Accelerating Scalable Fabrication of Quantum Hardware

Q4I, July 12 - 14, 2022

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VP, Research
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
NY CREATES: Statewide Impact

- Rochester
  AIM Photonics TAP Facility

- Dunkirk
  High tech Pharmacy Oncology Mfg - Immunity Bio

- Dewitt
  NexGen - GaN

- Buffalo
  TESLA (Riverbend)
  Athenex Medical Innovation and Commercialization Hub
  Curia
  IT Innovation Hub - IBM

- Plattsburgh
  North Country Hub for Innovation Mfg – Norsk Titanium

- Utica
  Marcy Nanocenter – Wolfspeed
  Quad C – Danfoss Silicon Power

- Albany
  Albany Nanotech Complex
  300mm R&D
R&D at Albany: Many Areas, Many Partners

- **GaN Power Electronics**
  - (enabling NexGen Power Sys)
  - [https://research.ibm.com/collaborate/ai-hardware-center](https://research.ibm.com/collaborate/ai-hardware-center)

- **SiC Power Electronics**
  - (enabling Wolfspeed)

- **Neuromorphic Computing**
  - (with SUNY Poly, AFRL)
  - [https://nexgenpowersystems.com/technology/](https://nexgenpowersystems.com/technology/)

- **Nanobiology**
  - (with Downstate)
  - [https://nexgenpowersystems.com/technology/](https://nexgenpowersystems.com/technology/)

- **Quantum**
  - (with Seeqc, AFRL, etc)
  - [https://research.ibm.com/collaborate/ai-hardware-center](https://research.ibm.com/collaborate/ai-hardware-center)

- **Heterogeneous Integration and Packaging Facility**

- **Non-volatile memory**
  - (MRAM, FeRAM, ReRAM)
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.
World-class facilities – and growing!

- NanoFab 200 (CESTM)
- NanoFab North
- NanoFab Central
- NanoFab South
- NanoFab Xtension

Another fab coming here!
Using existing state-of-the-art facilities, and best-known-methods for structure and organization will enable NSTC to come online much more rapidly.
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 Al₂O₃ 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
A Palette of Materials for Quantum Technologies

Superconducting materials
- Ta/TaN/Ta
- Nb/TaN/Nb
- Nb/AIN/Nb
- Al/AIOx/Al SiN

Cryo-dielectrics with low TLS density
- Damascus Ta, Nb, Al

High Kinetic Inductance materials
- TaN
- NbN
- TiN
- Co-Fe
- MgO
- AIN
- W-centers

Materials for magnetics

Optical (UV-IR) Materials

Superconducting
- 100 GHz Digital logic
- Quantum Computing

Superconduct. Optoelec.
- Neuromorphic Computing

Photonic Quantum Computing

Atom interferometry & Trapped ion Interface chips

Cryogenic Photonic I/O

UV-trans waveguides E/O mods
Cryo light emitter
How to Accelerate Scalable Quantum Hardware

Interchangeable Parts
History For Quantum Engineers (HS101)

Moving Assembly Line
### Reliability in Fabrication

#### Reliability Ratings

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SOURCE: Consumer Reports

### Design for Reliability

![Graph showing time to breakdown (s) vs. temperature (T = 105°C)]
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
http://www.computerhistory.org/revolution/digital-logic/12/278/1441?position=0
http://www.computerhistory.org/revolution/digital-logic/12/279
http://www.computerhistory.org/revolution/digital-logic/12/280
Creating levels of abstraction increases efficiency ...
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
Quantum Abstraction is Harder

Digital

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

Needs predictable devices!

Analog

More to specify

Quantum:
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
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
- umec
- Rochester Institute of Technology
- Auburn University
THANK YOU!