SUNY Polytechnic Institute

Progress Towards Enabling Quantum Engineering

Photonics for Quantum (PfQ) Workshop

RIT, Rochester, January 23-25, 2018

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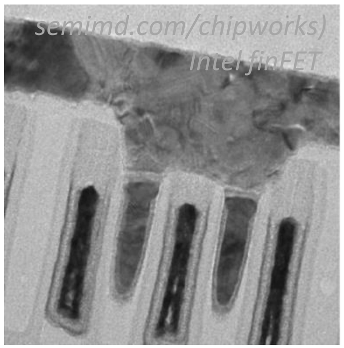
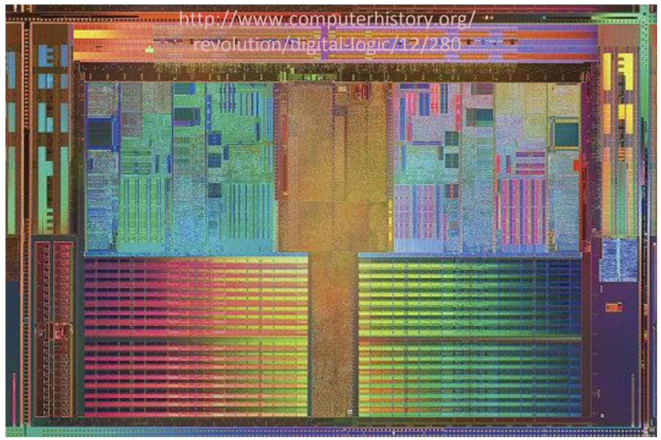
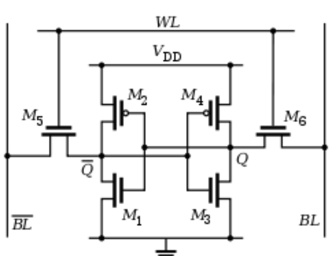
  - MIT (Dirk Englund)
  - William & Mary (Seth Aubin)
  - U. Maryland (Qudsia Quraishi)

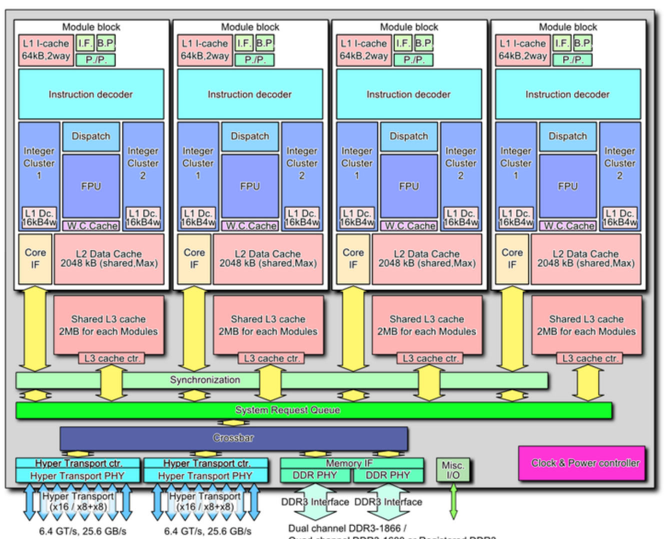
- Order! Order!





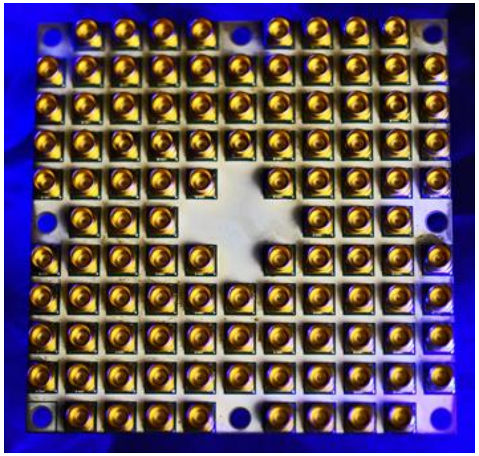


https://en.wikipedia.org/wiki/Static_random-access_memory

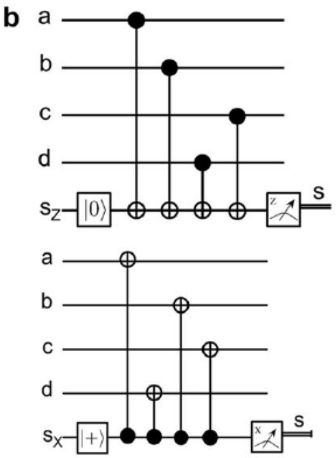


https://commons.wikimedia.org/wiki/File:AMD_Bulldozer_block_diagram_(8_core_CPU).PNG

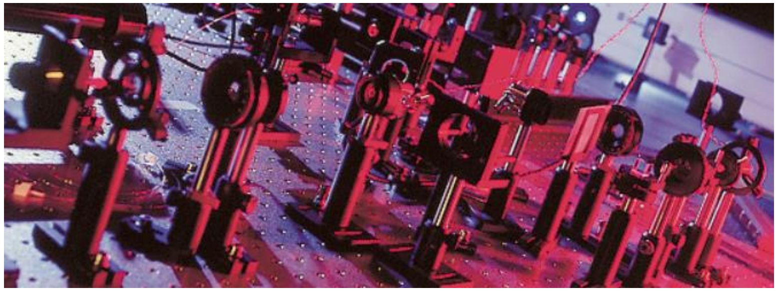
To Quantum Engineering



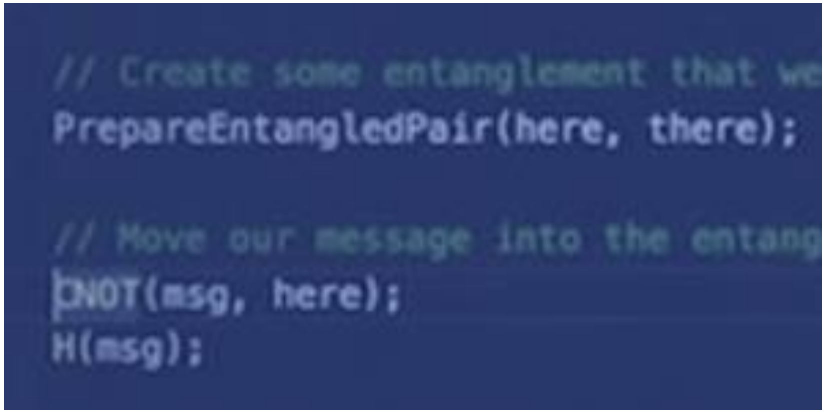
https://newsroom.intel.com/news/intel-advances-quantum-neuromorphic-computing-research/



Gambetta et al,
npj Quantum Information (2017) 3:2



www.cqc2t.org (Centre for Quantum Computation & Communication Technology

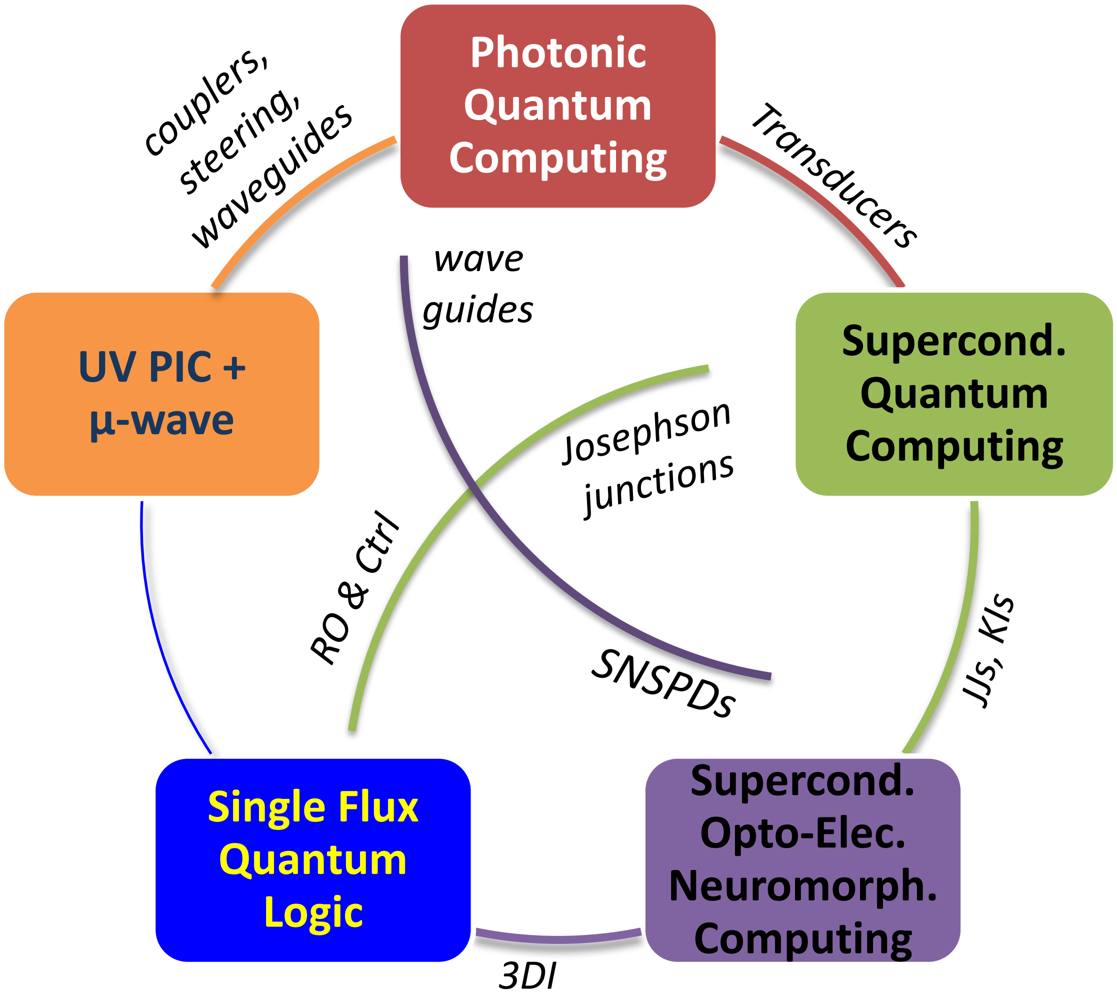


From https://www.microsoft.com/en-us/quantum/development-kit

https://www.dwavesys.com

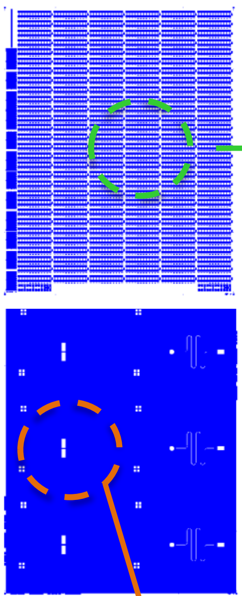
- Quantum Engineering ← adopt the 'manufacturability mantra'

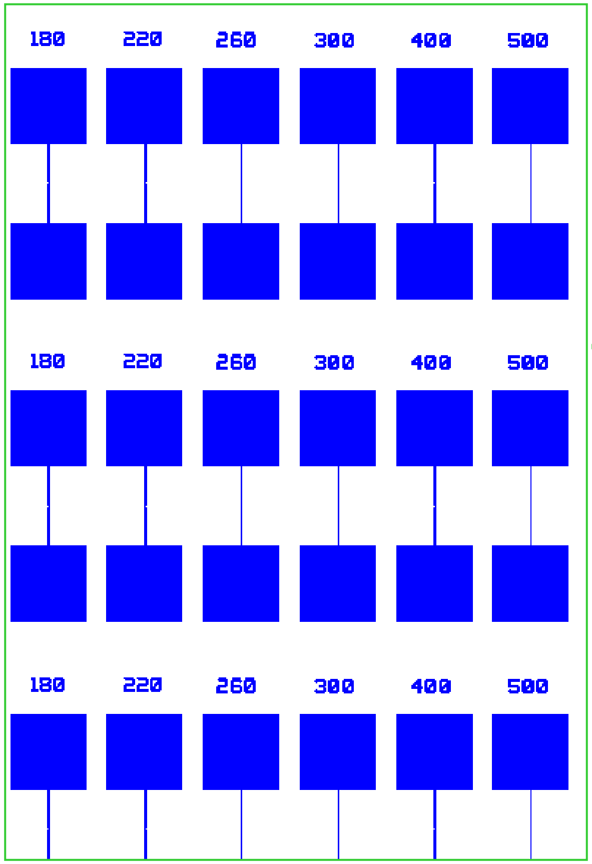
Efficient Technology Development

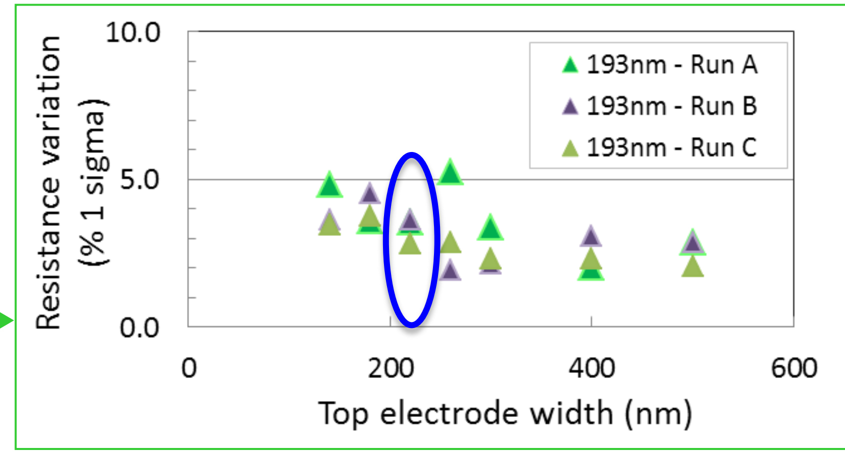


Qubits Using 193 nm Lithography

Josephson Junction Arrays







48 junctions measured for each datum
(JJ's distributed over 25 mm x 16 mm area)

Qubit measurements at ~10 mK (LPS)

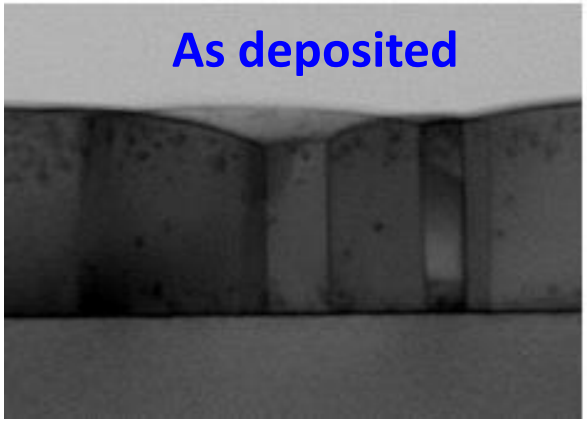
$$\frac{\omega_q}{2\pi} = \mathbf{4.76612}\ \mathrm{GHz} \quad \& \ \mathbf{4.70267}\ \mathrm{GHz}$$

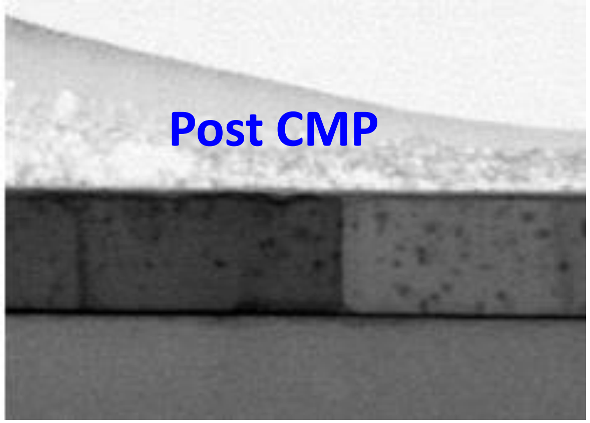
$$\mathrm{T}_1 = \mathbf{26.79}\ \mu\mathrm{s} \quad \& \ \mathbf{25.}93\ \mu\mathrm{s}$$

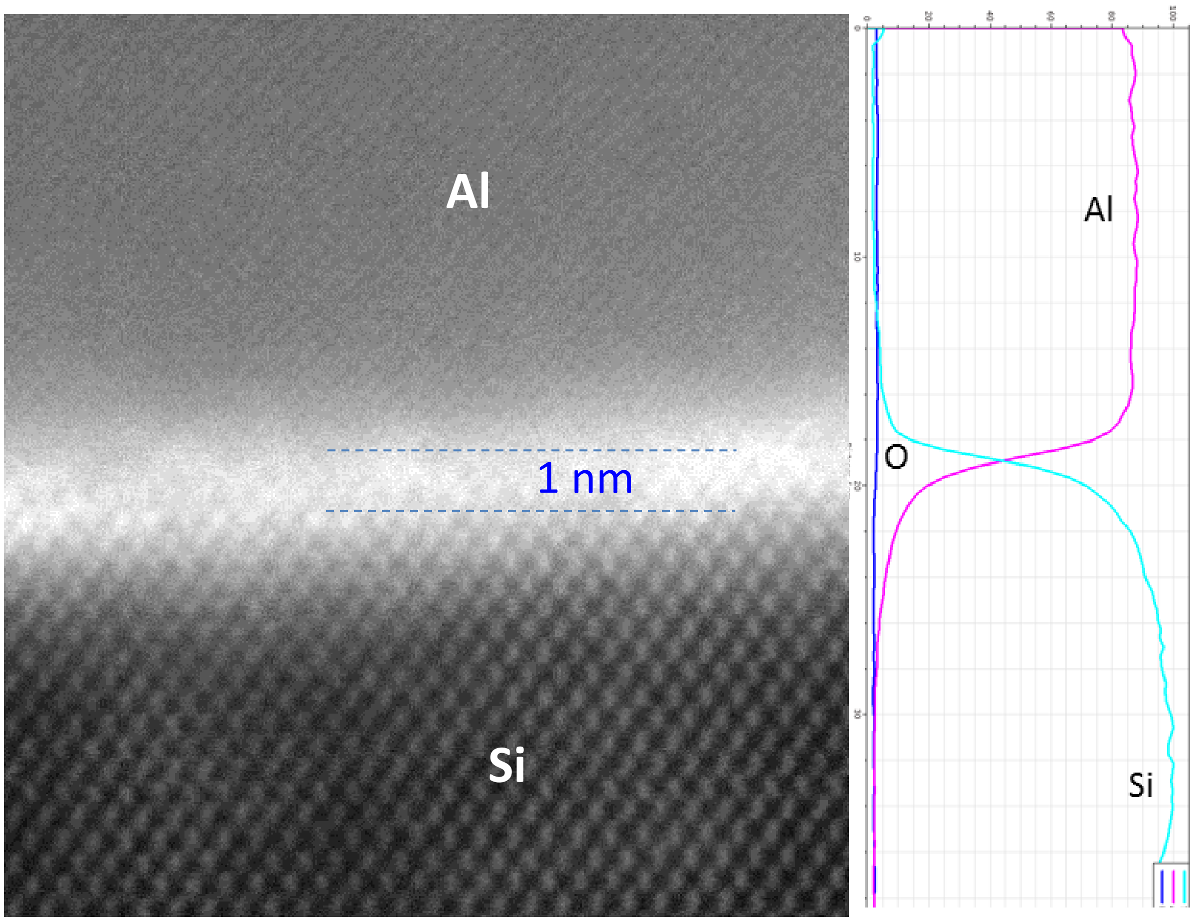
Foroozani et al, manuscript submitted (2018)

Why Advanced Fabrication (II)

- New processes → New device architectures
- New devices → Better systems → larger horizons for imagination



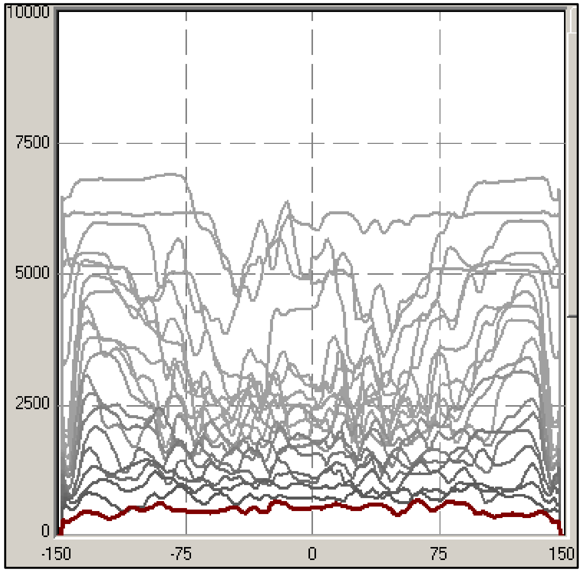


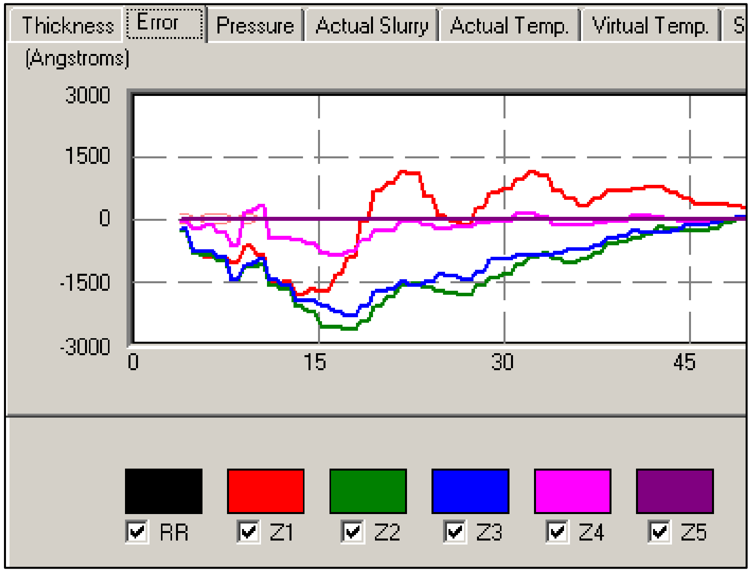


ECS Transactions 85(6) 151 (2018)

Across-Wafer Uniformity & Targeting

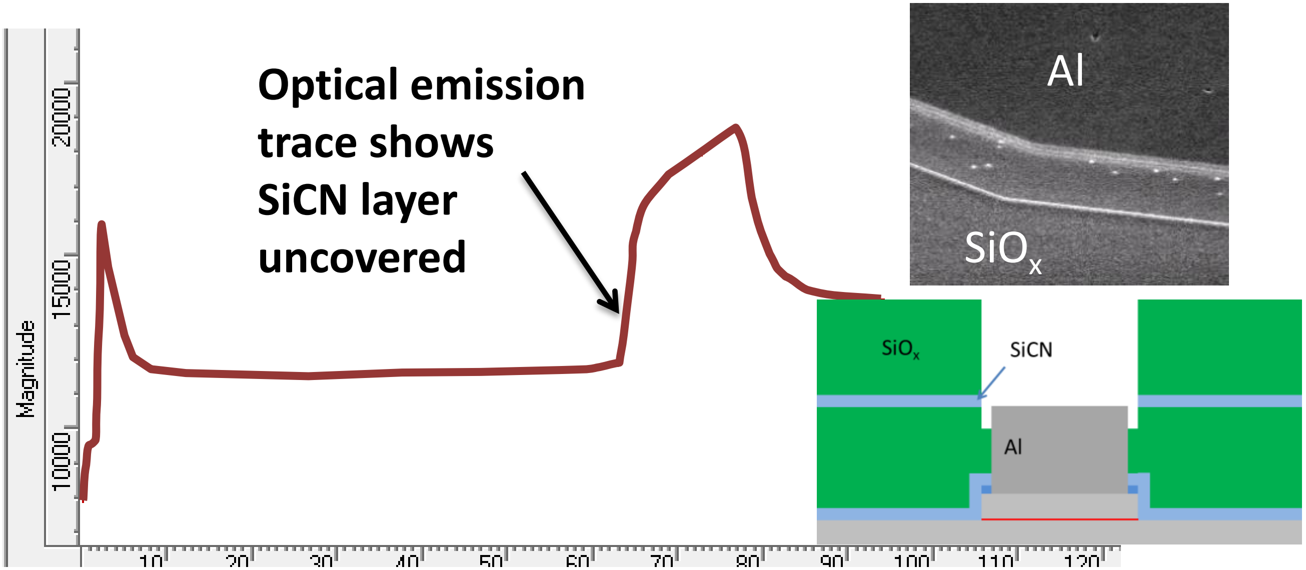
Metal film CMP: Automated adjustment of zone pressures for thickness uniformity





Reactive Ion Etch: Optical endpointing frequently harnessed to improve processes

New 300mm tools have chucks with multi-zone temperature controls

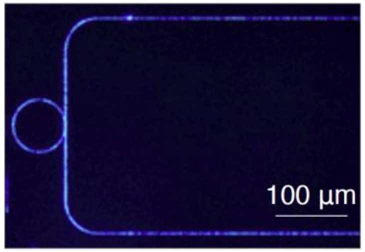


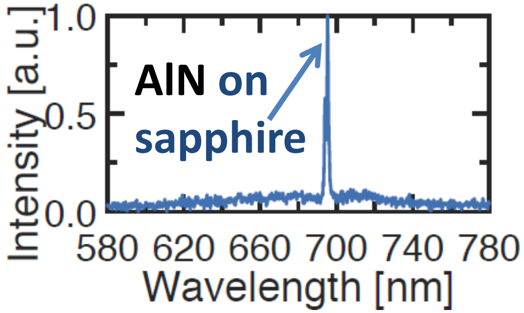
Aluminum Nitride at 300mm scale

- UV-PICs with Si/SiO_2/poly AlN at 300mm scale
- In partnership with RIT (Stefan Preble), AFRL (Mike Fanto) and MIT (Dirk Englund)

Ion	λ (nm)
$^{199}Hg^+$	282
$^{171}Yb^+$	369.5
$^{88}Sr^+$	422
$^{138}Ba^+$	650

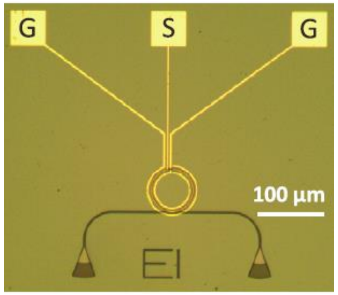
Crystalline AlN on Sapphire
Lu et al, *Optics Express* **26** (9) 11147 (2018)

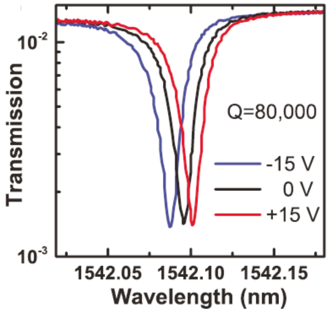




Low loss waveguides, grating couplers … for UV

Poly AlN on Si/SiO_2
Xiong et al, *New J Phys* **14**, 095014 (2012)



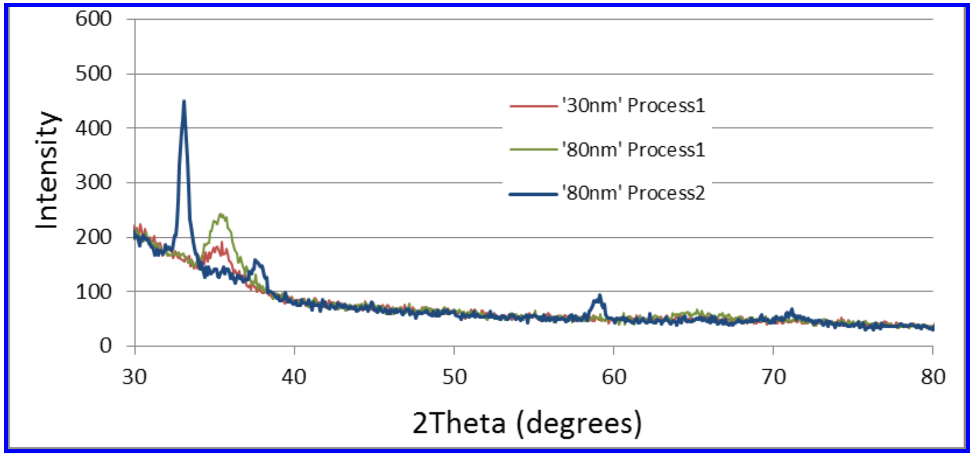


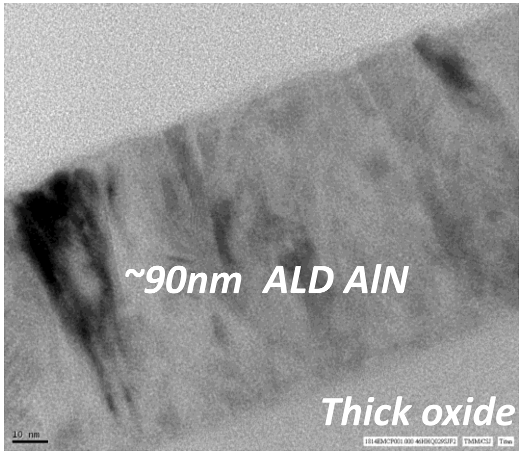
Electro-optic modulation with AlN

AlN Deposition & Characterization

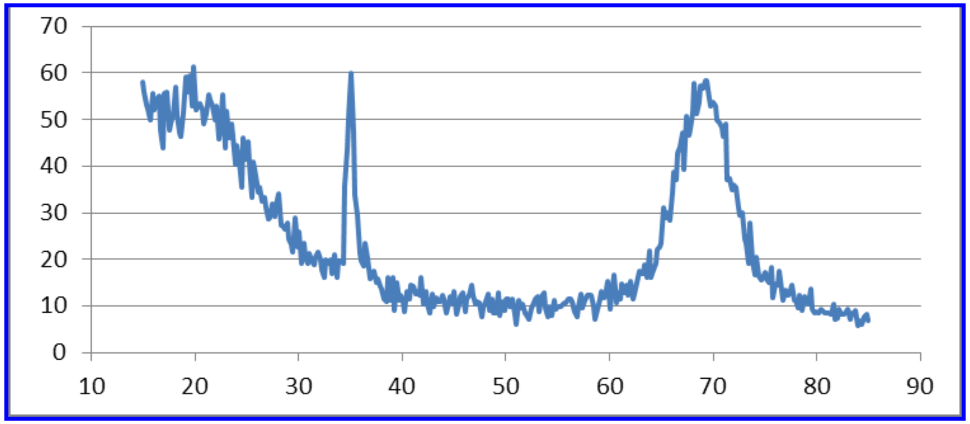
- AlN film characterization on 300 mm Si wafers

Glancing Incidence XRD from ALD AlN variants

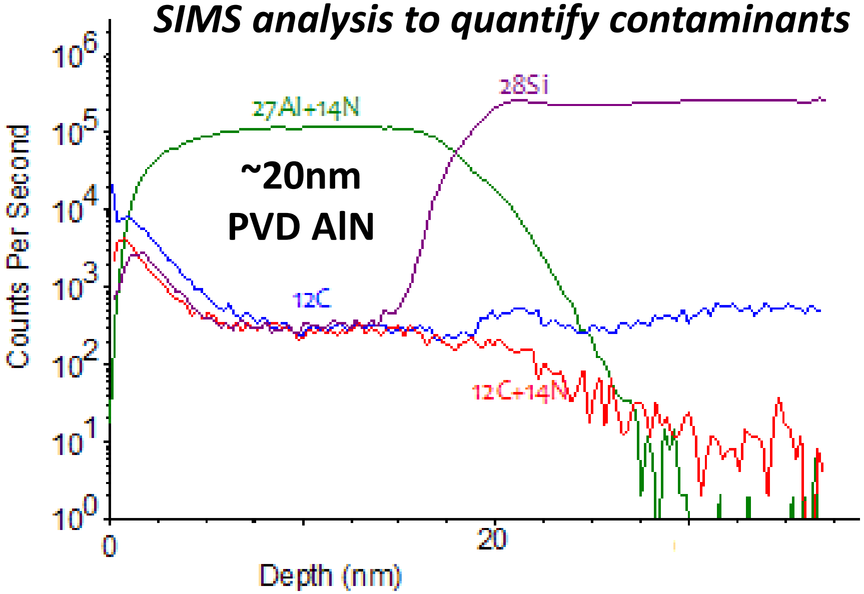




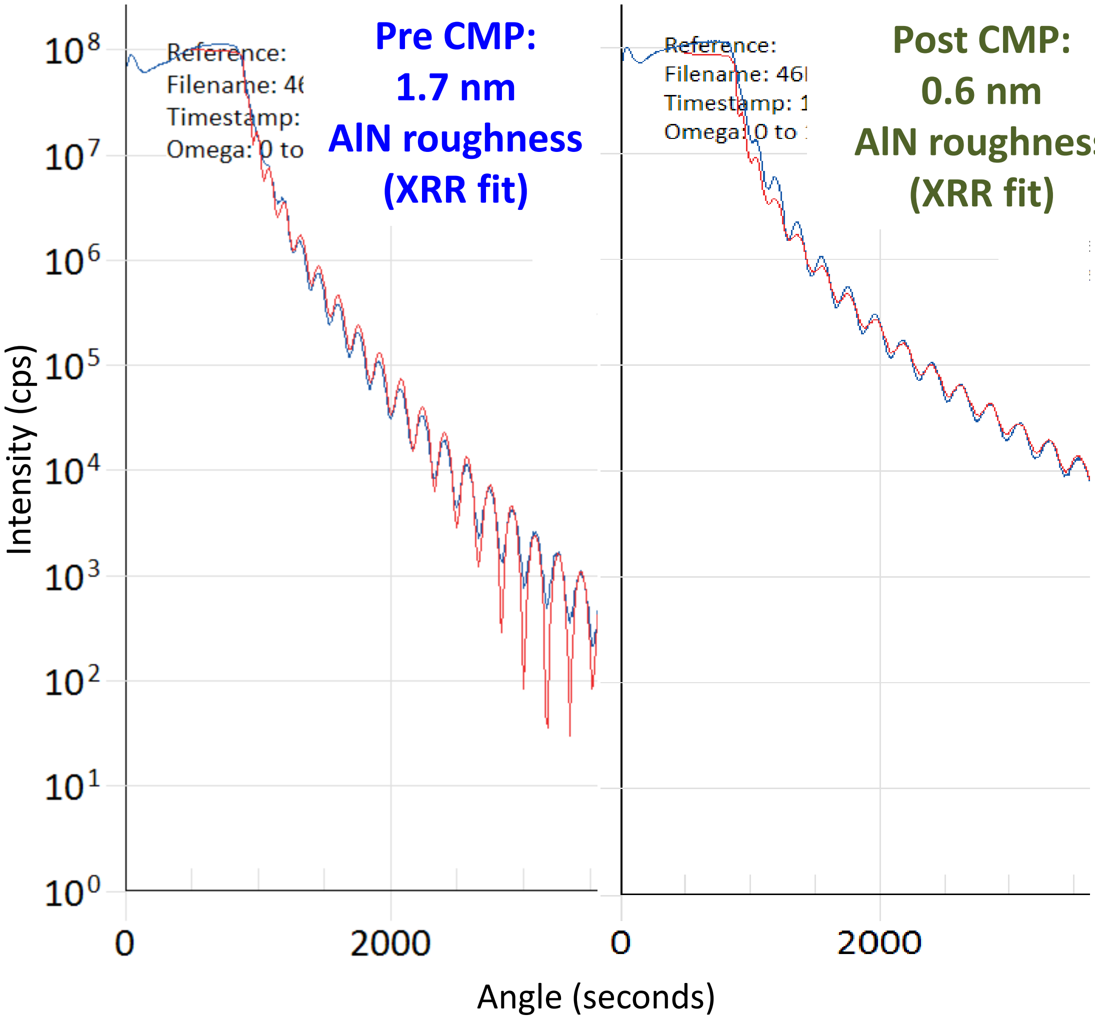
XRD spectrum from 20nm PVD-AlN film



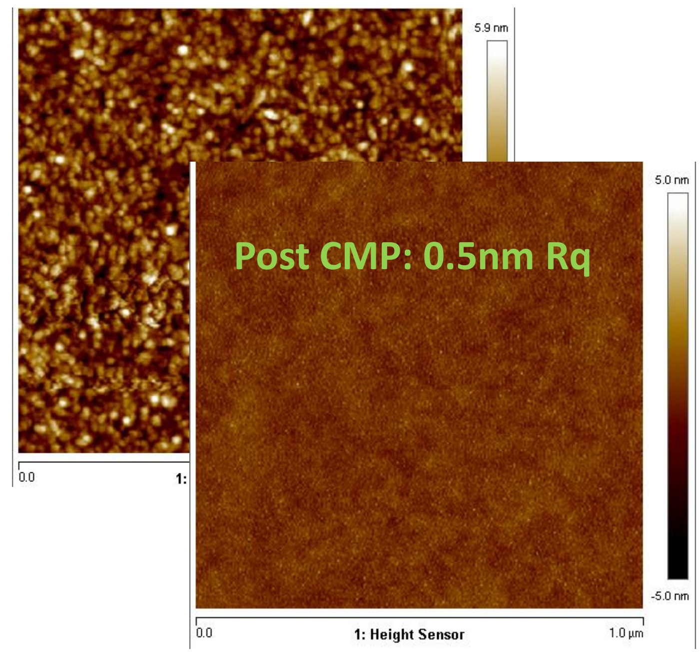
SIMS analysis to quantify contaminants

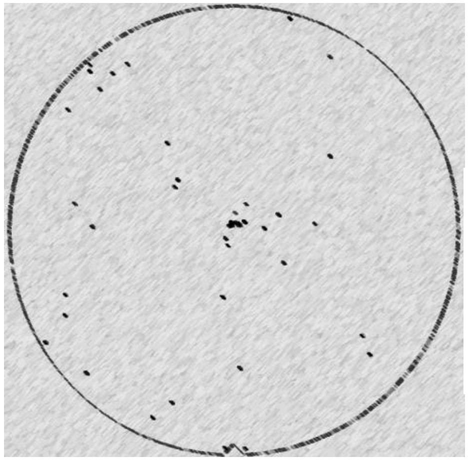


Chemical Mechanical Planarization of AlN films



Pre CMP: 1.6nm Rq





<100 defects post CMP (at ~0.12 um sensitivity)

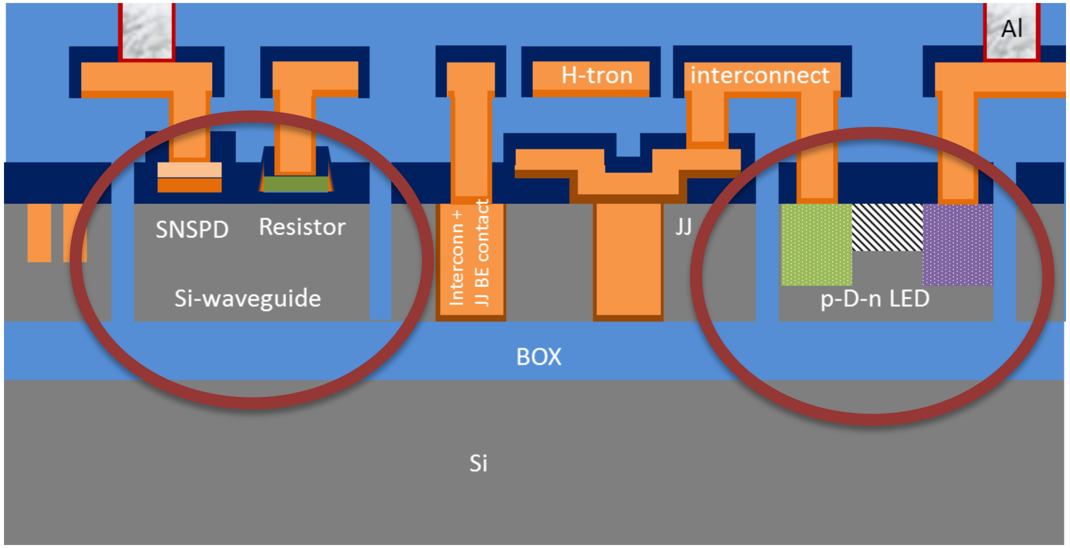
- Next: 193nm litho & RIE + Cu for RF

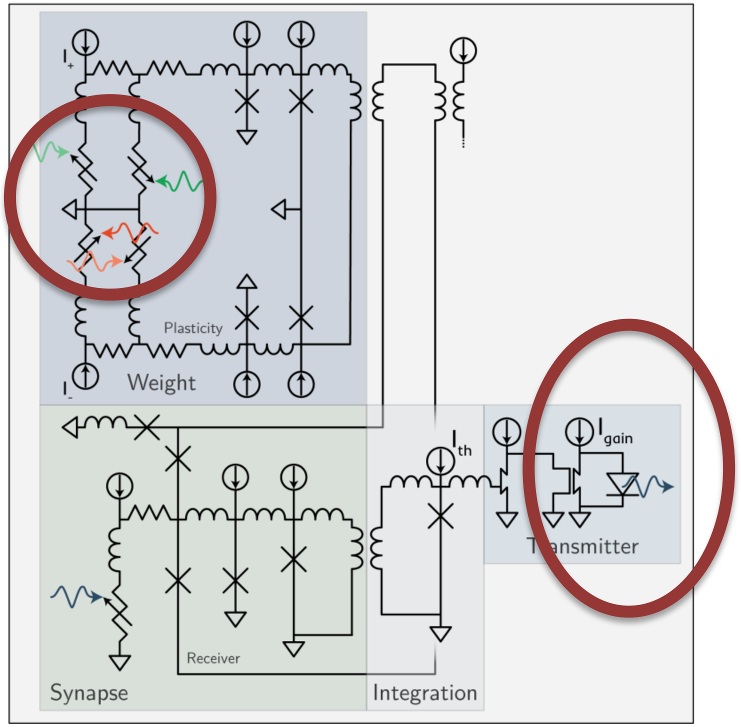
In partnership with NIST Boulder (Shainline, Buckley, Mirin, Nam) and using AFRL-funded maskset

Josephson junctions (fast, sub-aJ pulses!) → 30,000x faster than brain
→ spikes/s/W ~ human brain

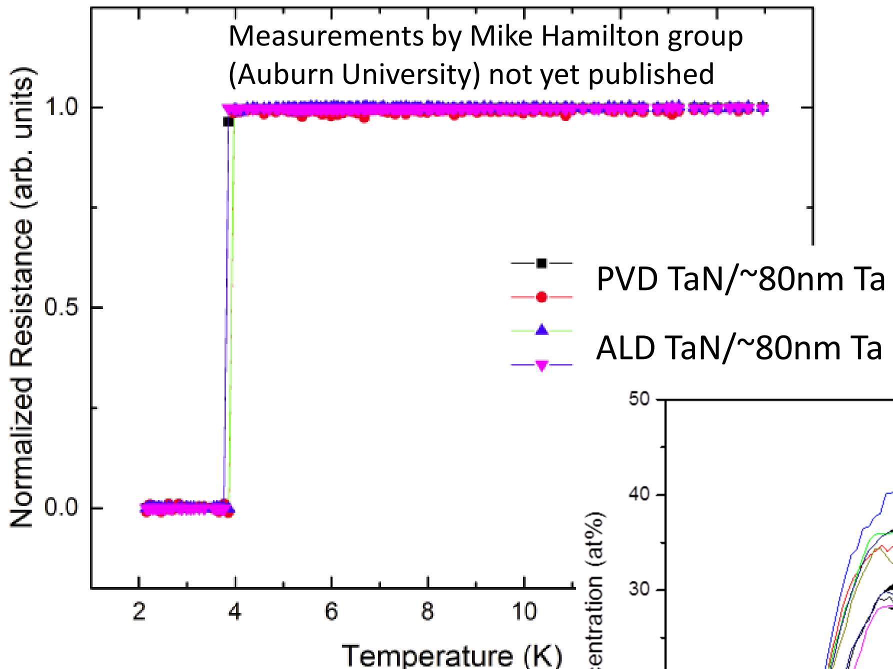
Cryo-photonics + SNSPDs → 1:1000 neuron connections

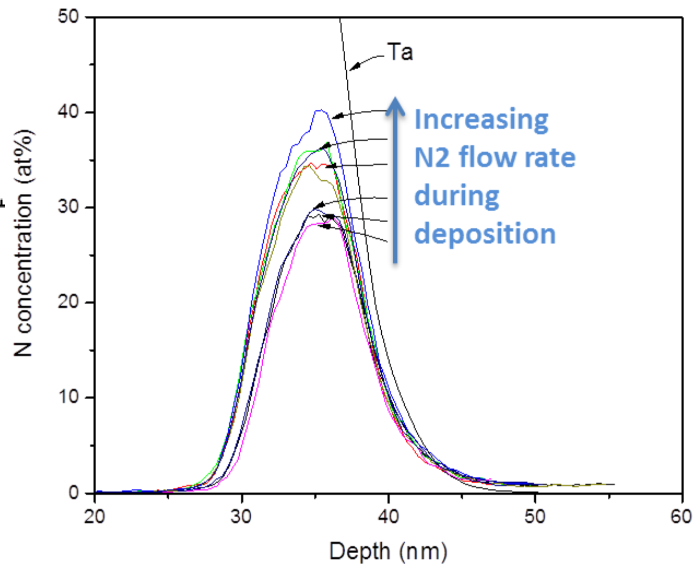
1 cm^2 die: 8k neurons + 330k synapses … and further scalable

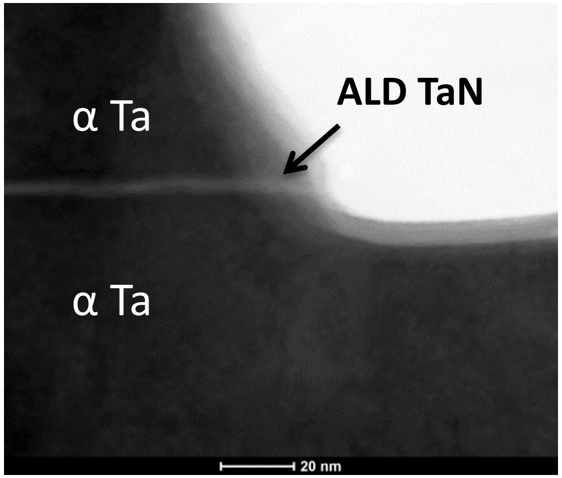


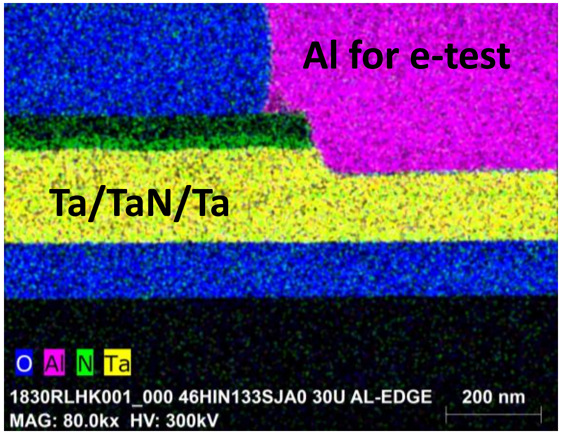


- CMOS-compatible Josephson junctions with α-Tantalum & ALD-TaN
- PVD TaN-based SNSPDs





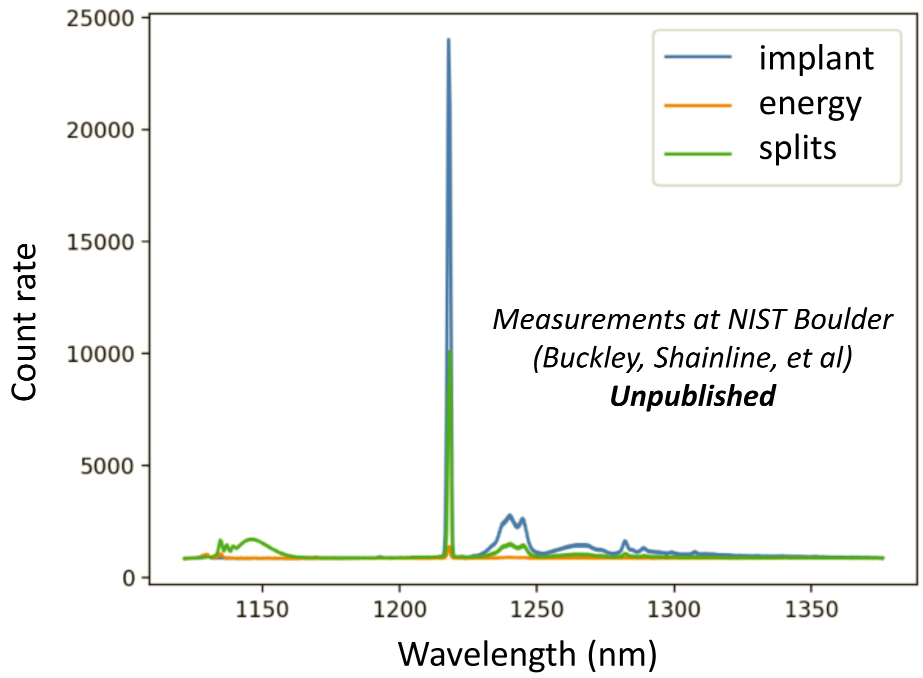




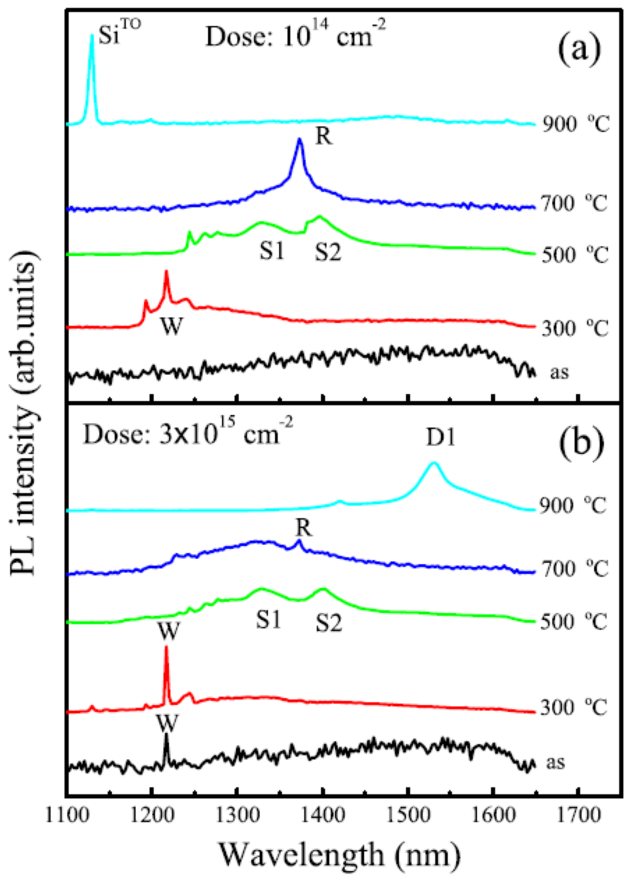
Light Emission by Si Defects at 4 K

- Si-defect based IR emission into SOI waveguides

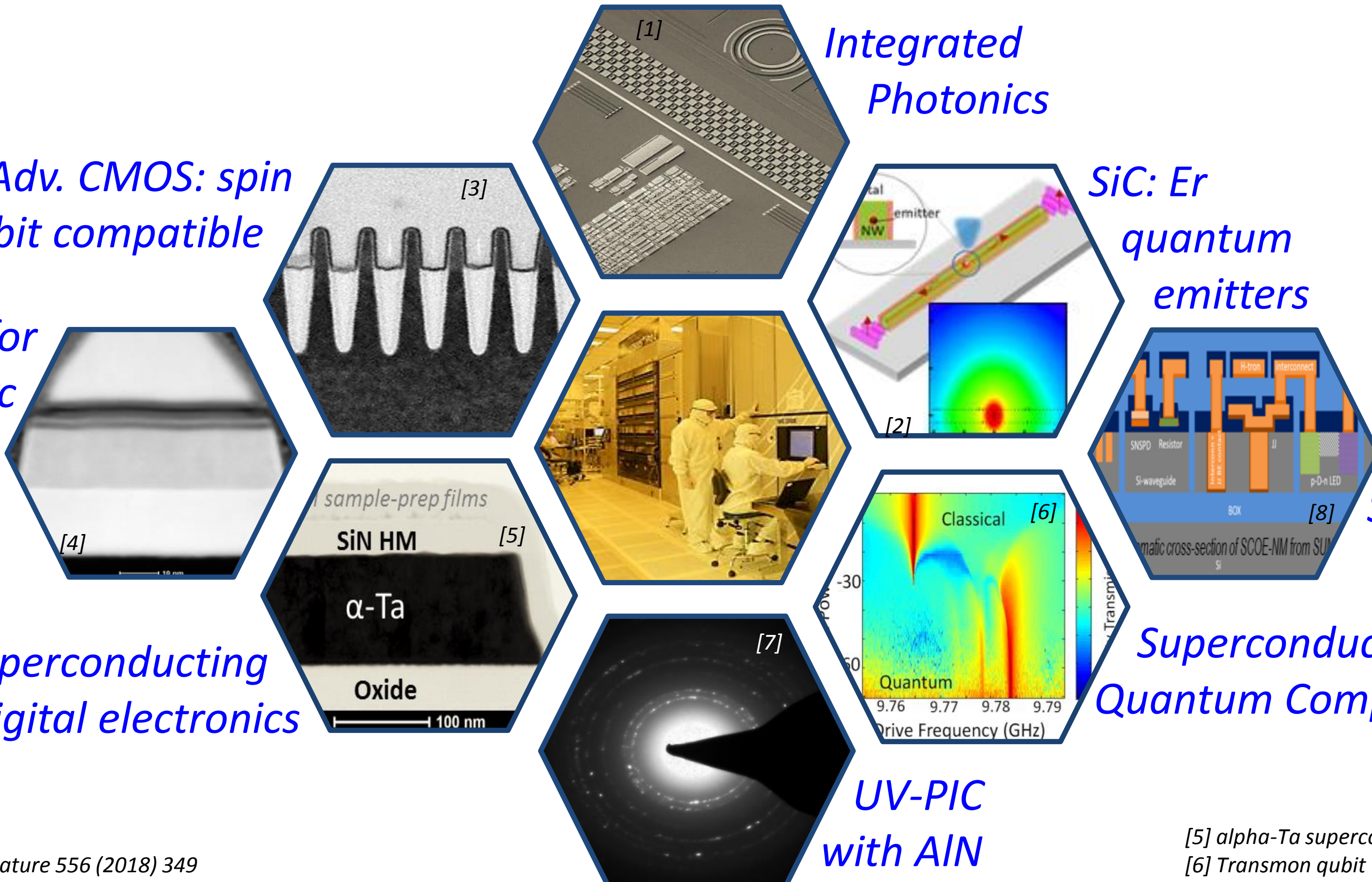
Cryogenic Si defect light emission
(Si on 300 nm BOX for faster testing)



Yang *et al.* J. Appl. Phys. **107**, 123109 (2010)



- One Fab to Make Them All… And With Light Bind Them!



[1] Atabaki et al, Nature 556 (2018) 349
[2] SiC:Er research by S. Galis group
[3] 7nm CMOS test chip fab'ed at SUNY Poly
[4] MTJ fabricated at SUNY Poly, 2015
[5] alpha-Ta superconducting line
[6] Transmon qubit using 193nm lithography
[7] fab-friendly UV-VIS waveguide material
[8] Supercond Optoelectronic Neuromorphic computing elements