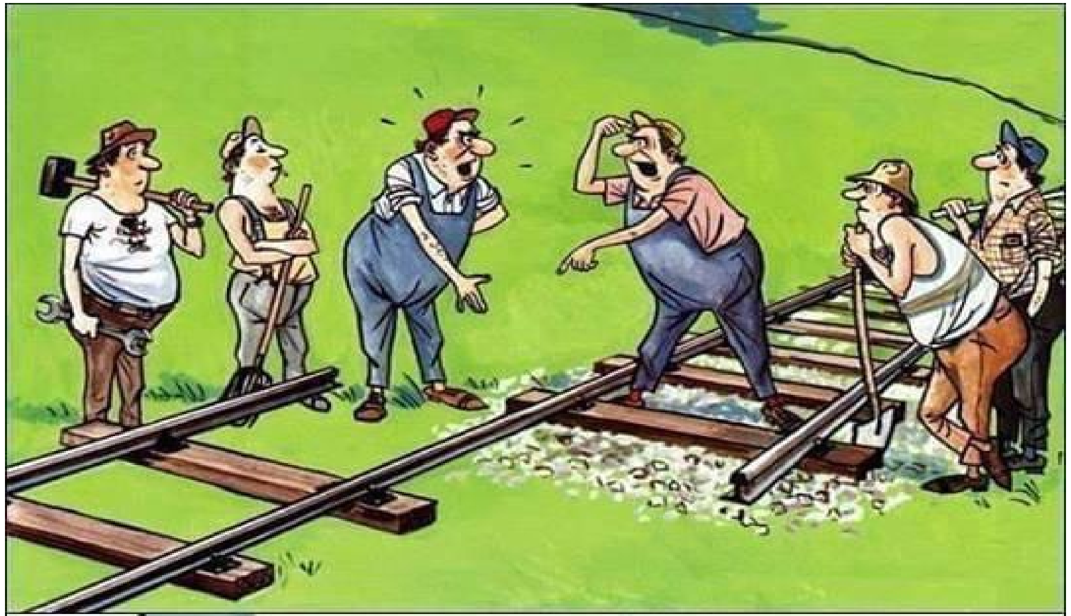
THE 20th U.S.–KOREA FORUM

ON NANOTECHNOLOGY

NC STATE

SEPTEMBER 14-15, 2026



US-Korea S&T Opportunities:

- ✓ *Collaboration*
- ✓ *Coordination*
- ✓ *Cooperation*

&

- ✓ *Communication*

Quantum & Neuromorphic Materials:
Two Key Challenges

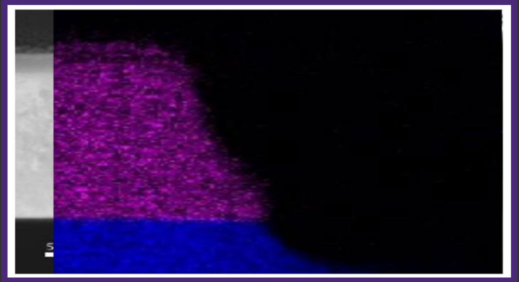
Processing-Structure-Property
Relationships:
➔ ***How/what to identify "cause" vs "correlation"?***

High Through-put Materials Discovery:
➔ ***How to do "more" and "different" from less?***
(But extremely fast! ☺)

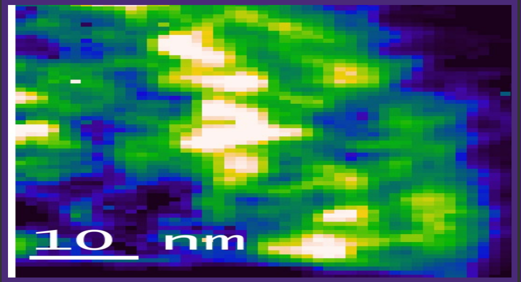
Emerging Electron Microscopy for Quantum & Neuromorphic Materials:

From Atoms to Architecture

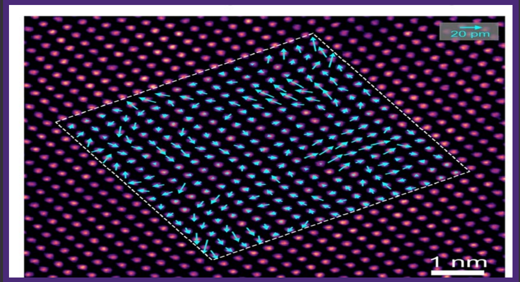
Finding the rare features that control function — and teaching the microscope what to measure next.



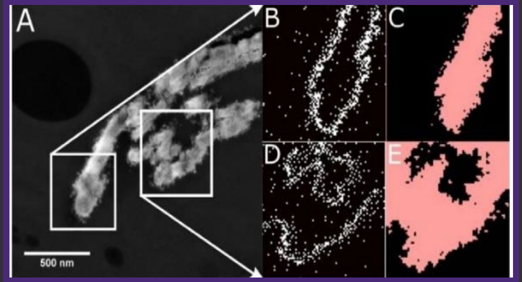
transmon footer



O K-edge EELS



ptychography



adaptive sampling

Vinayak P. Dravid

Department of Materials Science & Engineering ·
Founding Director, NUANCE Center
Northwestern University, Evanston, Illinois

Collaborators:
Chad Mirkin, Mercouri Kanatzidis, Mark Hersam, Chris Wolverton, James Rondinelli
T. Sargent, D. Swearer, Wei Chen – NU;
Amil Dravid (Cal/BAIR)..

Students/Researchers

Zizhen Cai, Alp K., Carolin Wahl, Jingshan Du, Stephanie Ribet, Yukun Liu,
Kunmo Koo (now at Pusan), Xiaobing Hu
Roberto dos Reis, …

Vinayak P. Dravid - Disclosures

- Mattiq Corp., Tera-PRINT (with Mirkin)

- Coral Innovations (AI/ML in water related topics)

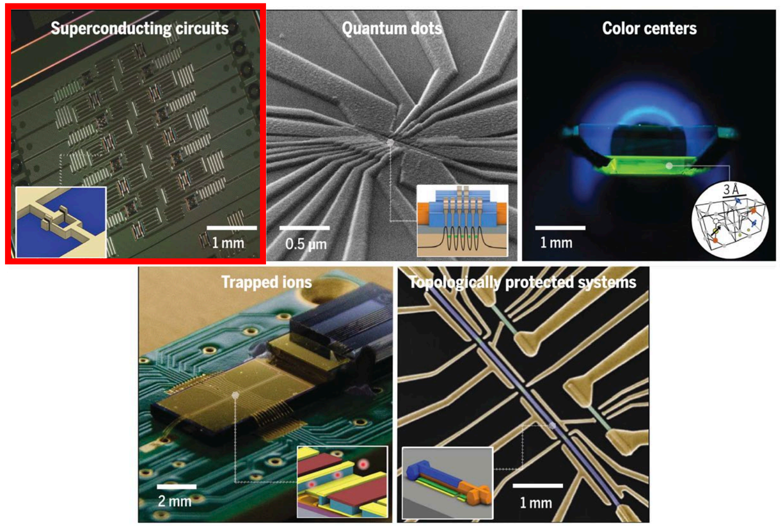
- IP filings/licensing (characterization/imaging)
  - UT membrane chip (with Xiaobing Hu & Kunmo Koo)
  - Ai-enabled and autonomous characterization (with Alfred Yan)
  - MCP protocol (Check ArXiv, with Roberto dos Reis)

Multifunctional Quantum Nanostructures:
Going Beyond Silicon/Electronic Functionalities

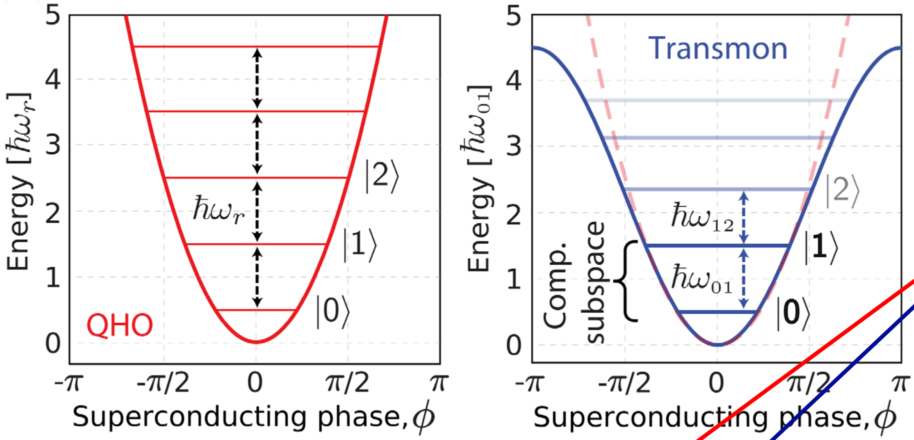
"We have lots of information technology. We just don't have any information."

Superconducting Integrated Circuits as Quantum Hardware Platforms

Transmons[1] are operated and measured using the framework of circuit quantum electrodynamics (cQED)[2]

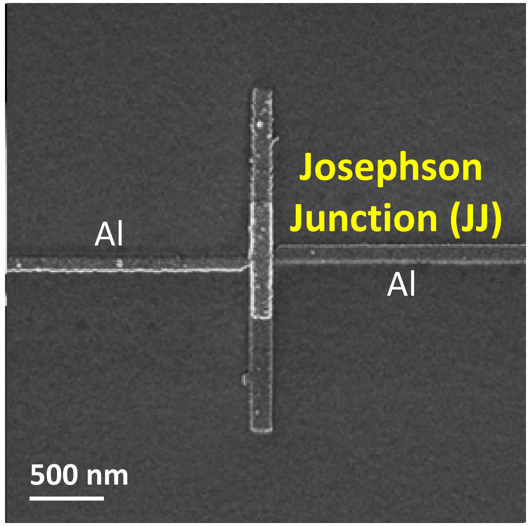


de Leon, N. P. *et al. Science* **372**, eabb2823 (2021)

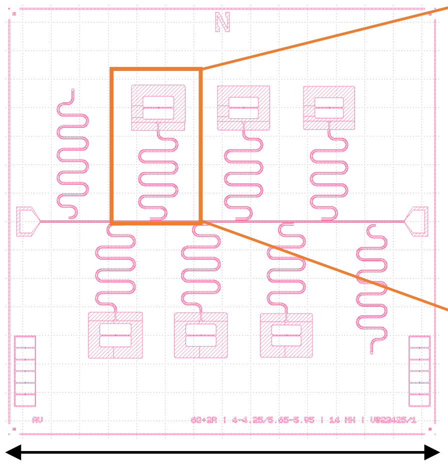


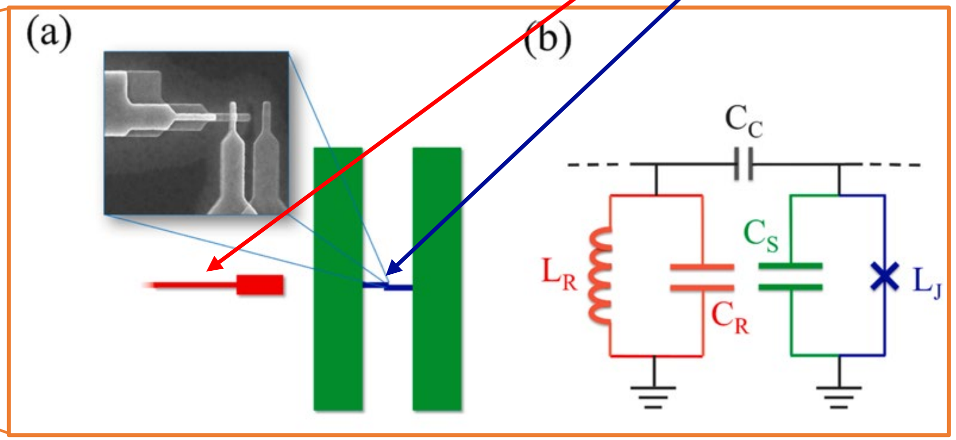
Krantz, P. et al. *Applied Physics Reviews* **6**, 021318 (2019)

Coplanar Waveguide (CPW) Resonator

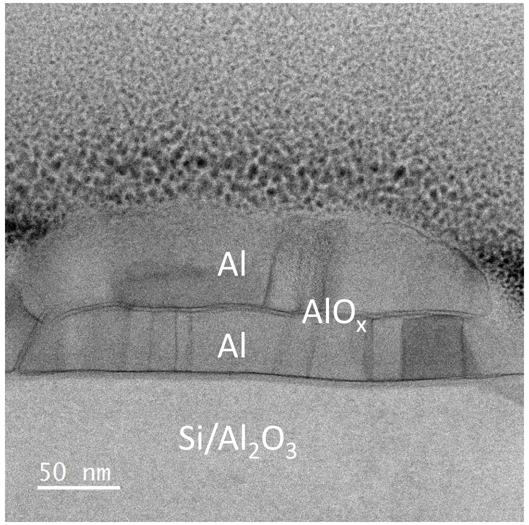


6-transmon qubit chip





Murray, C. E. *Materials Science and Engineering R: Reports* **146**, 100646 (2021)



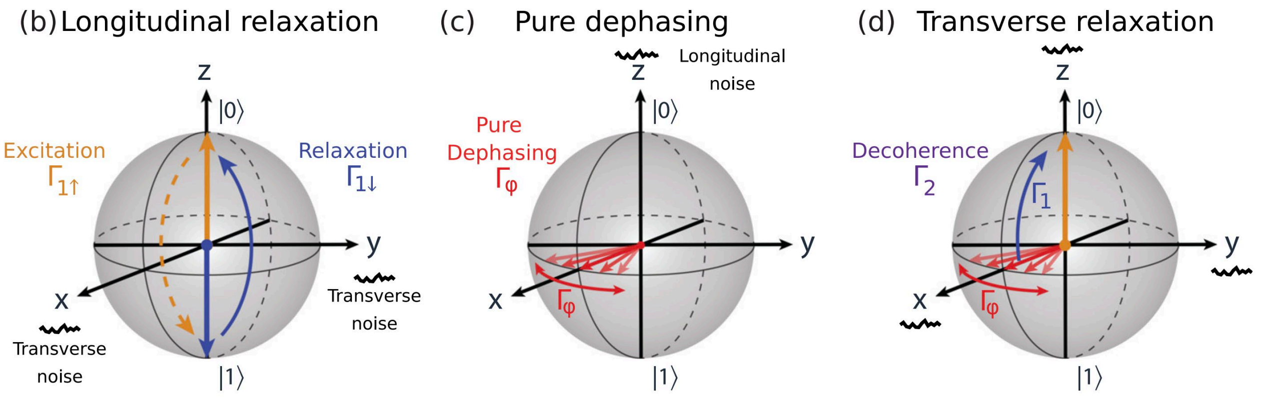
Northwestern | VPD GROUP | Hersam Group

1. Koch, J. *et al. Physical Review A* **76**, 042319 (2007)
2. Wallraff, A. *et al. Nature* **431**, 162–167 (2004)

Qubit Performance is Measured using Coherence Metrics

For fault-tolerant quantum computing, both the energy relaxation (T_1) and phase coherence (T_2) times must be maximized

Need long coherence (T_1, T_2) for practical & scalable implementation of quantum computation[1]



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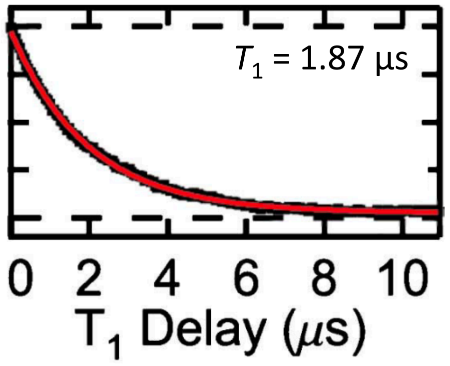
Qubit Decoherence:

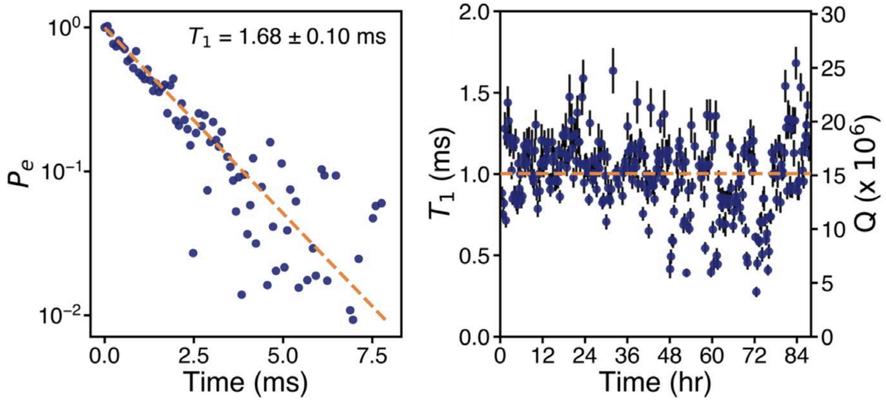
$$\frac{1}{T_2} = \frac{1}{T_\varphi} + \frac{1}{2T_1}$$

Circuit & materials engineering have helped push state-of-the-art transmons to $T_1 \geq 1$ ms



Schreier, J. A. *et al. Physical Review B* **77**, 180502(R) (2008)

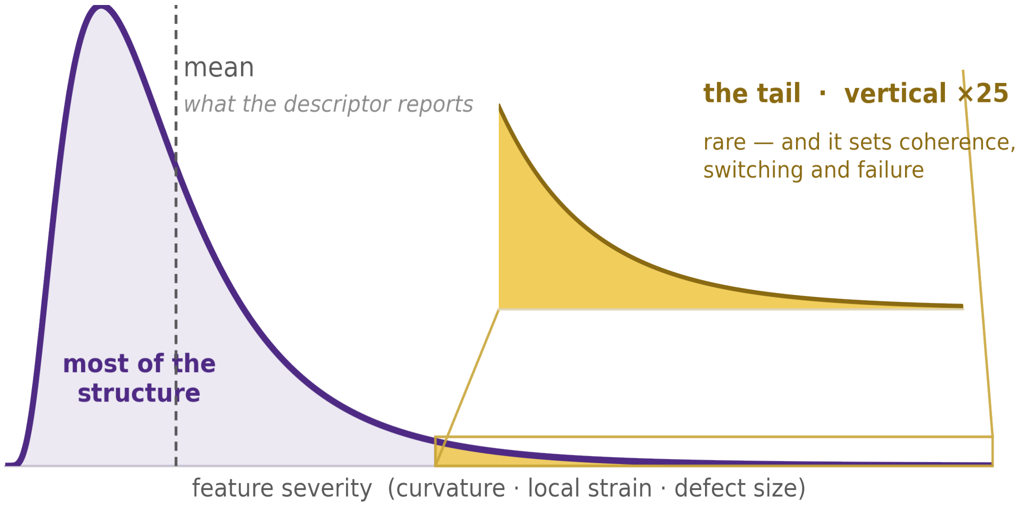
17 years



Bland, M. *et al. Nature* **647**, 343-348 (2025)

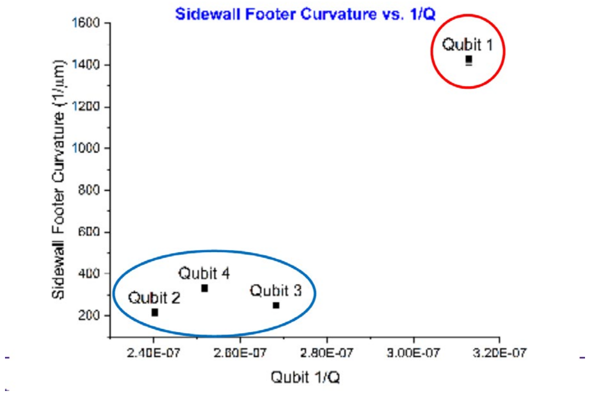
1. DiVincenzo, D. P. *Fortschritte der Physik* **48**, 771–783 (2000)

The Average Can Hide What Controls Performance



Schematic distribution. The mean is a poor summary when function is tail-dominated.

AND IT HAPPENS IN REAL DEVICES



Four transmons, one chip.

Three cluster near 240–310 μm^{-1}. One sits at ≈1410 — and that outlier is the worst performer. The mean of the four describes none of them.

Average descriptors

Mean roughness · mean grain size · average composition · average defect density

Tail-resolved observables

High-curvature corners · sparse defects · local strain · interface chemistry

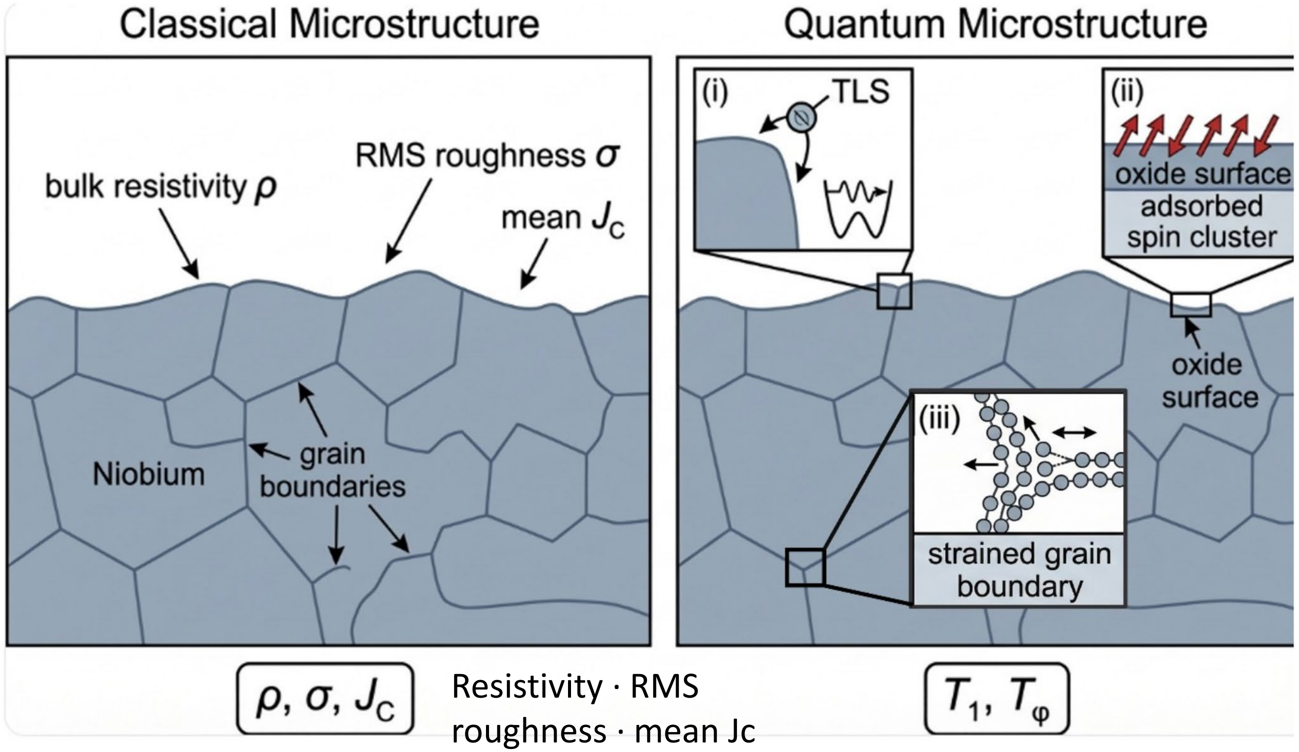
Consequence

Acquiring more data uniformly can dilute the signal when function is tail-dominated. Resolution is no longer the only bottleneck; attribution becomes the challenge.

The question is not only "What is present?"
It is "Which rare feature actually couples to function?"

From “What Is There?” to “What Actually Matters?”

DESCRIPTOR CEILING



The same Nb material system, described two ways.
Classical microstructure reports averages; quantum microstructure resolves the rare, local features that carry the loss.

SAME NIOBIUM, TWO DESCRIPTIONS

CLASSICAL MICROSTRUCTURE

ρ · σ · J_c

bulk resistivity · RMS roughness · mean critical current

Averages over the whole film. They benchmark the material — and they are blind to where it fails.

same material — different question

QUANTUM MICROSTRUCTURE

T_1 · T_φ

TLS in the amorphous oxide · adsorbed surface spin clusters · strained grain boundaries

Rare, local, and countable. These are the prescriptor-relevant observables.

More uniformly acquired data does not resolve a tail-dominated mechanism — it averages it away.

Resolution is no longer the only bottleneck. Interpretation and attribution are.

Descriptor → Prescriptor: A Falsifiable Measurement-to-Design Link

Dravid, V. P., et al. (2026). *Microstructural Topology as a Prescriptor for Quantum Coherence: Towards A Unified Framework for Decoherence in Superconducting Qubits*. **arXiv:2604.03951.**

$$\Pi_j = \rho_j \times G_j$$

contribution	population	coupling
What that feature class contributes to the system-level observable.	How much of the consequential feature exists. Measured independently.	How strongly that feature couples to function. Computed independently.

Each term is measured or computed on its own — that is what makes the product testable.

2 × 2 FALSIFIABILITY *predicted Π*

	ρ low	ρ high
G high	3×	6×
G low	1×	2×

Illustrative pre-committed ratios (ρ ∈1,2 · G ∈1,3). A measured Π that departs from ρ × G localises the cross-coupling or the missing variable.

INVERSION

solve the product backwards

target performance → required ρ → processing / architecture

Characterization becomes prescriptive when it can predict, falsify, and invert.

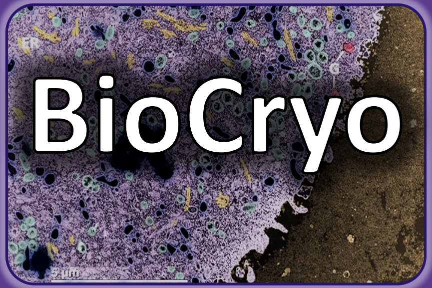
Failure of separability is itself diagnostic — not a failed fit.

Neuromorphic analogue: switching variability may likewise be controlled by sparse filament-nucleation sites, vacancy clusters, interface states or local hot-spots.

NU and Regional Facilities/ Coordination

NUANCE Center

ANL-APS, ANL-CNM/EMC, CHiMaD



Cryo- and Conventional Soft-matter EM

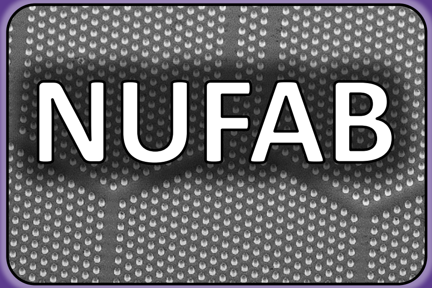
cryo-TEM, cryo-SEM, cryo-Ultramicrotomy

Dr. R. Bleher, E.W. Roth, Dr. C. Sharpe

Electron Probe Instrumentation

SEM, TEM, FIB, EDS, EELS, EBSD, eBL, Sample Prep

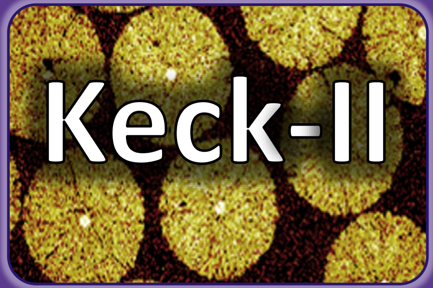
T. Abbott, Dr. X. Hu, Dr. R. dos Reis, Dr. P. Smeets, N. Gogola, Dr. Y. Wen



Nano- and Micro-scale Fabrication

Deposition, Dry Etching, Lithography, Wet Processing

Dr. N. Basit, Dr. Y. Jia, Dr. S. Butun, Dr. S. Lu, Dr. A. Dhote, D. De La Vega, Dr. N. Dvorak



Keck Interdisciplinary Surface Science

XPS, ToF-SIMS, FTIR, Ellipsometry

Dr. X. Chen, Dr. B. Seo

Scanned Probe Imaging & Development

AFM, BPL, NSOM, Confocal Raman, Nano-Indenter

Dr. G. Shekhawat, postdocs

Faculty Director
Vinayak P. Dravid

Business Office
Chad Goeser, Stephanie Torres

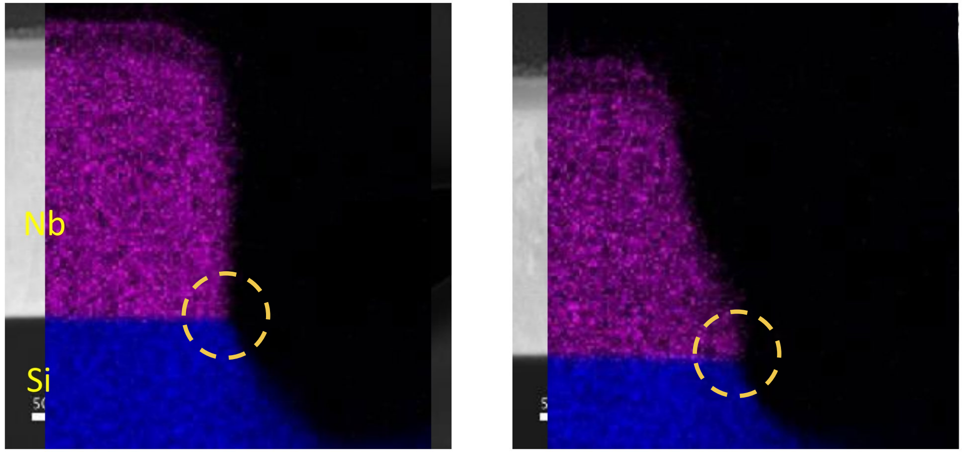
Outreach Coordinator
Katy Dean

Program Administration
Lourdes Vasquez/Liam Foley

Quantum Microstructure: A Few Features Can Dominate Coherence

SIDEWALL & FOOTER · Nb / Si

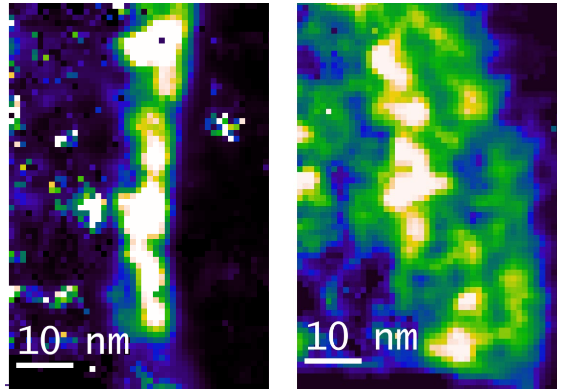
Qubit 3 — better | Qubit 2 — worse



footer 91.3° · κ = 581 μm⁻¹ | footer 65.6° · κ = 944 μm⁻¹

EDS overlay: Nb (magenta) · Si (blue). Gold ring marks the footer corner.

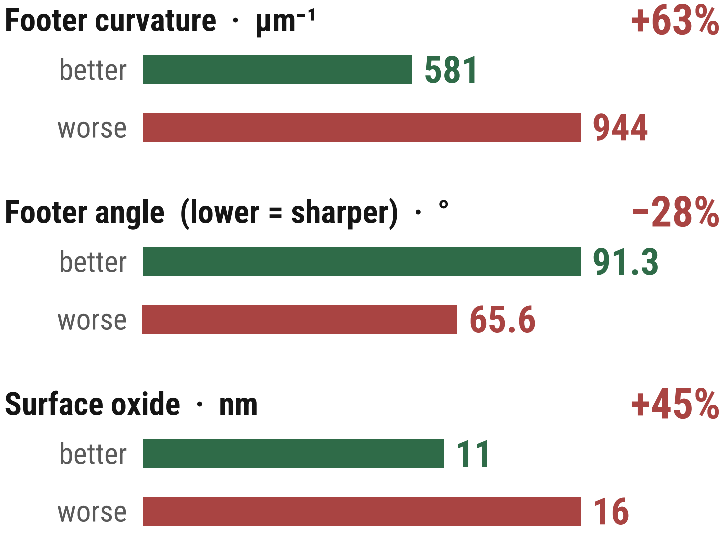
SURFACE OXIDE · O K-EDGE EELS



11 nm | 16 nm

Oxide thickness from the line profiles on p. 87.

WHAT CO-VARIES WITH LOSS



CONTROL trench depth 101.3 → 102.8 nm (+1.5%)

1 GEOMETRY → 2 FIELD PARTICIPATION → 3 OXIDE / TLS-HOSTING DEFECT POPULATION → 4 LOSS / DECOHERENCE

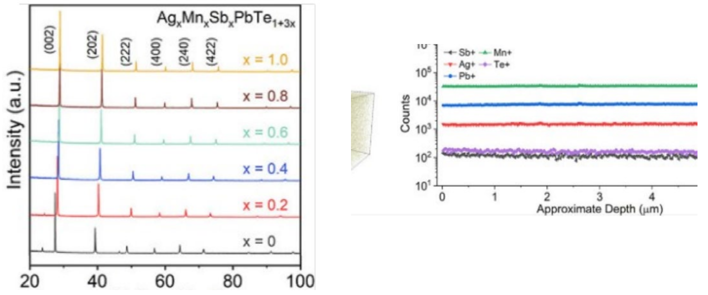
These co-variations identify candidate prescriptor components; the 2×2 separability test distinguishes mechanism from correlation.

Peter Lim / SQMS transmon work, U.S.–Korea deck 12 Sept 2026. Chip 2 (Nb/Si), Qubit 3 vs Qubit 2: EDS cross-sections p. 82; footer angle, curvature and trench depth p. 83; O K-edge EELS maps and oxide line profiles p. 87. Related w

Same Architecture, Different Physics: High-Entropy Thermoelectrics

PORTABILITY

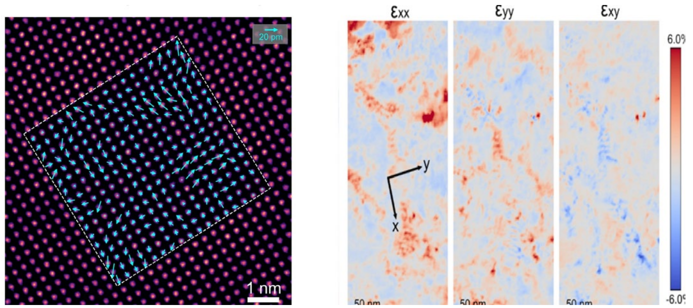
BULK AVERAGE



XRD · TOF-SIMS depth profile

Bulk averages alone do not explain the anomalously low thermal transport

HIDDEN HIERARCHY



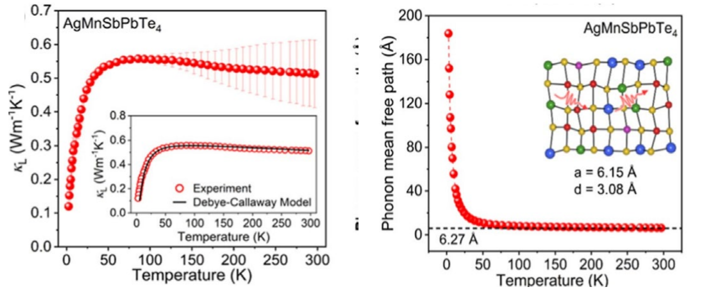
Multi-slice ptychography · strain maps ε

Ag-rich endotaxial nanophases 10–50 nm

Strain fluctuations ~5% over 10–30 nm

Atomic displacements ~23–25 pm

FUNCTION



κ_L and phonon mean free path vs temperature

κ_L ≈ 0.31 W m⁻¹ K⁻¹ at 800 K

phonon MFP ≈ 6.3 Å → glass-like transport

The average says “homogeneous.” The prescriptor-relevant variables say why heat transport is anomalous.

General principle: disorder is structural, not scalar — topology, correlation length, symmetry and dynamics determine selectivity.

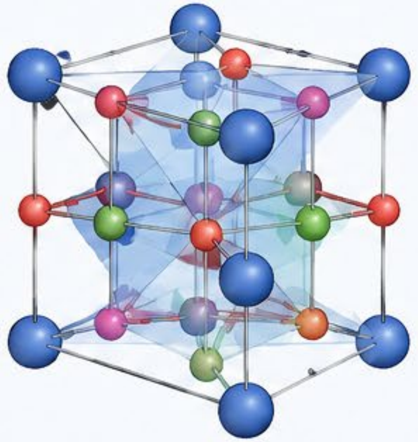
Same measurement-to-design architecture as the transmon case, in a completely different physics.

From Intrinsic Behavior to Extrinsic Performance

Intrinsic sets the rules. Extrinsic engineers the outcome.

INTRINSIC BEHAVIOR

Single Crystal Limit: Crystal chemistry & physics dominate



Crystal Chemistry
- Composition
- Bonding
- Electronic structure

Crystal Physics
- Band structure
- Phonons
- Scattering mechanisms

Intrinsic Properties (Single Crystal)

Electrical Conductivity (σ) | Seebeck Coefficient (S) | Thermal Conductivity (κ) | Carrier Mobility (μ)

Intrinsic behavior provides the fundamental limits and design principles.

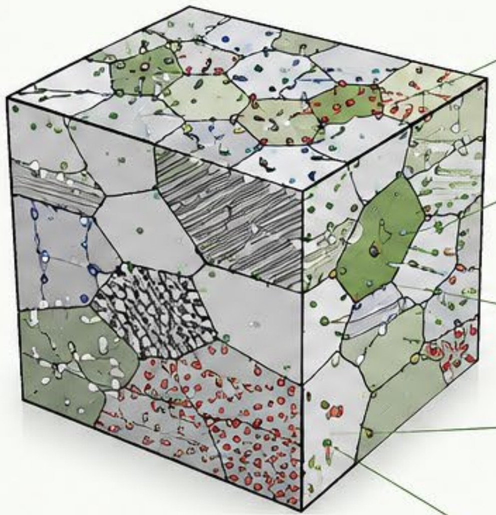
INFORMS & CONSTRAINS

Intrinsic sets the potential and the trade-offs.

Understand → Engineer → Optimize

EXTRINSIC (MICROSTRUCTURE) ENGINEERING

Real Materials: Microstructure dominates performance



Grain Boundaries
- Barrier/Filter
- Scattering
- Charge/Phonon blocking

Nanostructuring
- Phonon scattering
- Energy filtering
- Confinement effects

Textures / Orientation
- Anisotropy control
- Transport alignment

Second Phases / Precipitates
- Carrier scattering
- Phonon scattering
- Pinning

Defects / Strain Fields
- Point defects
- Dislocations
- Strain modulation

Extrinsic Effects on Properties

σ ↓↑ S ↑ κ (lat.) ↓ ZT ↑

Tailored microstructure enhances performance by manipulating transport.

THE BIG PICTURE

Intrinsic behavior = the potential *(what a perfect crystal can do)*

Extrinsic engineering = the pathway *(how real materials approach that potential)*

Goal: Optimize microstructure to maximize performance while staying within the bounds set by intrinsic crystal chemistry & physics.

Intrinsic provides the framework. Extrinsic delivers the performance.

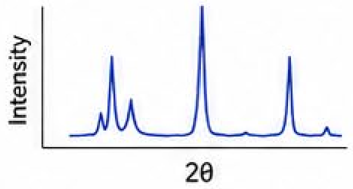
Why Both Perspectives Matter in Thermoelectrics

Bulk techniques reveal the average. Local microscopy reveals complicated but tractable story!

BULK / AVERAGE INFORMATION

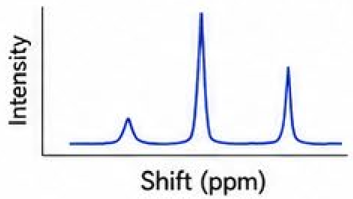
What is the sample telling us on average?

X-ray Diffraction (XRD)



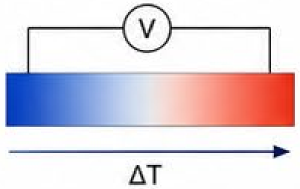
Average crystal structure, phase purity, lattice parameters

NMR



Average local environment, composition, dynamics

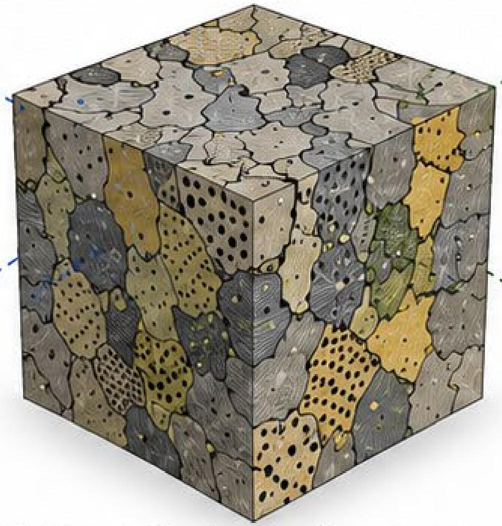
Transport Measurements (σ, S, κ, ZT)



Average transport behavior (electrons, phonons, heat, charge)

Powerful for benchmarking and trends, but averages can hide important details.

Real Thermoelectric Materials are Heterogeneous



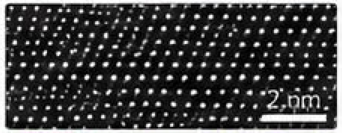
Hidden at the Average Level:

- Nano/atomic scale phases
- Defects and strain fields
- Grain boundaries and interfaces
- Compositional fluctuations
- Local variations in transport

LOCAL / ATOMIC-SCALE INFORMATION

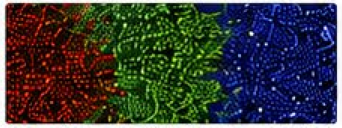
What is really happening locally?

S/TEM Imaging



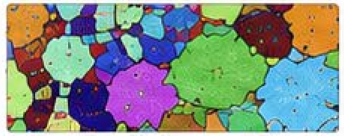
Atomic structure, defects, strain, interfaces, nanoinclusions

STEM-EDS /EELS



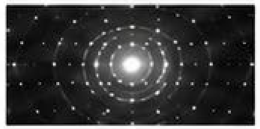
Local composition and chemistry variations

STEM-4D / Mapping



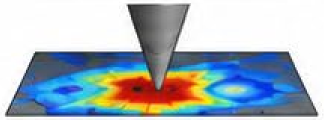
Grain boundary character, strain mapping, phase distribution

Nanodiffraction / e-scattering



Local symmetry, strain, orientation, diffuse scattering, phase variations

Local Transport (Probes)



Local variations in electrical/thermal response

Reveals the nanoscale origins that control macroscopic thermoelectric performance.

THE COMPLETE PICTURE = AVERAGE + LOCAL

Bulk measurements tell us how a material performs.
Local microscopy tells us why.

Higher ZT
Smarter Design
Better Materials

Both average and local probes can also be dynamic in time under stimuli such as heat, bias, current, and temperature gradients.

For more than a dozen years, combining bulk and local approaches has driven advances in thermoelectrics.

Descriptor → Prescriptor:
A Falsifiable Measurement-to-Design Link

Dravid, V. P., et al. (2026). *Microstructural Topology as a Prescriptor for Quantum Coherence: Towards A Unified Framework for Decoherence in Superconducting Qubits.* **arXiv:2604.03951.**

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contribution

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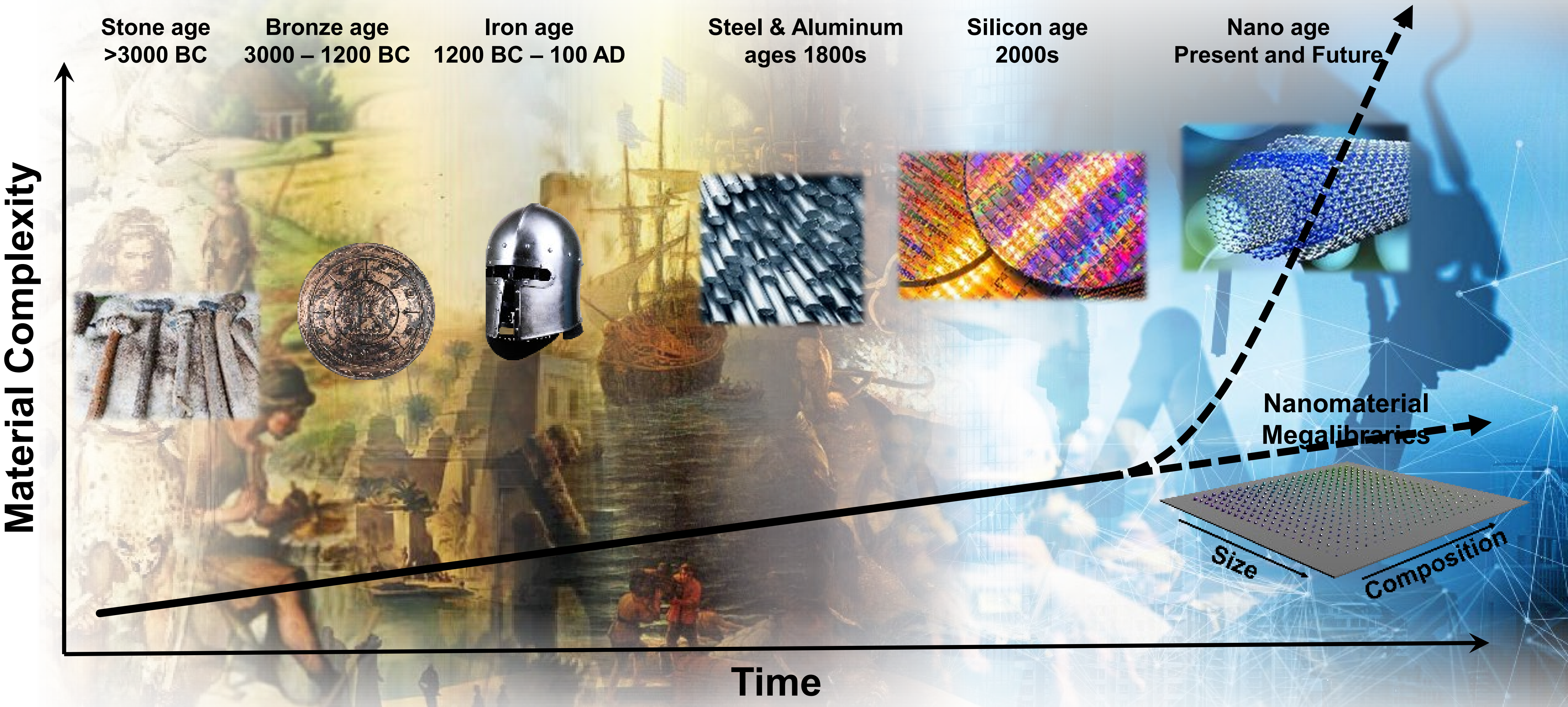
(But extremely fast! ☺)

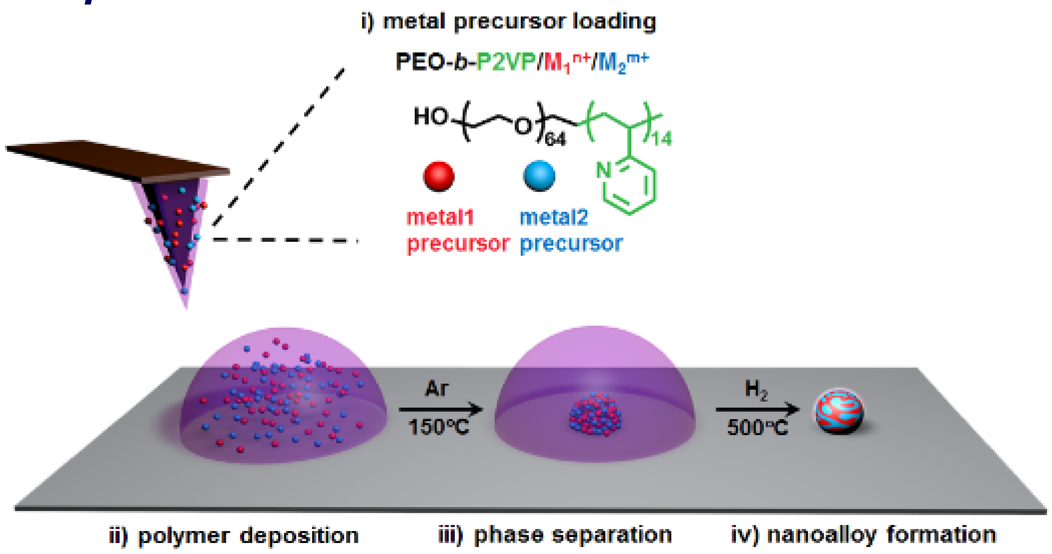
Materials & Human Development

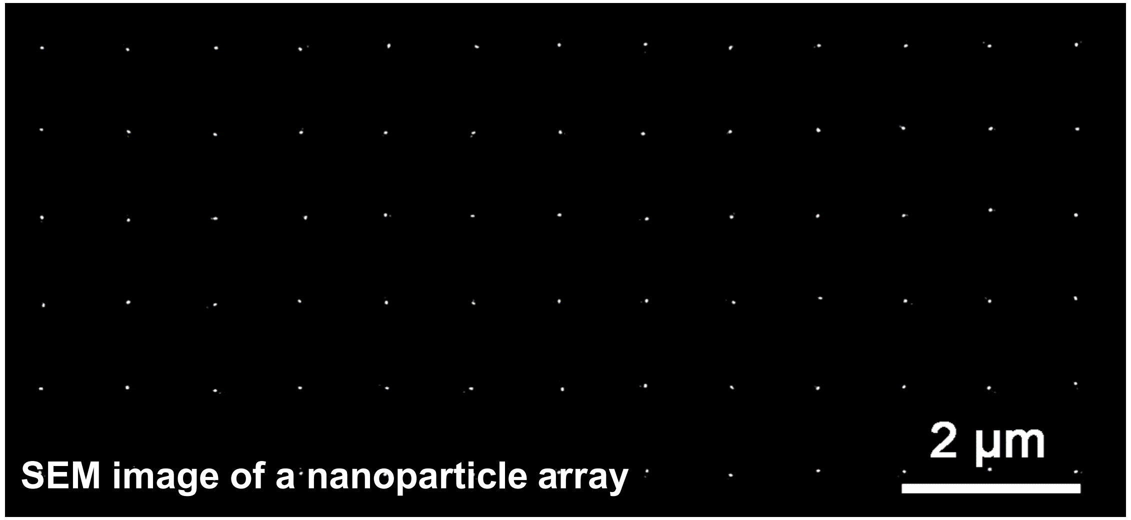


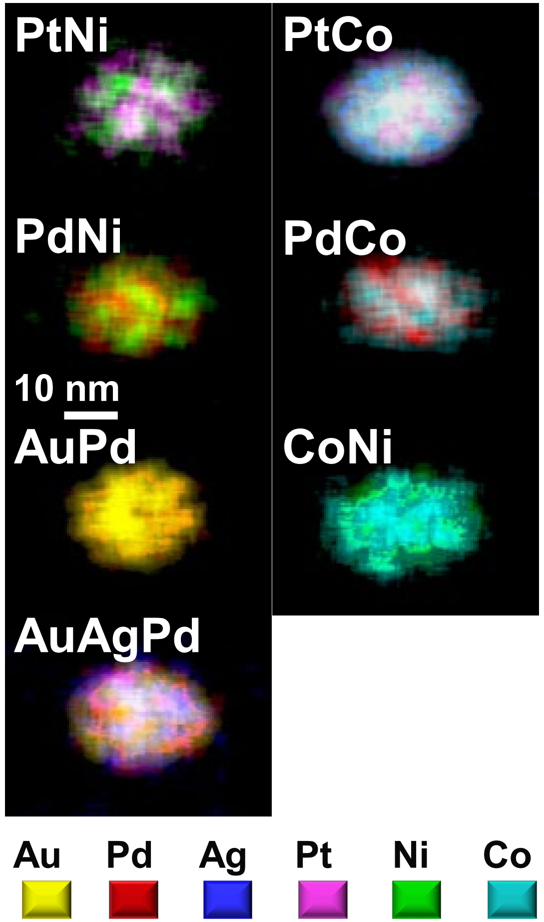
Smith, N., *Engineering & Technology* **2019**

Site-selective Multicomponent Nanoparticles

Choosing your color palette!







Chen, P.-C., Dravid, V.P., Mirkin, C.A. *et al.*, *JACS*, **2015**

Chen, P.-C., Dravid, V.P., Mirkin, C.A. *et al.*, *Science*, **2016**

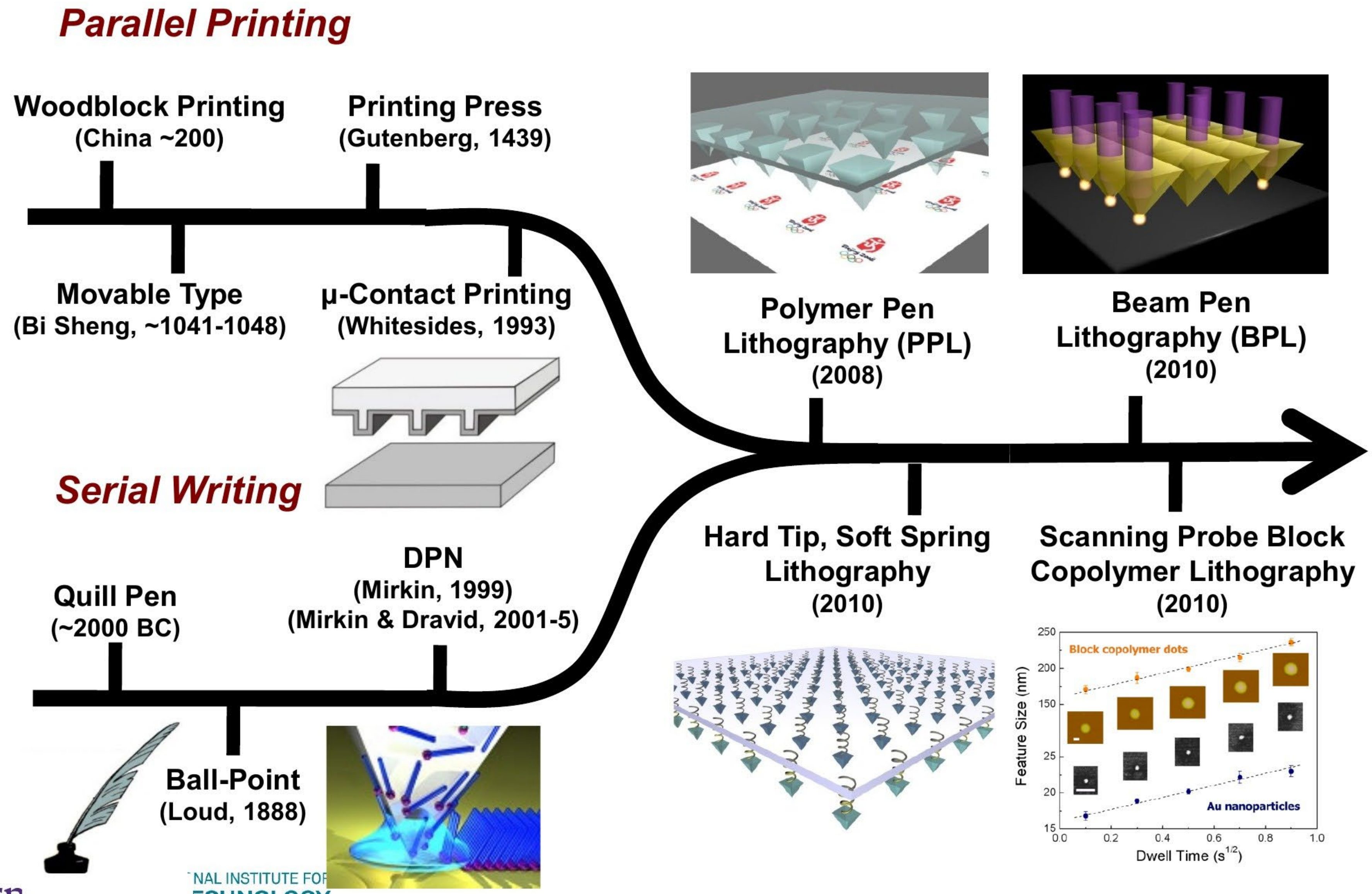
Chen, P.-C., Dravid, V.P., Mirkin, C.A. *et al.*, *JACS*, **2017**

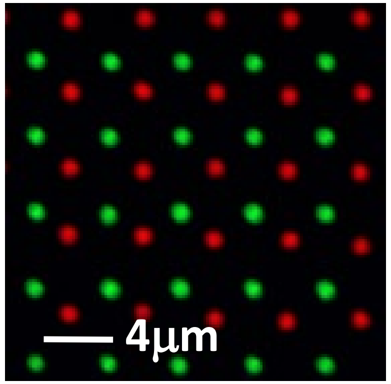
Huang, L., Wolverton, C., Mirkin, C.A. *et al.*, *PNAS*, **2018**

Chen, P.-C., Dravid, V.P., Wolverton, C., Mirkin, C.A. *et al.*, *Science*, **2019**

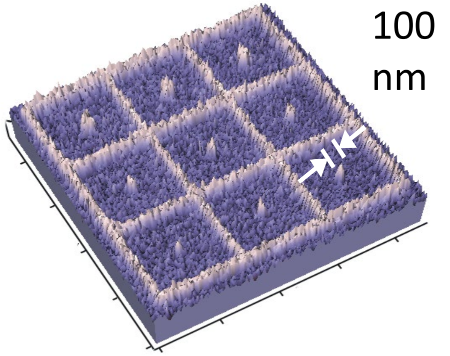
Chen, P.-C., Dravid, V.P., Mirkin, C.A. *et al.*, *JACS*, **2020**

Development of Writing & Printing Tools





DNA Nanoarrays



Protein Nanoarrays

Northwestern

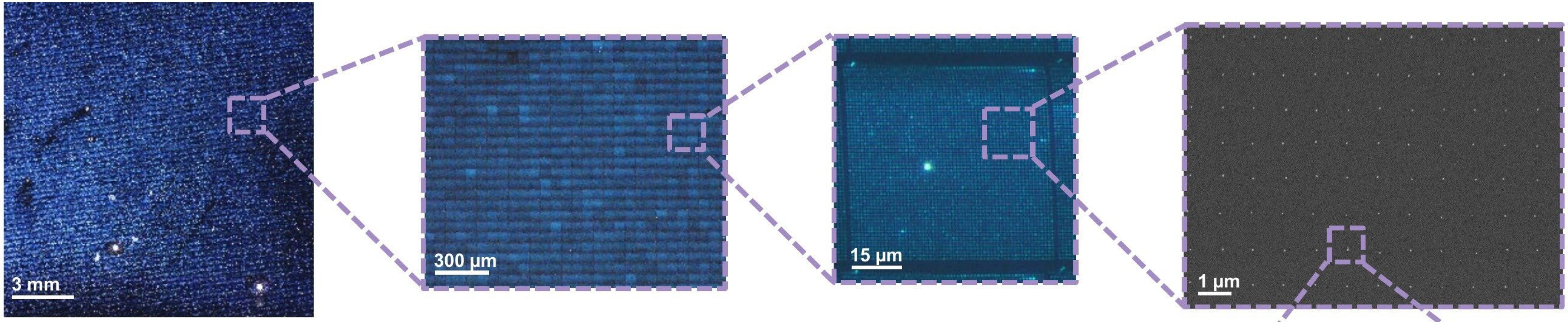
NAL INSTITUTE FOR
ECHNOLOGY

Materials Discovery – what's it all about..

Writing	***Nanoparticles/Nanostructures***
Reading	***Characterization/Measurement***
Comprehension	***Identity/implications***
Math	***How to get it done..***

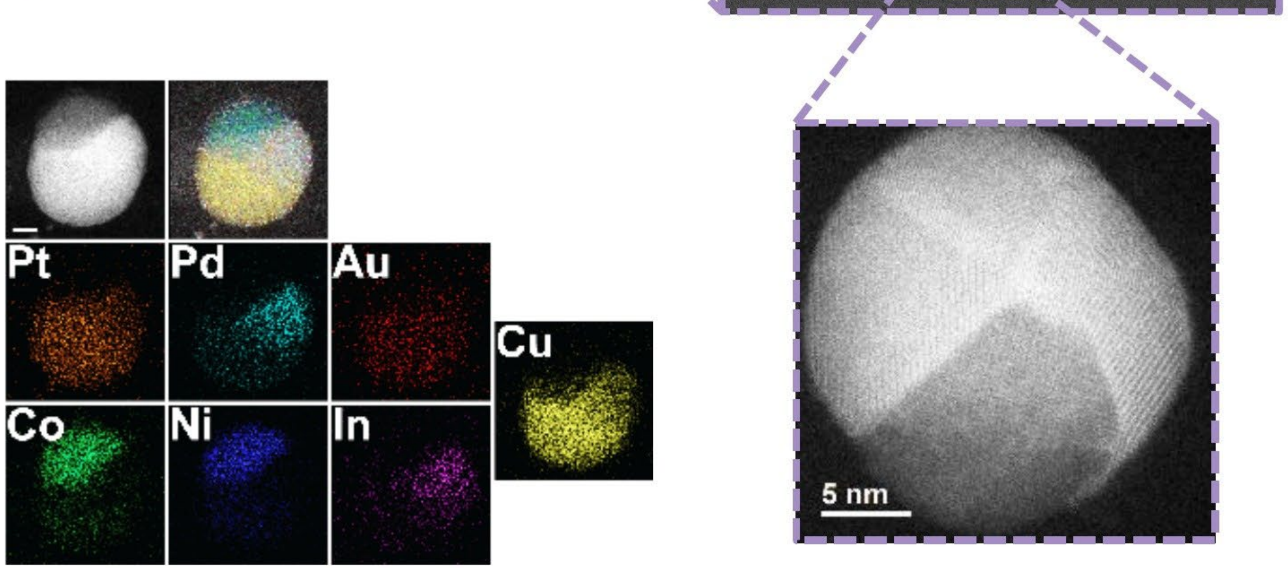
An Unprecedented Scale for Discovery

Wahl,, Dravid & Mirkin,
Adv Mater (2025)



Megalibrary specifications

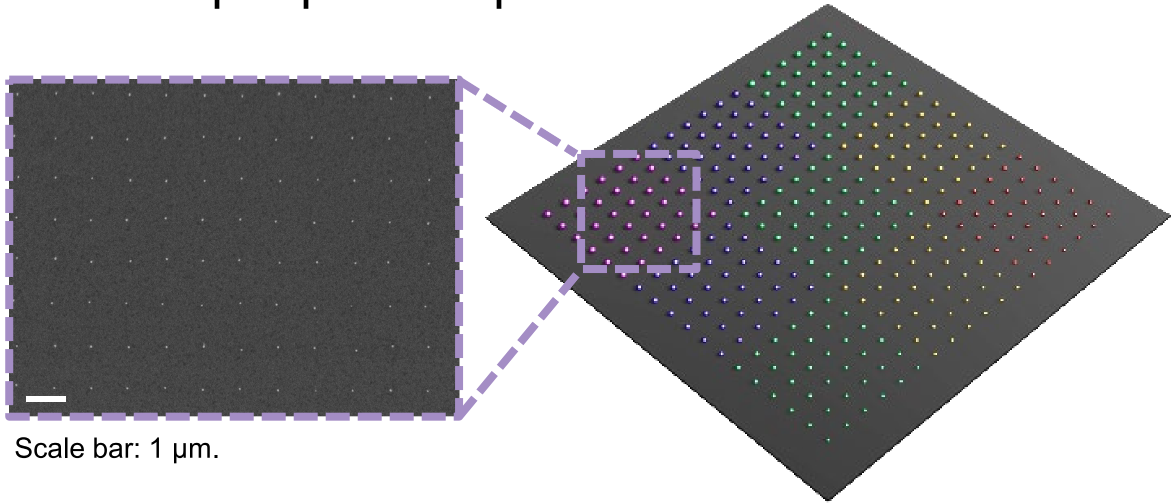
- 1.5x1.5 cm area on a 2.0x2.0 cm chip
- 10^6 unique materials per library
- 10^8 nanoparticles per library
- 3600 nanoparticles per material
- 60x60 µm per material



How about Structural Screening with Electron Microscopes?

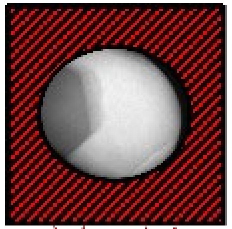
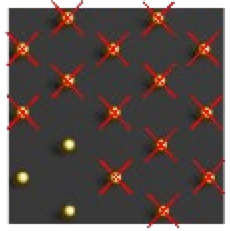
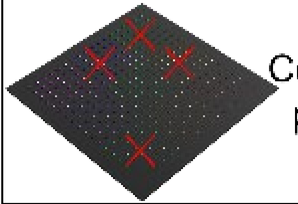
Library specifications

- 1.5x1.5 cm area on a 2.0x2.0 cm chip
- 10^6 unique compositions per library
- 10^8 nanoparticles per library
- 3600 nanoparticles per composition
- 60x60 µm per composition



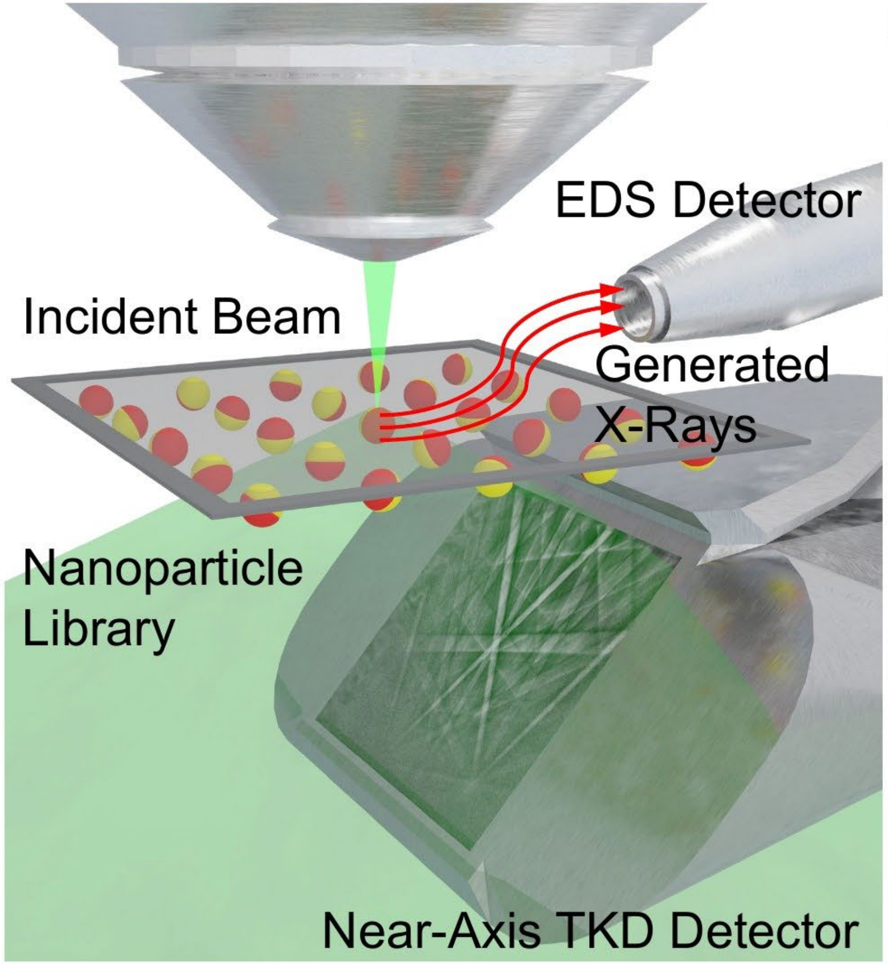
Scale bar: 1 µm.

Multilevel adaptive sampling for materials discovery at scale

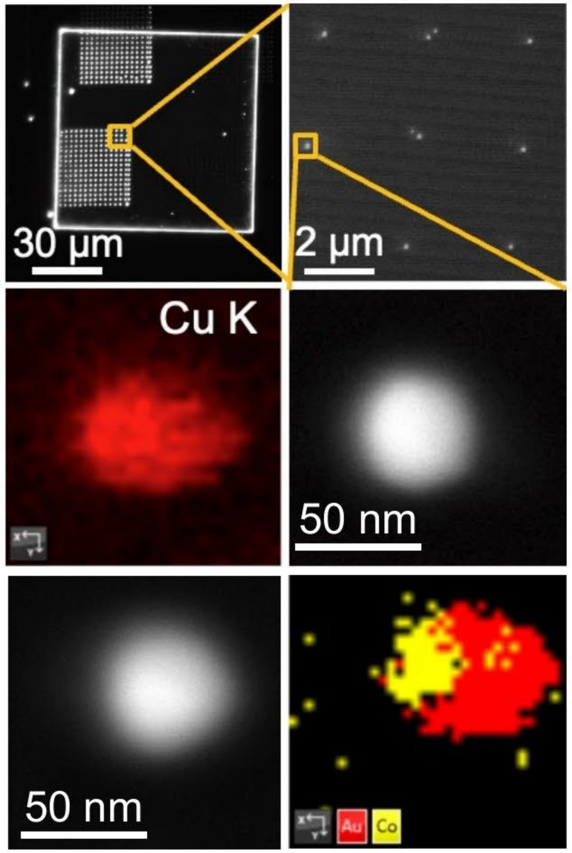
	Adaptive Sampling Level	Expected Reduction	Data Size	Acquisition Speed*
	None	-	100 PB (100k HDDs)	64 yrs
	Pixels per Particle	> 50%	50 PB	32 yrs
	Particles per Unique Composition	> 98%	1 PB	231 d
	Compositions per Library	~ 90%	100 TB (72 GB ea.)	23 d (24 min ea.)

*Based on 4DSTEM acquisition only using a STELA-type high-speed detector, assuming 20 s acquisition time per particle if fully automated.

SEM as a reliable high throughput nanoparticle characterization platform



Structure and Composition Characterization in SEM



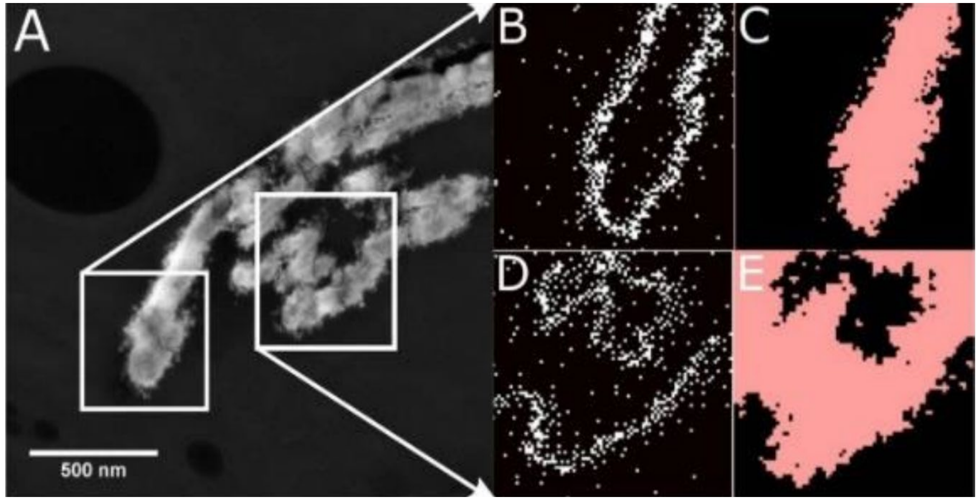
Comparison	STEM	SEM
Max. sample diameter	3.05 mm	> 100 mm
Number of NPs	~ 10^4	~ 10^8
Min. probe diameter	10^{-2} nm	1 nm
Acceleration voltage	40 – 300 kV	< 1 – 30 kV
Space in chamber	10^{-1} cm	10^2 cm
Simultaneous acquisition	ADF/ABF Diffraction Detector EDS/EELS SE/BSE	SE/BSE EDS ADF/ABF Diffraction Detector*
In situ	Specialized holders	Stage modules
Acquisition software	Custom Scripting	Custom Scripting

Kulaksizoglu, A. et. al. in prep.

AI Should Decide Where to Spend the Next Electron

ADAPTIVE ACQUISITION

ADAPTIVE EELS / EDS · ~10% OF POINTS



A HAADF B selected scan points C reconstructed spectrum map

Gallionella bacterial residue. The sampled points are not spread evenly — they land on the structure.

TIME BUDGET · ONE SPECTRUM IMAGE

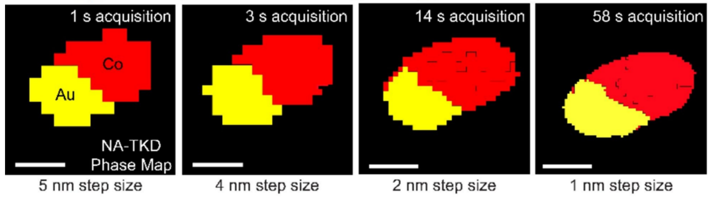
Full scan	2.7 h
Adaptive	24 min

6.8× faster

FAST READ CHANNEL · PER PARTICLE

40 s	manual SEM
< 5 s	NA-TKD map
1 s	5 nm step

FAST ACQUISITION KEEPS THE PHASE MAP



Au–Co NA-TKD phase maps: 1 s → 58 s acquisition, 5 → 1 nm step.

INFERENCE COST IS FLAT

	1 phase	270,000
Dictionary indexing	22 min	11 years
...with PCA	14 s	44 days
Neural network	0.25 ms	0.25 ms

Time to index 100,000 patterns against N candidate phases.

DECISION RULE

Do not classify everything.
Find what does not belong.

1. **Train on normal** — Learn the expected phase distribution.
2. **Score the rest** — How badly does each new pattern fit?
3. **Spend time there** — Only anomalies earn the expensive measurement.

0.74	0.88	0.92–0.99
PR-AUC, all experimental EBSD	PR-AUC, high pattern quality	ROC-AUC, simulated Ni–Al

Adaptive measurement is the experimental counterpart of the prescriptor: measure the tail, not the haystack.

VPD M&M 2026 deck, 5 Aug 2026: adaptive EELS/EDS p. 15 (Hujsak, K. et al., Micron 2018, 108, 31–40); NA-TKD read channel p. 20; Au–Co phase maps p. 21 (scalebars 20 nm); inference-cost table p. 28; anomaly-detection PR-AUC p. 31.

Automation Is Not Autonomy if the Experiment Cannot Remember

ATLAS / MCP / PROVENANCE

“A self-driving microscope that cannot recall what it already measured is not autonomous — it is merely automated.”

THE GAP TODAY

Terabytes / day

across JEOL, Thermo Fisher, Hitachi, Zeiss and Tescan instruments…

No provenance captured at the point of generation. Siloed by vendor format, disconnected from experimental context, unfindable once a session ends.

CAPTURE

Metadata at birth

Harvested automatically from scheduler and file headers. Zero user interaction — near-100% capture instead of 10–30 min of skipped hand entry.

CONNECT

Vendor-neutral context

Cross-vendor schema crosswalk. Persistent identifiers, checksummed transfer logs, an auditable chain from instrument to publication.

MOBILIZE

Governed reuse

The unpublished majority — dark data — is the highest-volume and often highest-value asset for training scientific AI. It needs a governed, rights-clean route to reuse.

Structure + function + context in one coordinate space, with provenance attached at birth.

That is what makes the next iteration smarter than the last.

A U.S.–Korea Opportunity: *Shared Scientific Infrastructure for AI*

WORKSHOP RECOMMENDATION

1 SHARED TESTBEDS

Matched quantum and neuromorphic materials measured across U.S. and Korean facilities on common calibration — so a number from “Evanston” and a number from “Daejeon” mean the same thing.

2 RARE-EVENT BENCHMARKS

Curated datasets built around interfaces, defects, distribution tails, switching events, dose damage and decoherence-correlated structures — the cases where averages fail.

3 AUTONOMOUS MICROSCOPY CHALLENGE

A shared task: the agent detects an anomaly, changes acquisition, adds spectroscopy or diffraction, and tests a prescriptor — scored on what it discovered, not how much it collected.

4 PROVENANCE + INTEROPERABILITY

Common metadata, instrument context and a rights-aware data layer, so models can learn across vendors and institutions without relitigating access each time.

Joint objective: connect instruments, data, physics and device platforms — not merely exchange datasets.

Acknowledgements

Students, postdocs/researchers & staff

NUANCE Center & SHyNE Resource

Q & A

Discussion

Measure the Tail. Prescribe the Architecture.

1 → 2 → 3 → 4 → 5 → 6

1. RARE FEATURE
2. OBSERVABLE
3. PRESCRIPTOR
4. ADAPTIVE MEASUREMENT
5. FUNCTION / ARCHITECTURE
6. TRUSTWORTHY DATA

← FEEDS THE NEXT EXPERIMENT

From seeing atoms → deciding what to measure → deciding what to build next.

U.S.–Korea collaboration can make this loop shared, interoperable and trustworthy.

Vinayak P. Dravid · NUANCE Center, Northwestern University · v-dravid@northwestern.edu

From Adaptive Acquisition to a Scientific Digital Twin

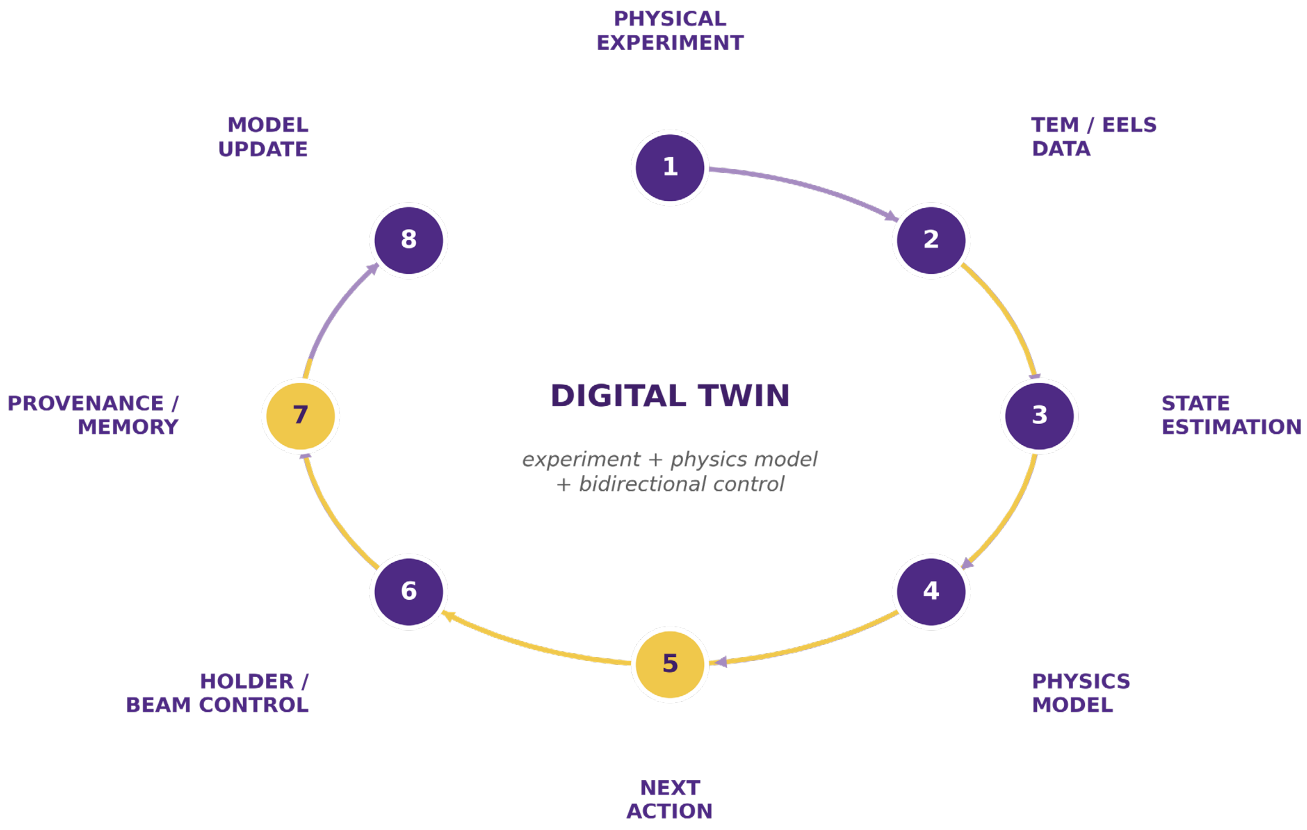
CLOSED LOOP

What exists today

In-situ TEM runs open-loop: acquire, then interpret afterwards. The holder, the beam and the model never talk to each other during the experiment.

Working concept

DENS-holder API + a thermal / bond-integrity model + real-time deconvolution, so state estimation runs while the experiment is still on the stage.



What closes the loop

Steps 5–6 write back: the model chooses the next action and the holder and beam execute it.

What makes it cumulative

Step 7 keeps provenance and memory, so step 8 updates a model that remembers every prior session.

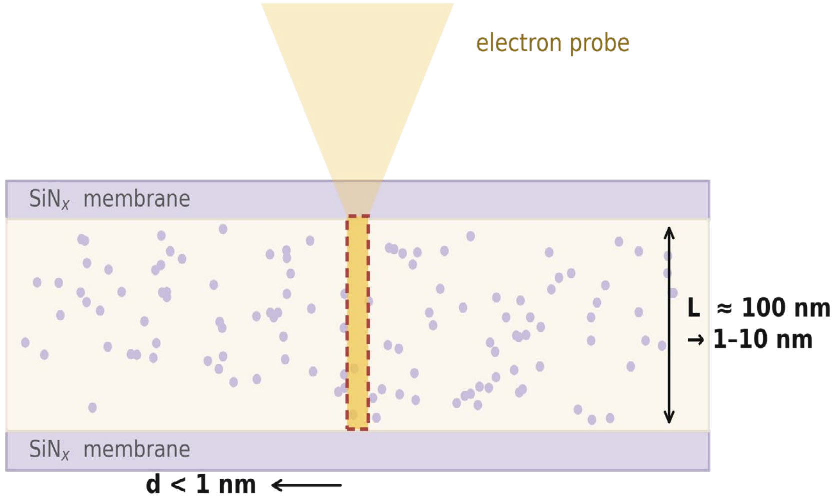
A digital twin is experiment + physics model + bidirectional control — not a static simulation running alongside.

G. Trindade dos Santos, "Digital twins for in situ TEM experiments," Aug. 2026, slides 3–11. Working concept and future direction — not a demonstrated system.

BACKUP — Ultrathin Chip: Approaching the Few-Molecule Limit

EXTREME REGIME

At 1 atm and 300 K, the instantaneous electron-beam interaction volume can hold N ≈ 1–2 molecules.



$$V = \pi(0.5\ \text{nm})^2 \times 100\ \text{nm} \approx 8 \times 10^{-26}\ \text{m}^3 \qquad N = PV / k_BT \approx 1\text{-}2\ \text{molecules}$$

Ultrathin SiN_x membranes shrink the confinement length and cut scattering, enabling gas EELS at high pressure.

The measurement volume can itself sit in the tail.

THE OPTICS SET THE STATISTICAL REGIME

1 · Focused probe *Stochastic limit*

Sub-Å convergent beam. N ≈ 10–100 molecules. $W \gtrsim k_BT$. Transient violations are observable.

2 · Broad beam *Continuum limit*

Wide-field illumination. $N \approx 10^6$ molecules. $\sigma_W \to 0$. The ensemble averages perfectly.

3 · Raster scan *NESS driver*

Programmed spatial scan. Injects ΔE_{loss}. Active observation — extracts ΔF from chaos.

Why it matters here

When the measurement volume itself enters the extreme-statistics regime, fluctuations stop being noise and become the signal — a route to nanoscale thermodynamics and rare-event microscopy.

Dravid, "UT Chip as a Quantum System," IMC 2026, 3 Sept 2026, slides 19–23. Interaction volume $V = \pi(0.5\ \text{nm})^2 \times 100\ \text{nm} \approx 8 \times 10^{-26}\ \text{m}^3$; $N = PV / k_BT$.

The asymmetry at the heart of accelerated discovery

2

hours

WE CAN WRITE

One megalibrary:
10^6 compositions,
$>10^8$ addressable nanoparticles.

<5

hours

WE CAN SCREEN

Functional mapping across the whole library.

>100+

years

WE CANNOT READ

Phase-mapping every particle at 40 s each.

In literacy, reading runs 15–20× faster than writing. In nanoscience we have inverted it — and structural inference, not synthesis, is now the rate-limiting step.

Phase-mapping estimate assumes 40 s per nanoparticle across 600 million nanoparticles · Wahl CB et al., Adv. Mater. 2025, 37(18), 2500088

BACKUP — What Makes a Prescriptor More Than a Correlation?

FALSIFIABILITY

THREE NECESSARY CONDITIONS

1 — Tail dominance

Function is controlled by rare features, not by the mean of the distribution.

2 — Separability

Population ρ and coupling G factorize at leading order — the product is meaningful.

3 — Independent controllability

Experiments can vary ρ at fixed G, and G at fixed ρ.

2 × 2 TEST

	ρ low	ρ high
G high	3×	6×
G low	1×	2×

Pre-commit the ratio predictions before the experiment.

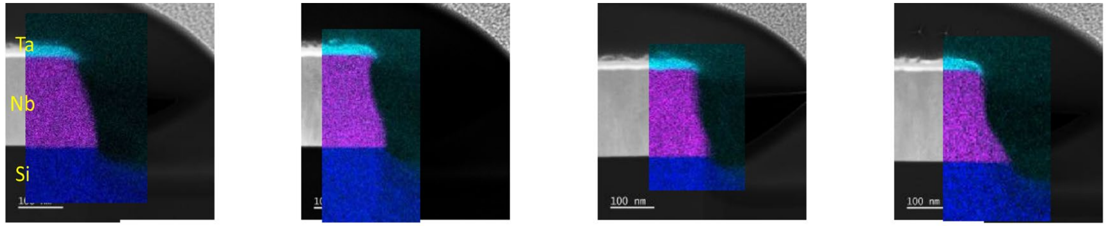
If the ratio predictions fail,
the failure identifies cross-coupling or a missing variable. That is useful science — not a failed fit.

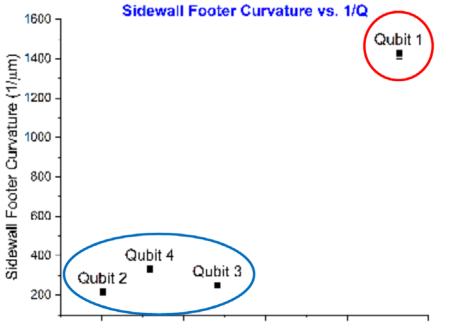
Prescriptor Perspective Outline v1 (2026), Sections II.C and V. Working formalism.

BACKUP — Quantum Evidence Chain: Geometry → Field → Oxide → Loss

SOURCE FIGURES

A Sidewall & footer geometry — chip 1, four qubits



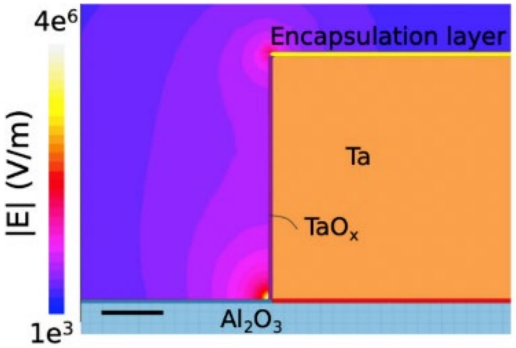


Footer curvature separates the outlier from the cluster; footer angle does not separate as cleanly on this chip.

Peter Lim, p. 78

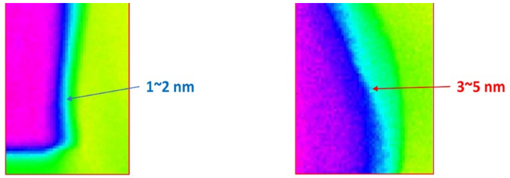
The chain, end to end: a sharper footer concentrates the field, the region of high field participation carries more lossy oxide, and that oxide population is where the TLS loss lives.

B Field participation



DC FEM: |E| concentrates at sidewall corners. Chang, R. D. et al., arXiv:2408.13051v1 (2024), via Peter Lim p. 79.

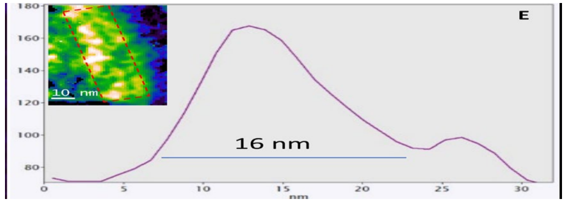
C Oxide at the footer

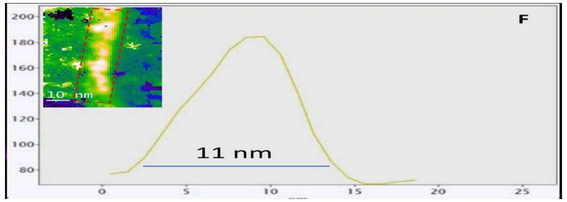


1–2 nm better **3–5 nm** worse

O K-edge (532 eV) at the footer. Peter Lim, p. 84.

D Sidewall oxide thickness — line profiles





16 nm — worse **11 nm — better**

Peter Lim, p. 87.

Peter Lim / SQMS transmon work, U.S.–Korea deck 12 Sept 2026, pp. 78, 79, 84, 87. Panel B is a third-party figure (Chang et al. 2024) reproduced from p. 79 with its original citation. Slide 88 of the source deck is noted as in preparation — confirm clearance before public presentation.