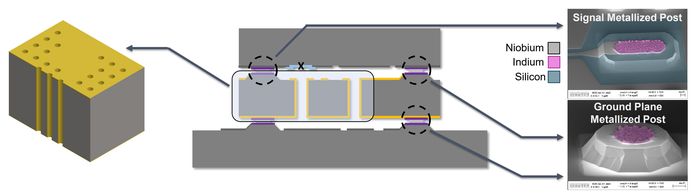
Goal: correlate material behaviors with RF performance

Fabrication Efforts @ EQuS

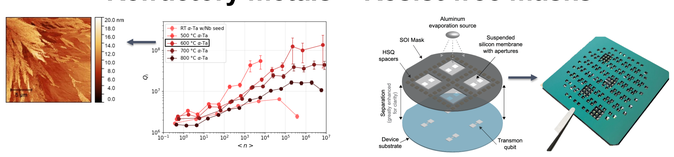
Developing advanced foundry-scale techniques for modular and highly coherent qubits

- Larger effort within EQuS towards 3D device integration + understanding qubit dissipation

3D Integration
Superconducting TSVs + Flip Chip bump bonding



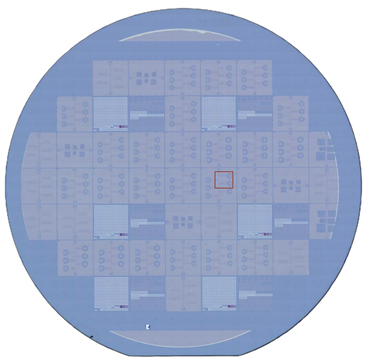
Material and Interface advancements:
Refractory metals + Resist-free masks

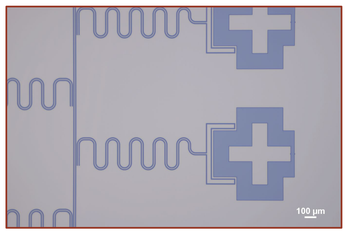


Outlook

Further materials development is necessary for the advancement of superconducting qubits

- Baseline wafers of Nb and Nb/Ta grown and being fabricated into qubit devices
- Refractory metal diffusion studies planned
- Gas processing studies planned utilizing *in-situ* XPS





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