Accelerating Scalable Fabrication of Quantum Hardware

Q4I, July 12 - 14, 2022

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VP, Research

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Albany Nanotech Complex

The NY CREATES 300 mm wafer fab at the Albany Nanotech Complex is the most advanced, publicly-owned semiconductor R&D facility in the U.S.

- **> $15 billion cumulative investment**
- **> 150,000 SF of cleanroom space**
- **> 2,700 on site**
- **> 25 years of R&D**
- **Several successful R&D programs**
  - **G450C**
  - **Center for Semiconductor Research**
  - **AI Hardware Center**
  - **SEMATECH**
  - **META Center**

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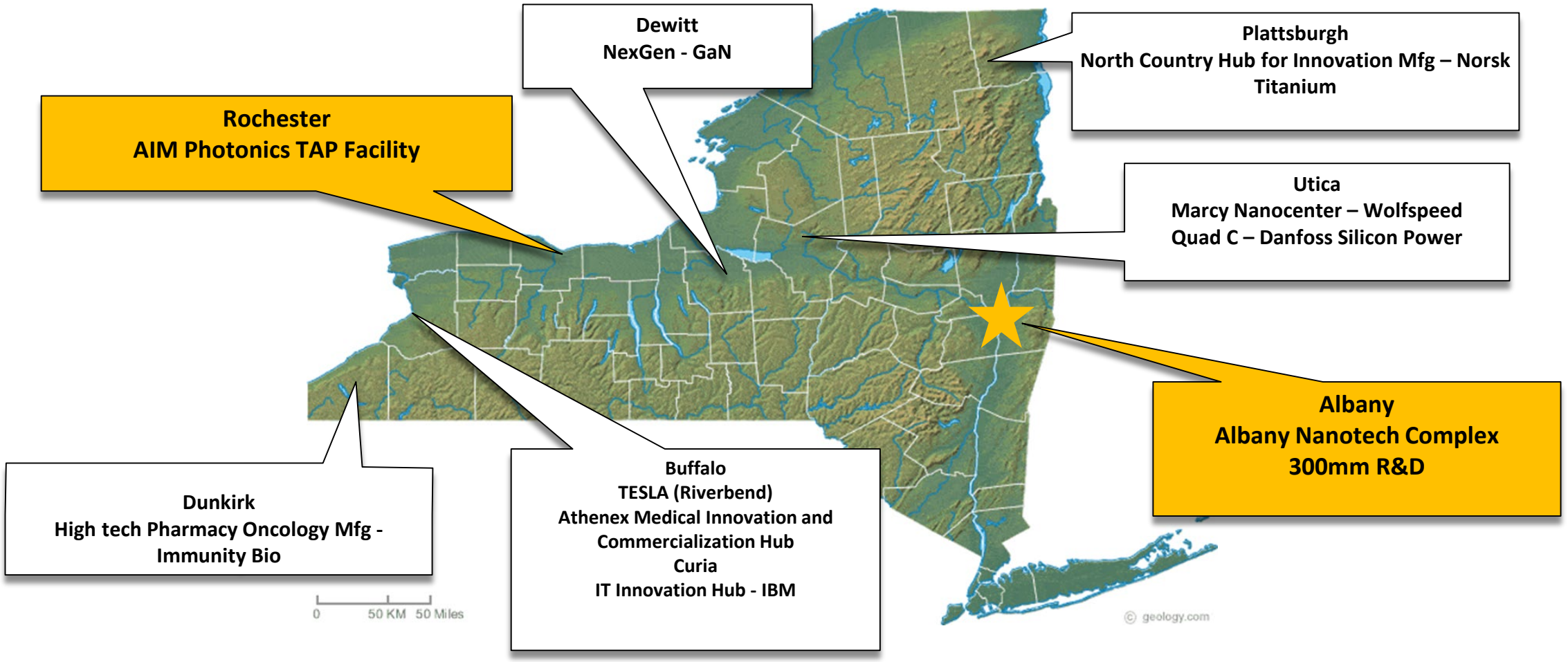
NY CREATES: Statewide Impact



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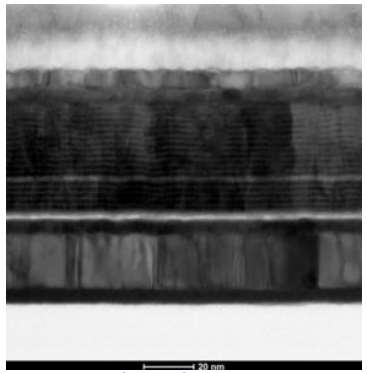
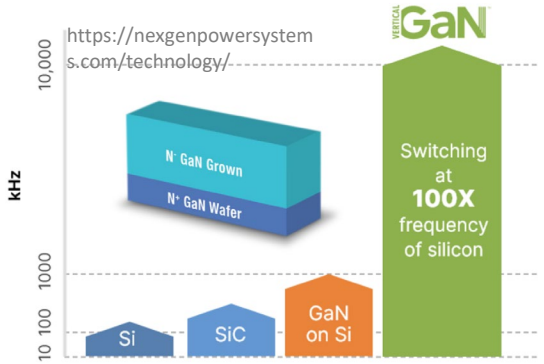
R&D at Albany: Many Areas, Many Partners



Non-volatile memory
(MRAM, FeRAM, ReRAM)

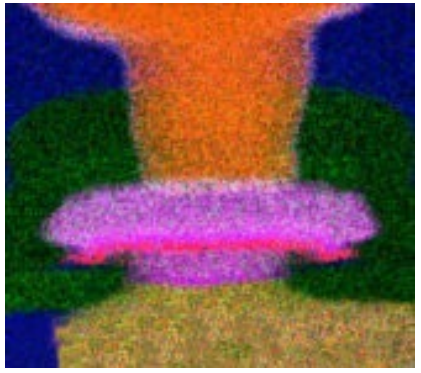


GaN Power Electronics
(enabling NexGen Power Sys)

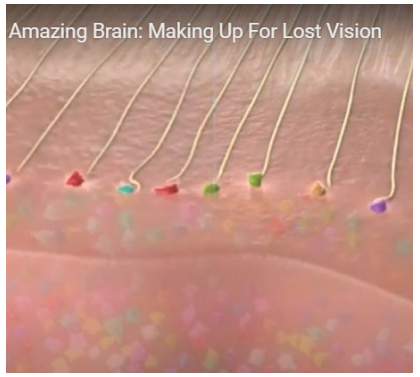
Heterogeneous Integration
and Packaging Facility

IBM Research AI Hardware Center
at Albany Nanotech Complex

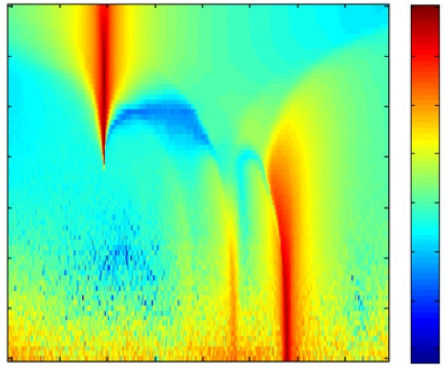
SiC Power Electronics
(enabling Wolfspeed)



Neuromorphic Computing
(with SUNY Poly, AFRL)



Nanobiology
(with Downstate)



Quantum
(with Seeqc, AFRL, etc)

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Chip R&D and Fabrication: Resurgence in US

In particular, the bipartisan FY2021 NDAA semiconductor provisions:

Established a Department of Commerce incentive program to provide financial assistance to build, expand, or modernize commercial semiconductor fabrication, assembly, testing, advanced packaging, and R&D facilities in the U.S.

Provided support for domestic microelectronics industry, including new R&D programs at the Department of Defense.

Authorized a multilateral semiconductor fund to support the adoption of a secure semiconductor supply chain and greater alignment of export control and other related politics among partner countries.

Created a National Semiconductor Technology Center, a National Advanced Packaging Manufacturing Program, and additional R&D programs at the Department of Commerce to conduct research, prototyping, and workforce training in advanced semiconductor technology with private sector and interagency participation.

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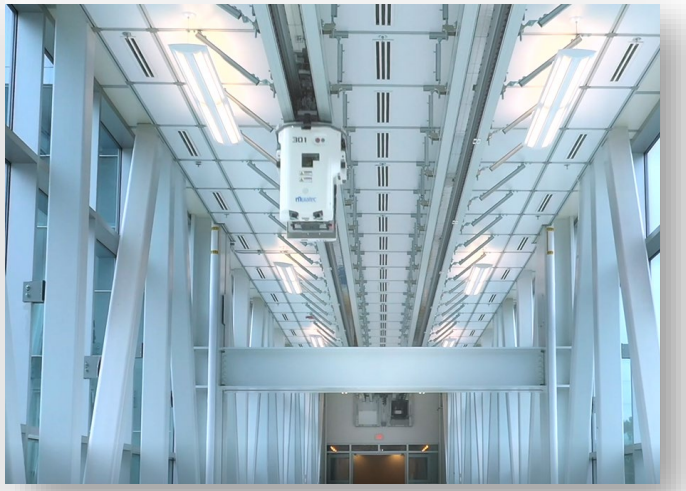
World-class facilities – and growing!



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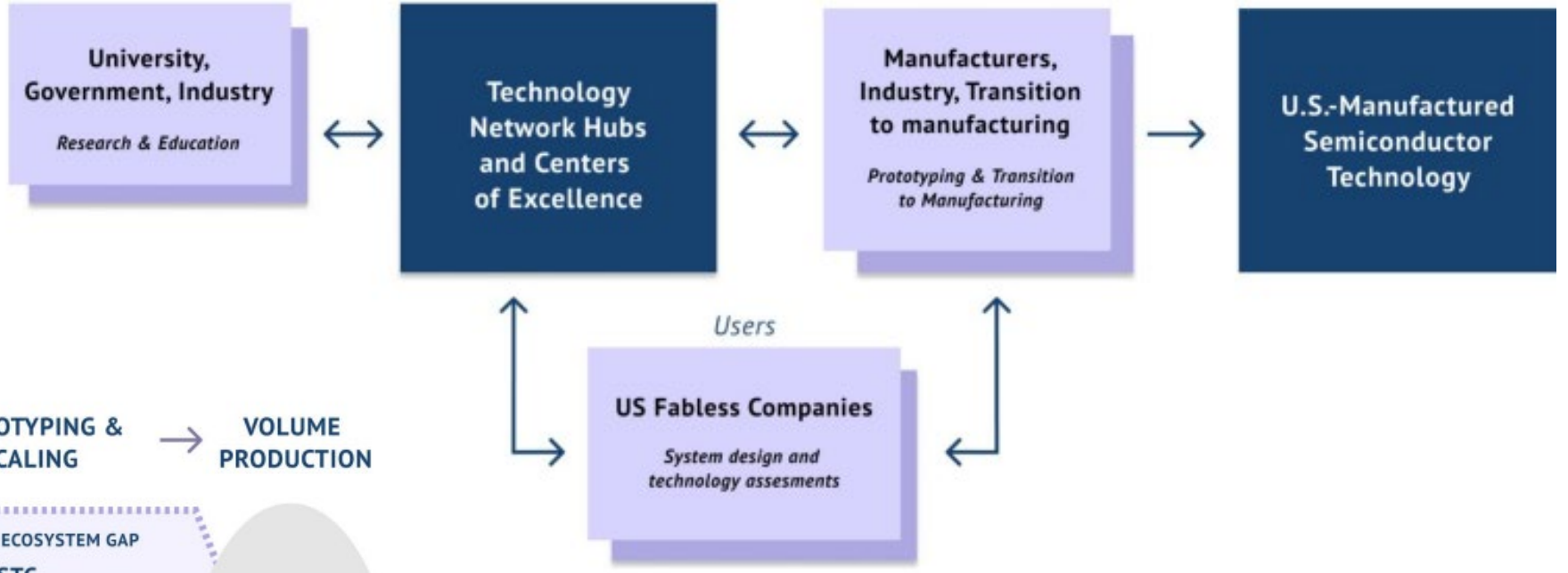
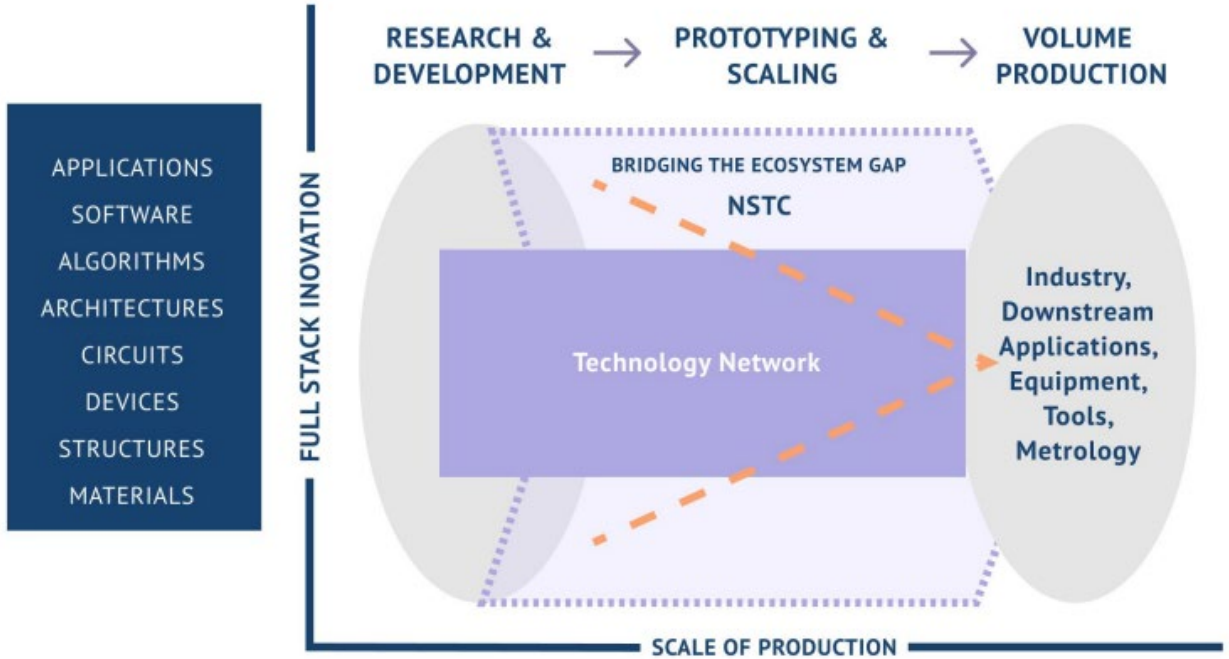
American Semiconductor Innovation Coalition



https://asicoalition.org/vision-for-nstc



Using existing state-of-the-art facilities, and best-known-methods for structure and organization will enable NSTC to come online much more rapidly

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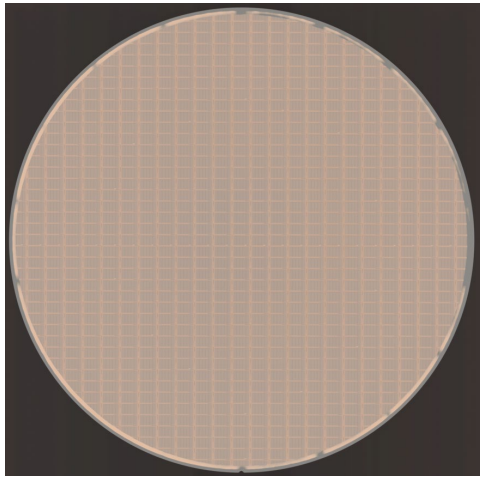
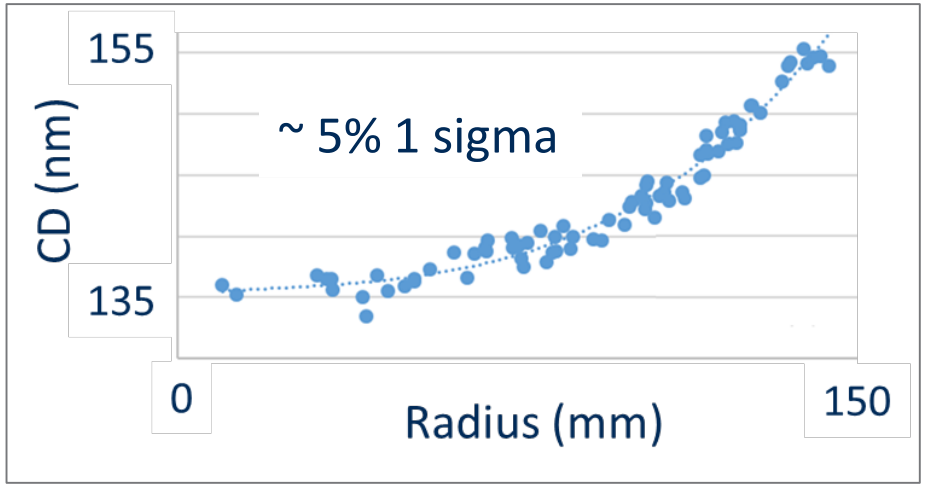
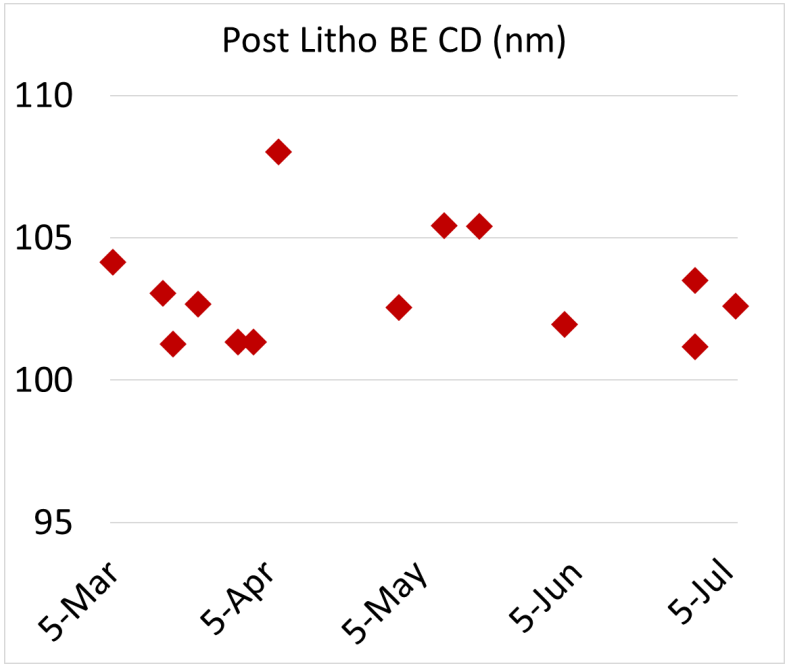
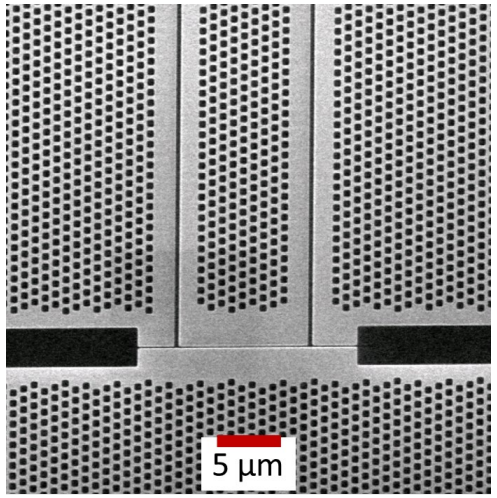
NY CREATES R&D in Quantum Technologies

- Fluxonium Qubits at 300 mm wafer scale (AFRL STTR Phase II)
- Superconducting Optoelectronic Neuromorphic Computing (AFRL)
- Engineering surfaces to improve qubit coherence (with Brookhaven National Lab, DOE NQI)
- ALD AlN and Al_2O_3 for UV-PICs (with RIT, U. Mass)
- NbN/TaN/NbN for SFQ circuits at 300 mm scale (with imec)
- NbN and TaN for superconducting nanowires









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A Palette of Materials for Quantum Technologies

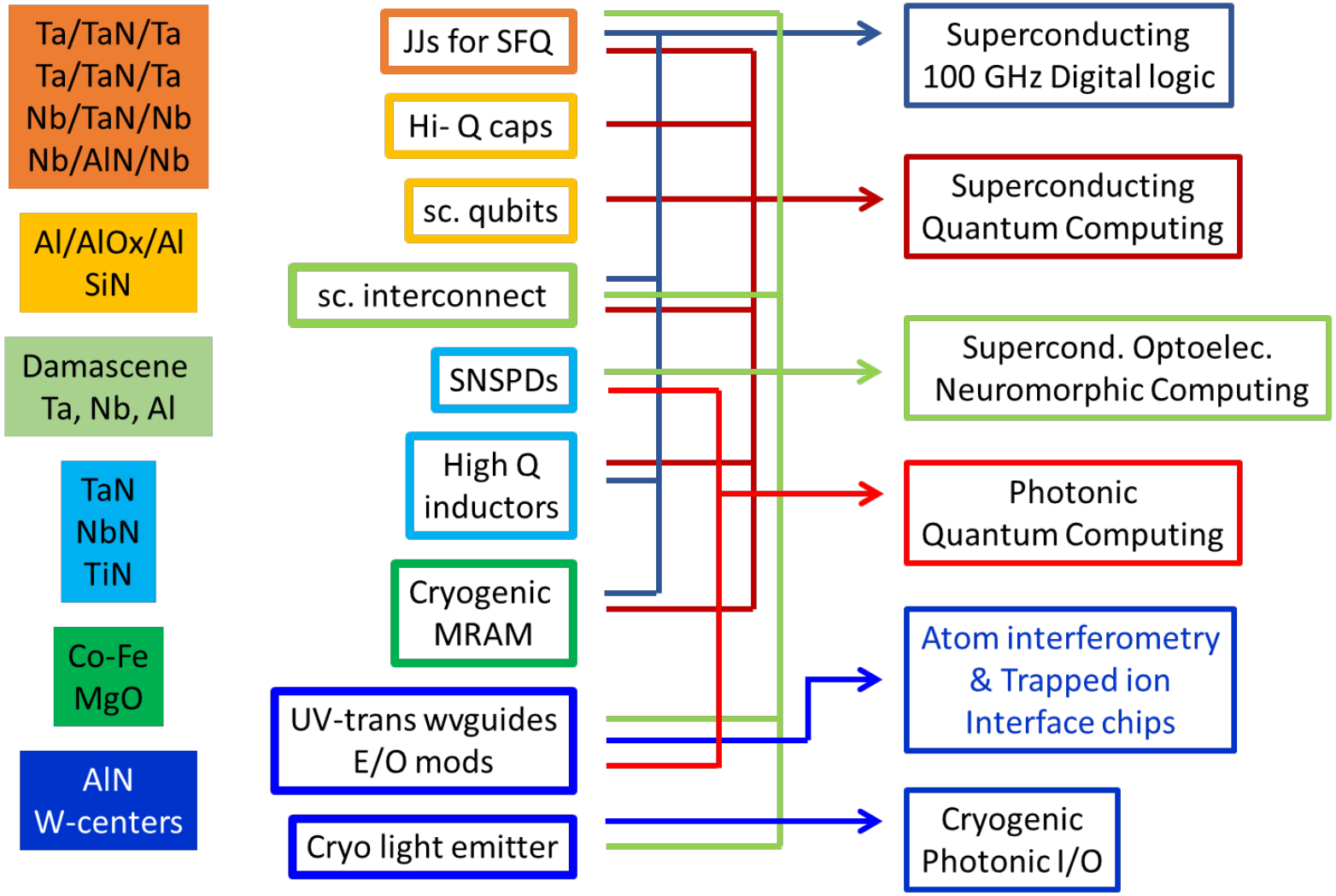
Superconducting materials

Cryo-dielectrics with low TLS density

High Kinetic Inductance materials

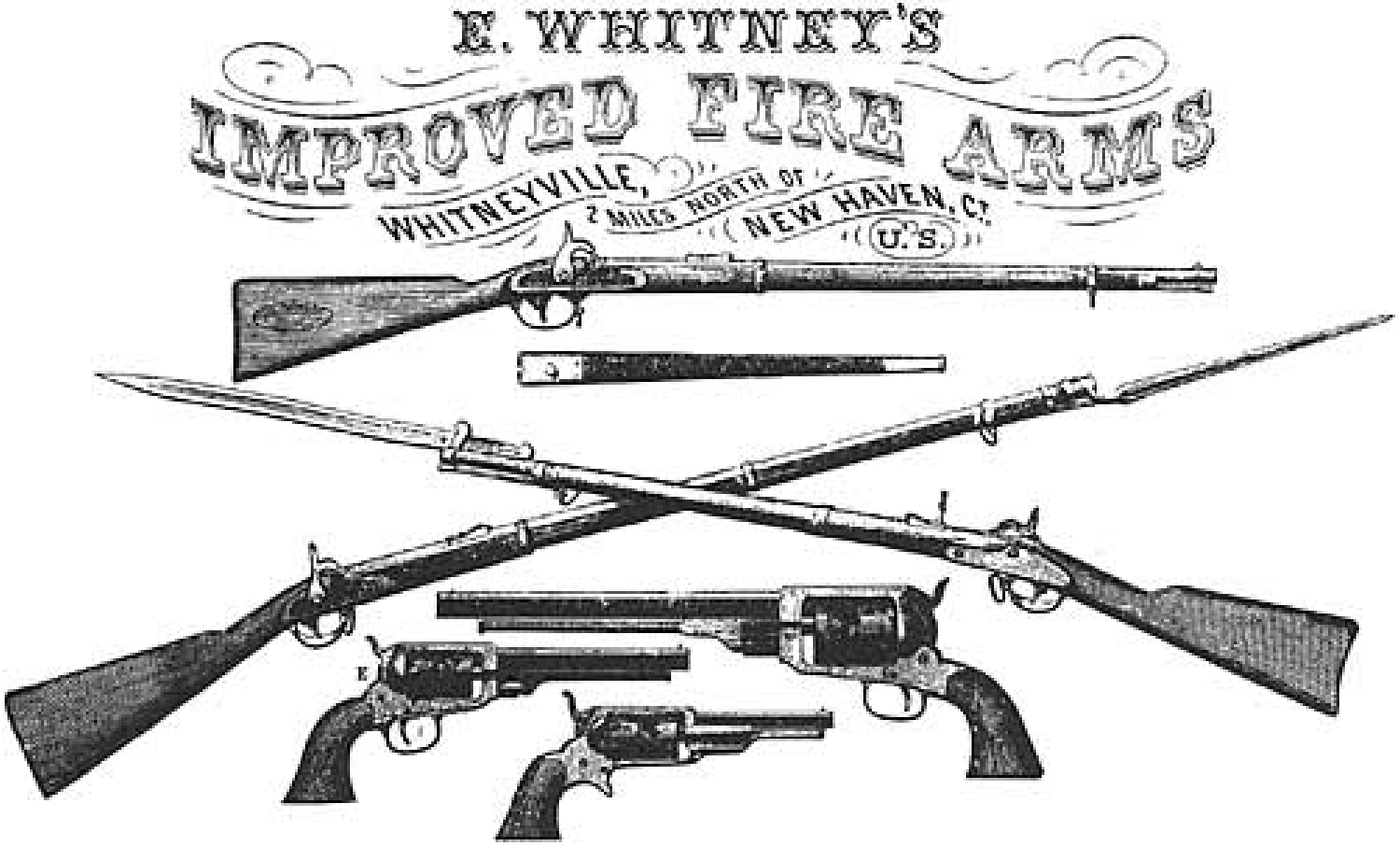
Materials for magnetics

Optical (UV-IR) Materials



How to Accelerate Scalable Quantum Hardware

Interchangeable Parts



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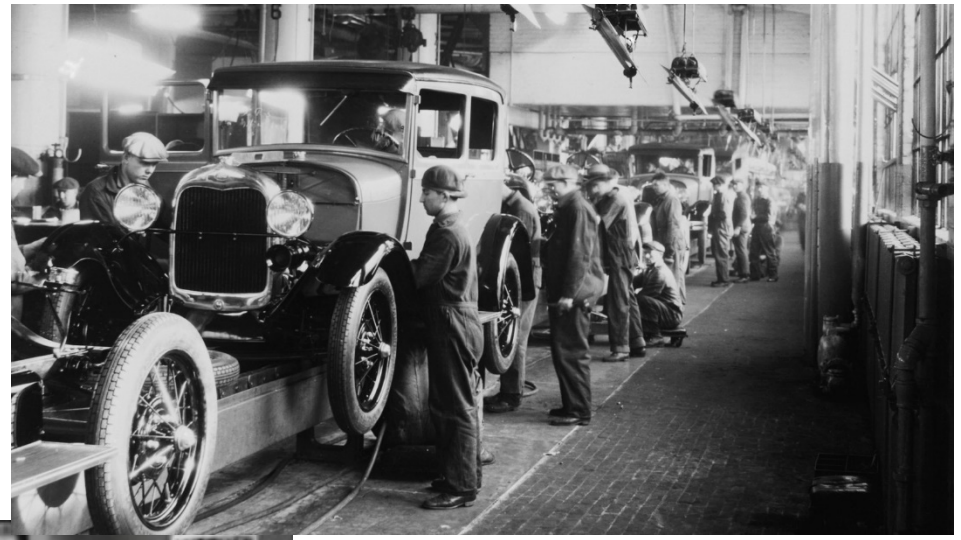
History For Quantum Engineers (HS101)

Moving Assembly Line



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History For Quantum Engineers (HS 201)

Reliability in Fabrication

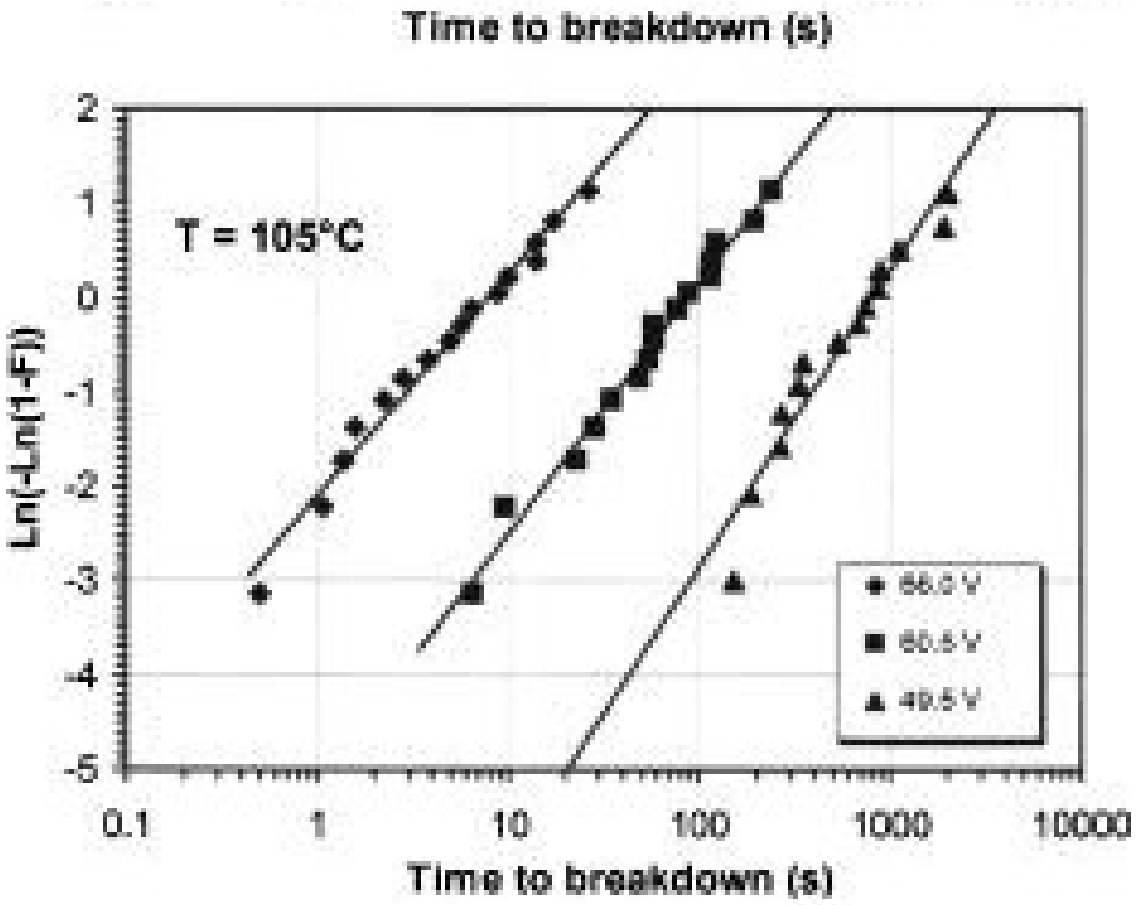
Reliability Ratings

Category	Brand	Rank	Rank change	Rating
Top		1	↑ 2	81
		2	↑ 2	77
		3	↓ 2	77
		4	↑ 5	75
		5	↑ 11	71
		6	↓ 1	69
		7	↓ 5	68
		8	↑ 13	63
		9	↓ 1	62
		10	↑ 5	59
		11	↑ 1	57
		12	↑ 2	55
		13	↑ 3	53
Mid		14	↓ 7	51
		15	↓ 4	50
		16	-	50
		17	↓ 7	46
		18	↓ 5	46
		19	↑ 7	44
		20	-	43
		21	↓ 1	42
		22	↑ 2	40
		23	↑ 4	39
		24	↑ 1	38
Bottom		25	↓ 3	37
		26	↓ 3	35
		27	↓ 9	33
		28	↓ 9	29
		29	-	27
		30	↓ 2	23

SOURCE: Consumer Reports

CNBC

Design for Reliability



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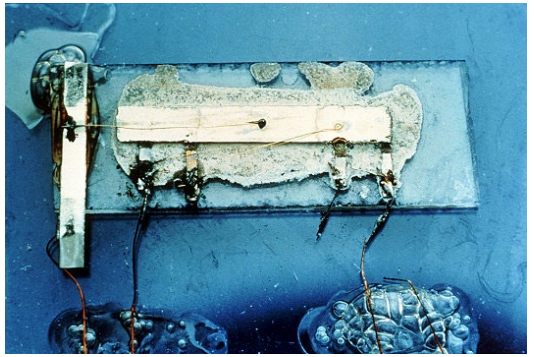
IC Industry History Lessons (HS301)

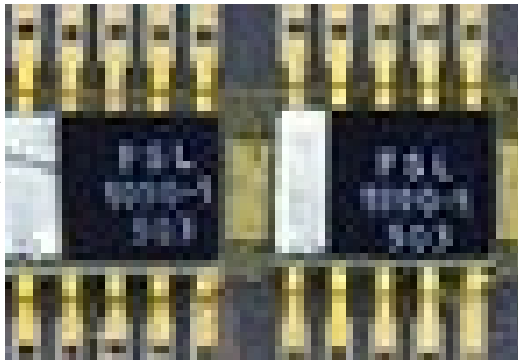
From the IC industry:

- Embrace change - ITRS
- “Copy Exact” / “Copy Smart” and other tech transfer mantras
- Control of process *and* control of inputs



http://www.computerhistory.org/ revolution/digital-logic/12/276

Si BJT



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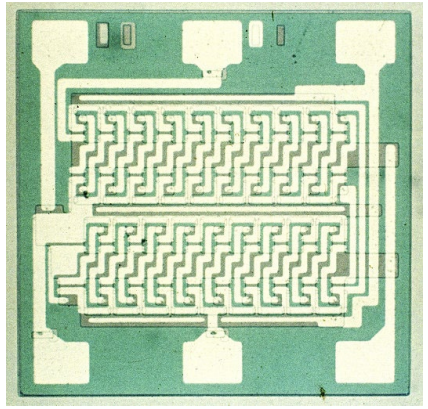
MOS



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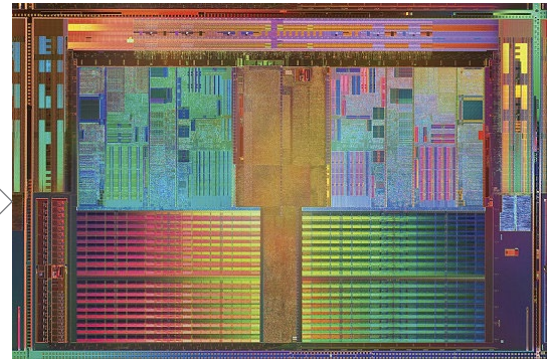
CMOS



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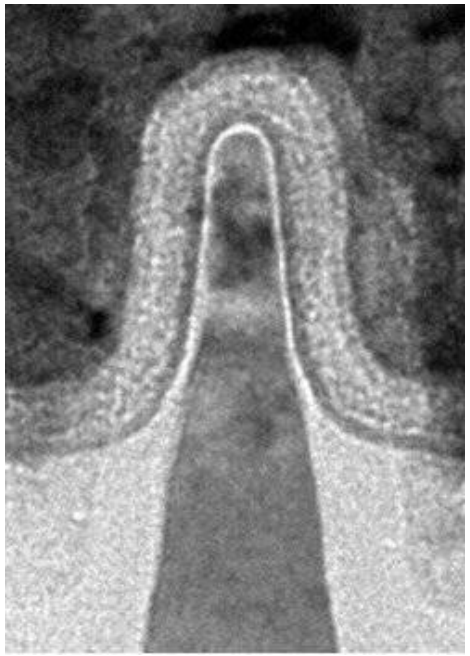
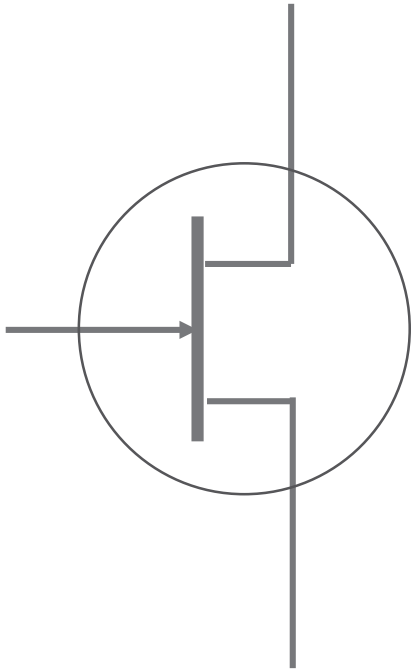
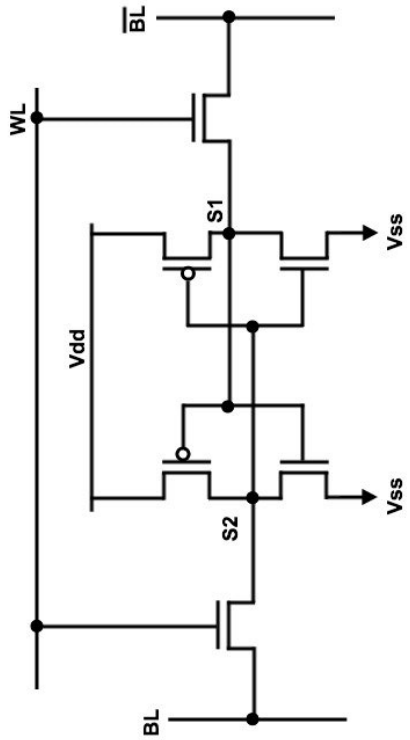
Advanced IC History (HS 411)

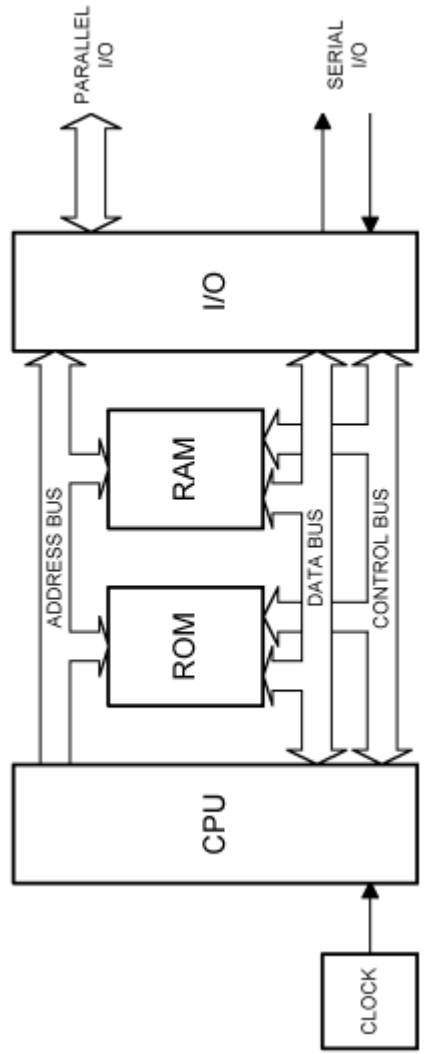
Creating levels of abstraction increases efficiency …



Intel FinFET
(EE Times Asia)



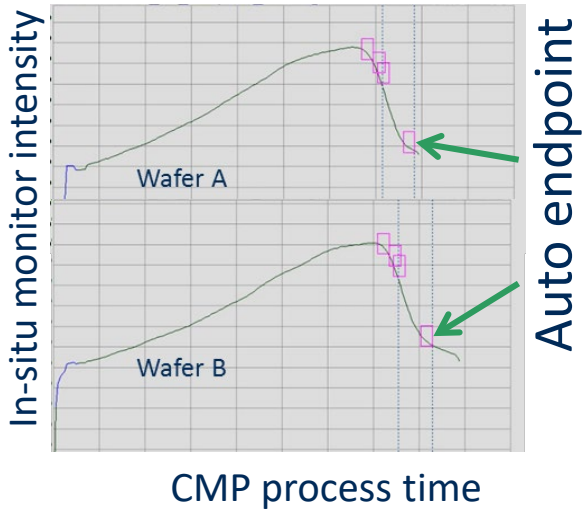




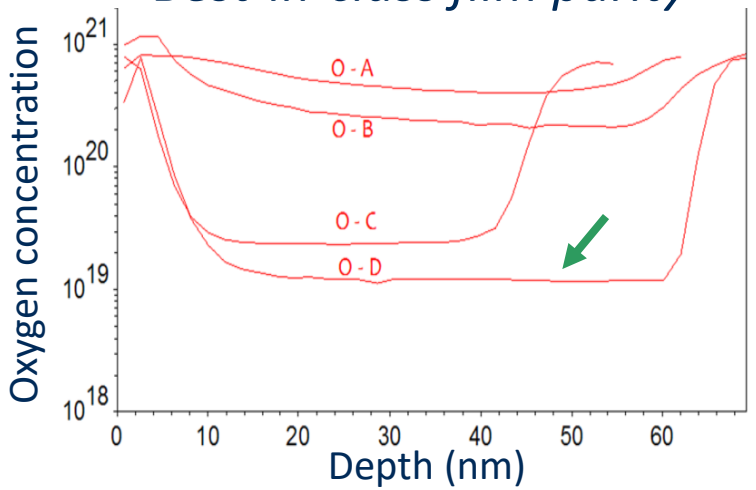
Abstraction needs Hardware with Predictable Properties

300 mm to the rescue:

- Less to do about wafer size! More to do with significantly advanced process capability
- Protocols in a typical 300 mm fab allow:
  - ➢ Higher signal to noise ratio in experiments
  - ➢ Less time wasted in development
  - ➢ **More robust data to support PDK development**



Best-in-class film purity



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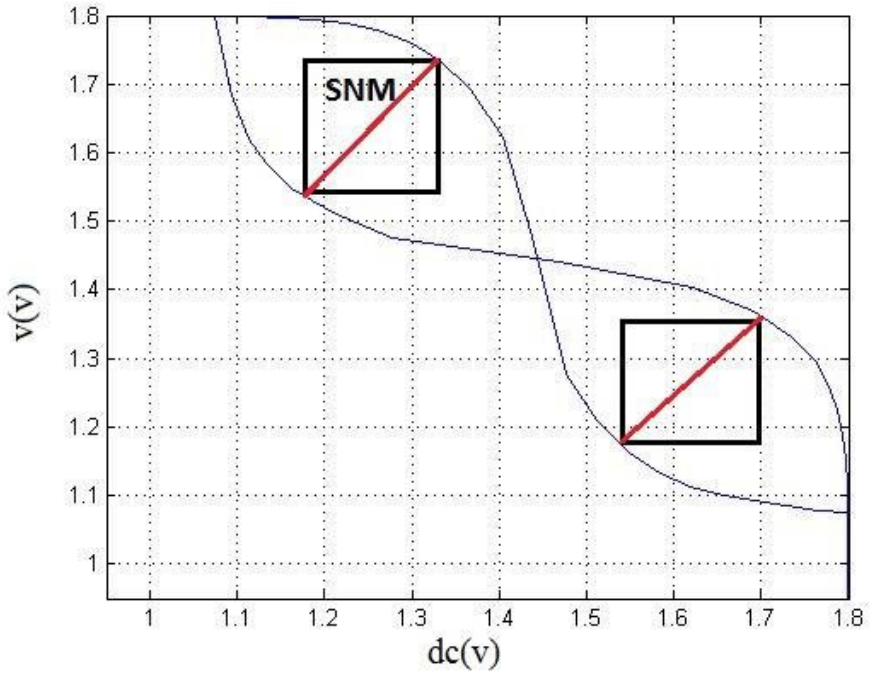
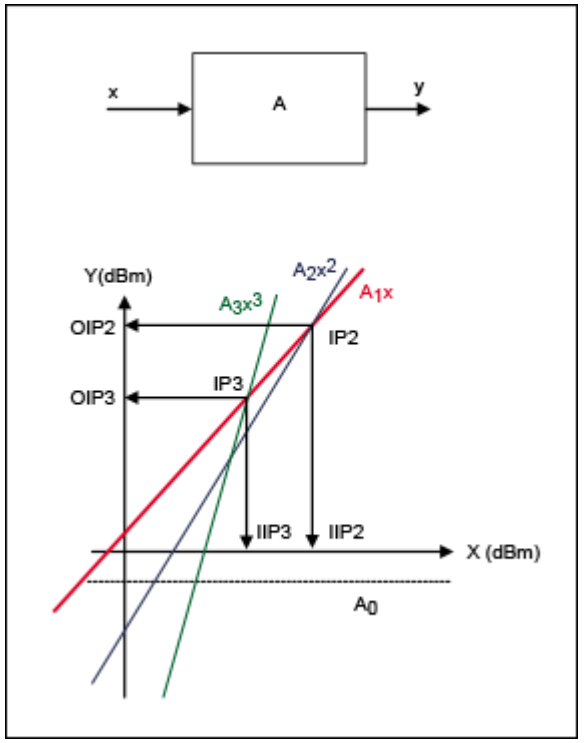
Quantum Abstraction is Harder

Digital



Analog
more to specify



Quantum:

Need to define:

- Native oxides
- Interfaces
- Materials (XRD? Purity?)
- Spatial extent of model
- Speed/frequency
- Noise behavior
- Variation over time
- Cosmic ray impact

Needs predictable devices!

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Co-Design

From Devices to Chips to Algorithms and Quantum Systems

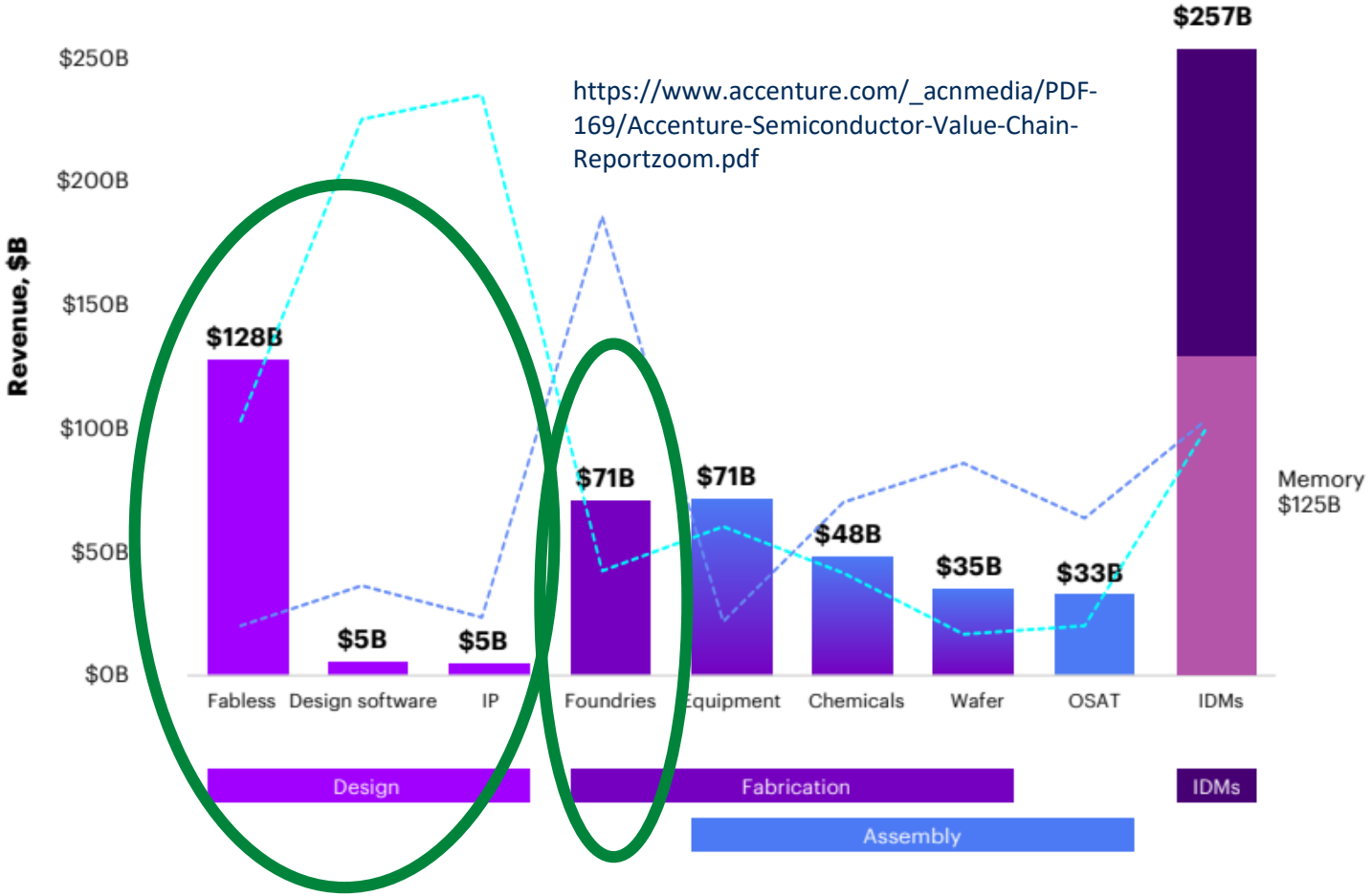
People already looking at:

- Qubit connectivity – and impact on algorithms
- Tunable qubits / trimmable qubits / fire-and-forget qubits
- Tradeoffs between state preparation and computation time/resources
- Hybrid systems – but anticipate deleterious ‘nearest-neighbor’ interactions
- Algorithms to partition problems to run on smaller quantum systems

Co-Design Center for Quantum Advantage (C2QA) has a strong effort in this area: “Abstract Machine Models”, chartered by Mark Ritter (IBM), Ike Chuang (MIT), Jim Misewich (BNL) *et al*.

Developing Quantum PDK will be worth it

PDKs enable much wider access



Photonic Quantum PDK at 300 mm by Dr. Fanto *et al* at AFRL Rome, with AIM Photonics

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Democratizing Access

Open PDK will decrease barriers to entry for start-ups and academia

Increase access through:

- Deeper collaboration
- Open PDK
- Multi-part wafers (MPW)
- Open test-bed
- More patient capital investment

NY CREATES aims to help by leveraging our non-profit status, and working closely with partners for easier technology access

Our Quantum Partners – Hope to add you!

Currently active partnerships

seeQC

AFRL

NIST

Brookhaven National Laboratory

TEL™

imec

RIT Rochester Institute of Technology

AUBURN UNIVERSITY
SAMUEL GINN COLLEGE OF ENGINEERING

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