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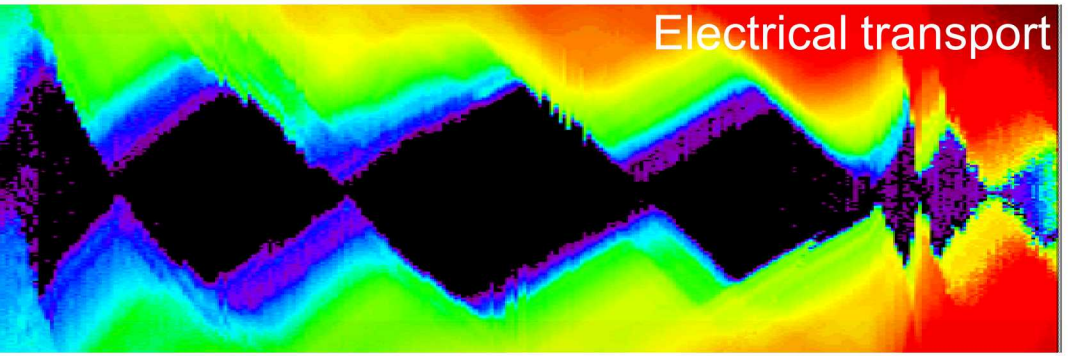

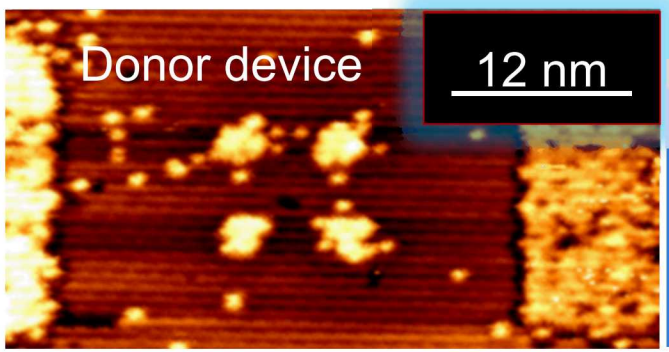

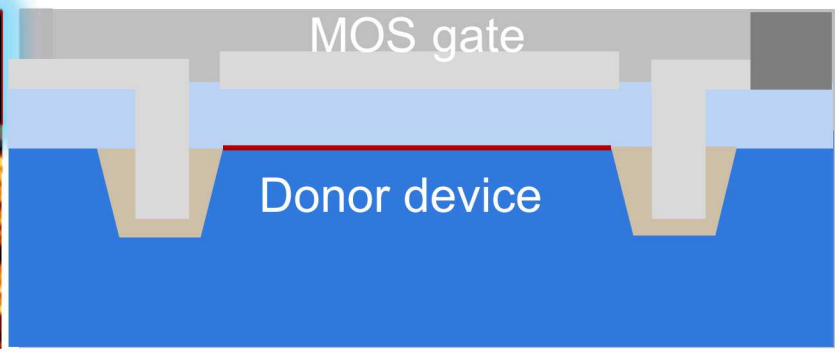

Surface gated atomically precise single electron Islands

Dan Ward, Evan Anderson, Leon Maurer, DeAnna Campbell, Mike Marshall, Lisa Tracy, Andrew Baczewski, Tzu-Ming Lu, Shashank Misra

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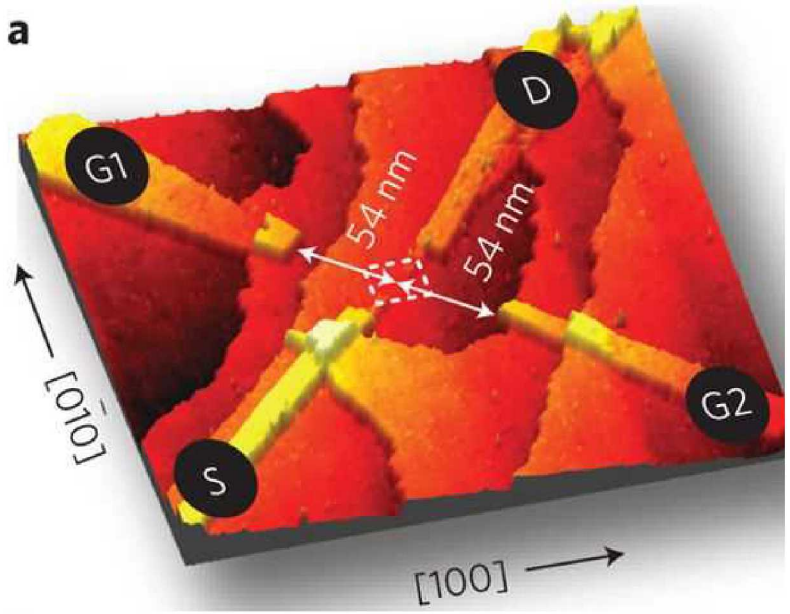
Atomic precision advanced manufacturing (APAM)

Sandia National Laboratories

STM-based fabrication of physics-focused devices

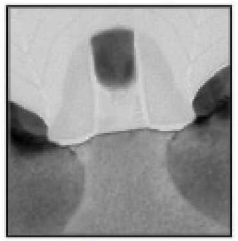


Fueschle, Nat. Nano (2012)

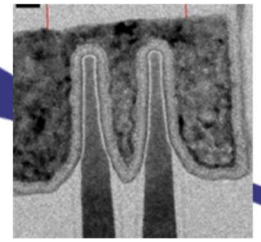
UNSW, SNL (historically), NIST

Sandia project targeting microelectronics

Tooling cost of successive generations climbs exponentially.



65 nm



10 nm

?

5-7 nm

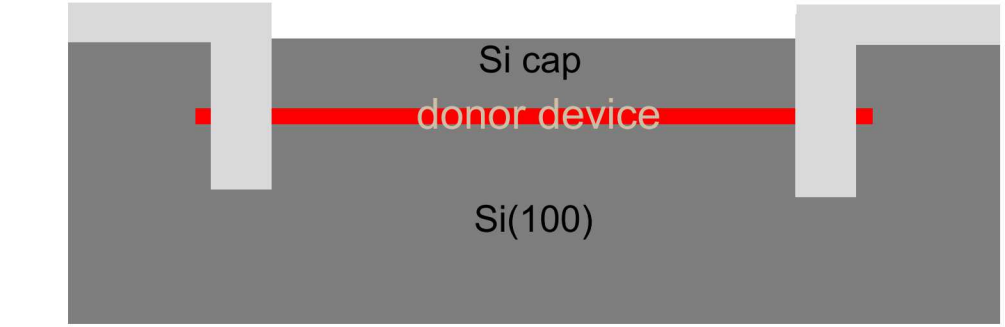
Relax manufacturability – explore opportunities in microelectronics at the atomic limit now

Atomic Limit

Sandia goal: Increase sophistication of APAM devices

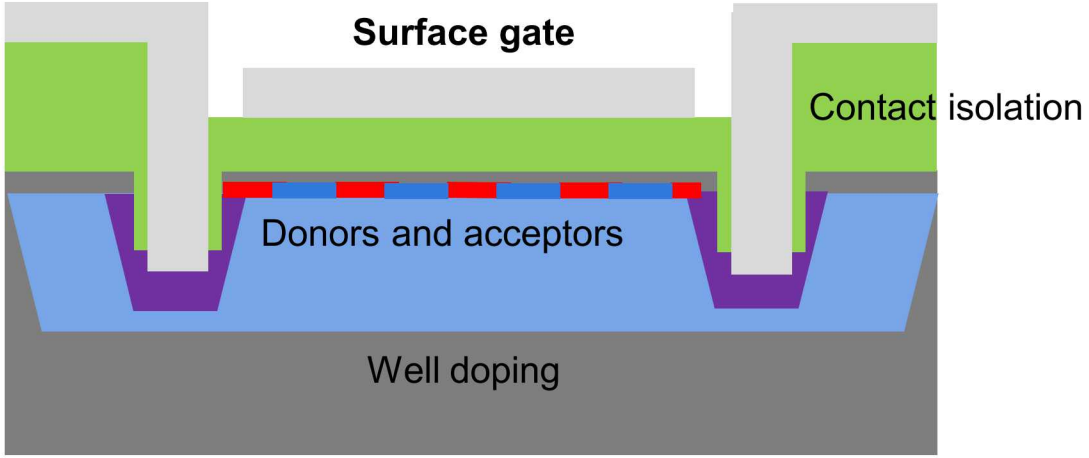
Sandia National Laboratories

2018



Device cross section

2021 goal



Device cross section

Need more sophisticated devices to find application to microelectronics…

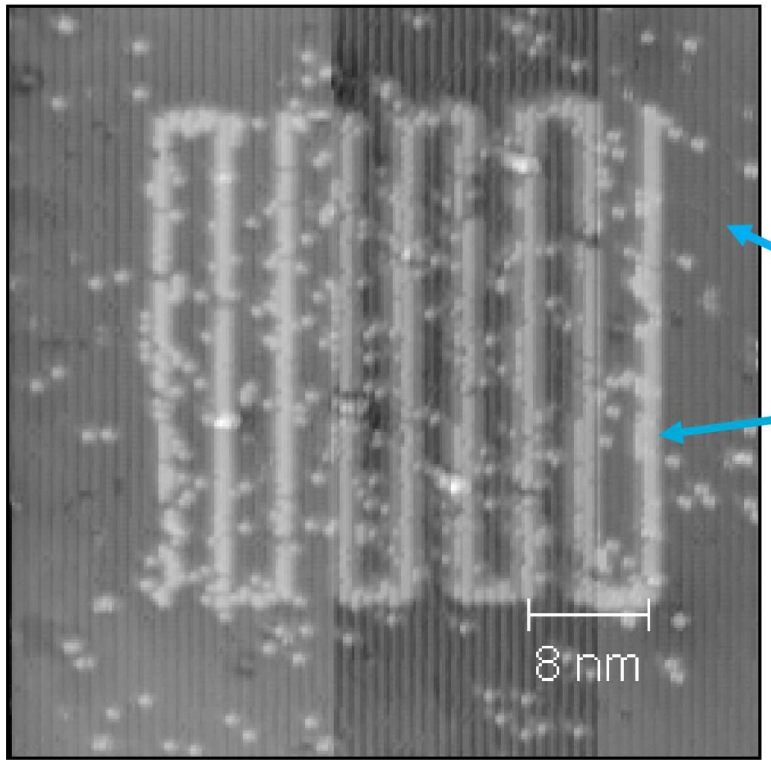
- high gain
- room temperature operation
- complementary transistors

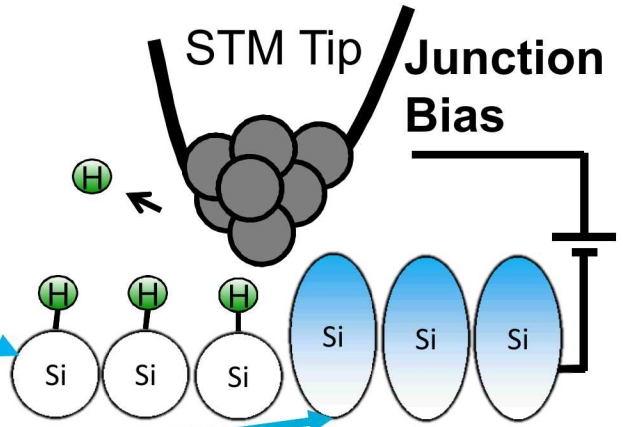
→ Requires development of surface gates.
Useful for atomic precision quantum devices too!

How does APAM work?

"Chemical contrast" at Si surface

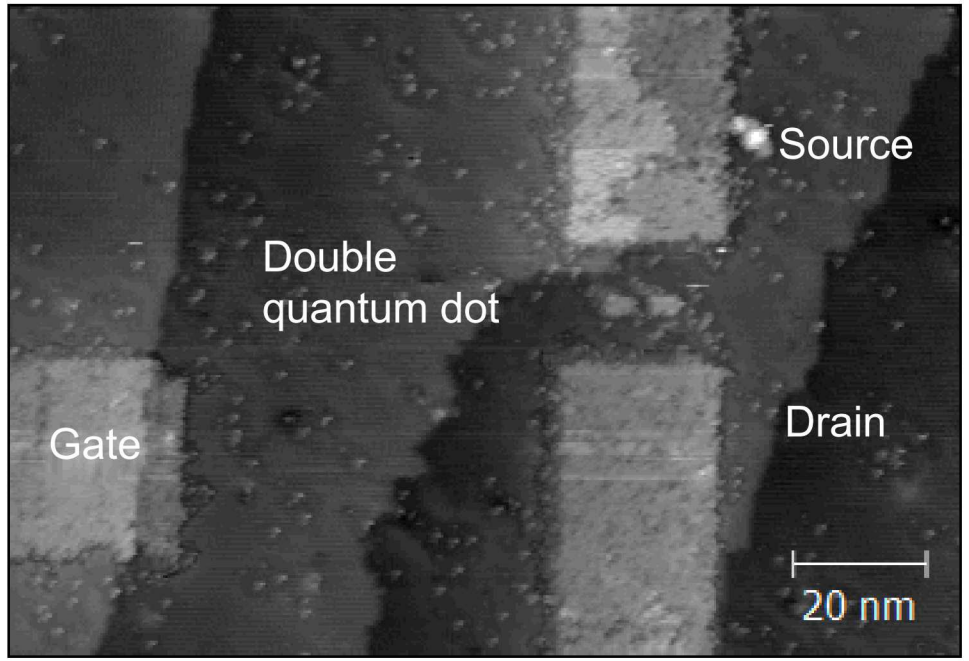
- Unterminated Si: 1 reactive bond/ atom
- H-terminated Si: unreactive

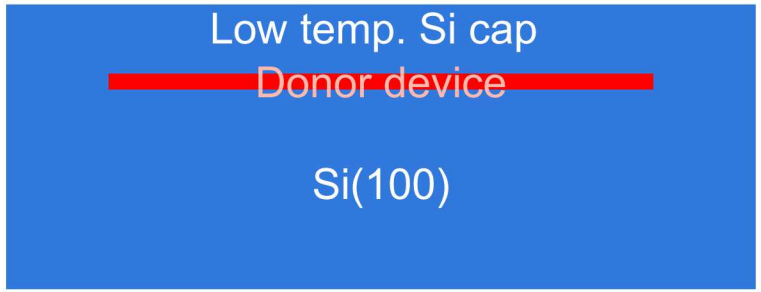




Phosphine produces donor-based devices

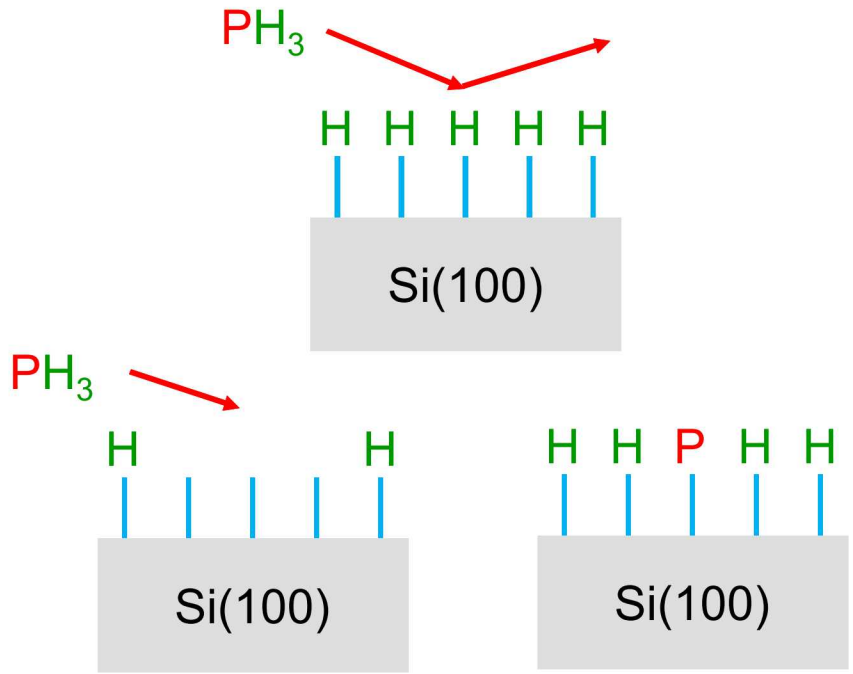
Top view



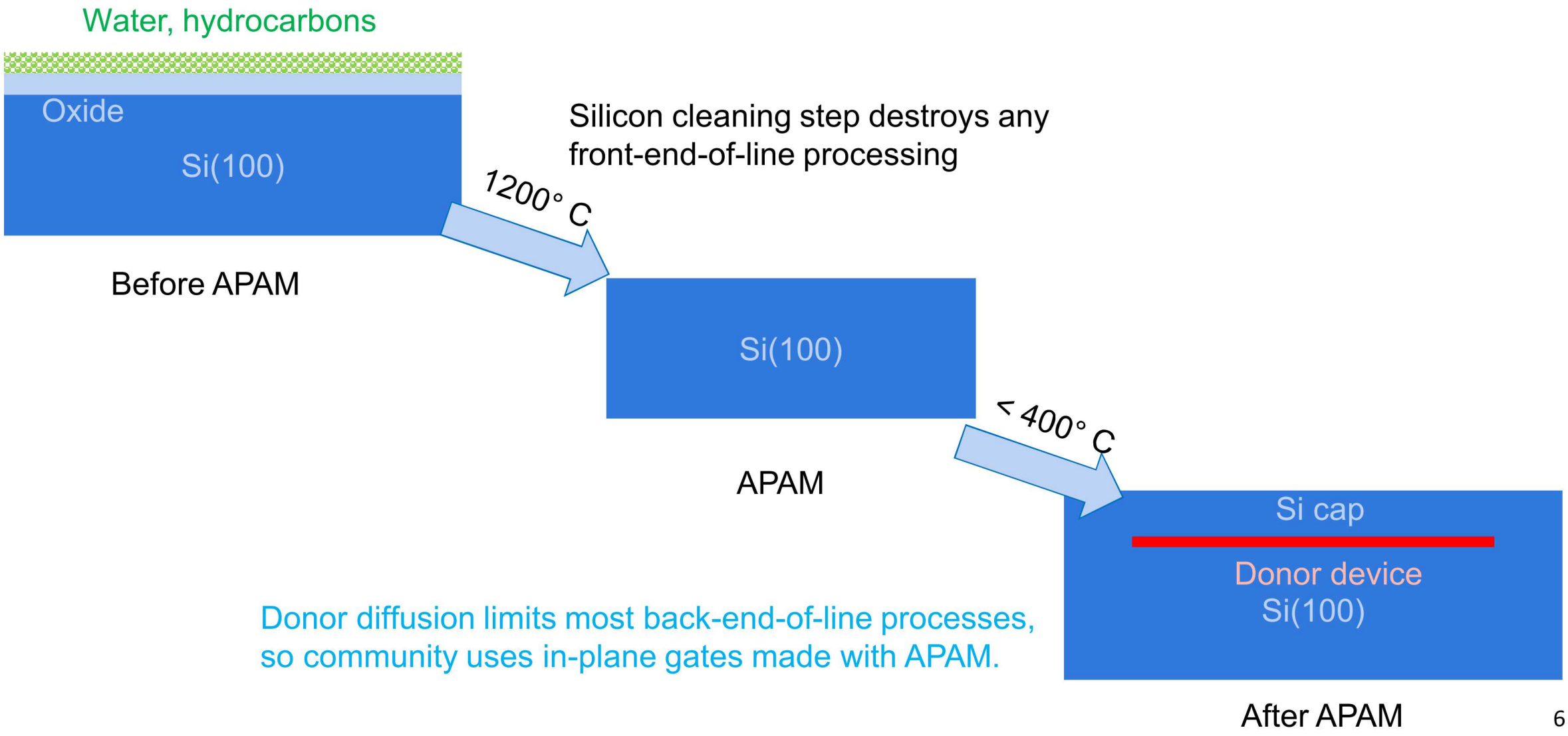


Device cross section

Phosphorus ‘donates’ an electron to silicon.



Why is gating an APAM device hard?



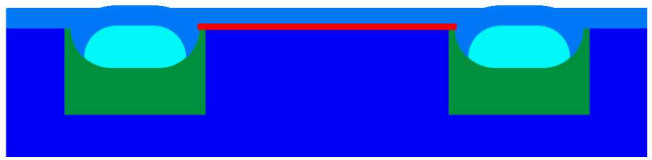
Donor diffusion limits most back-end-of-line processes, so community uses in-plane gates made with APAM.

Back-end-of-line fabrication process (after APAM)

Sandia National Laboratories

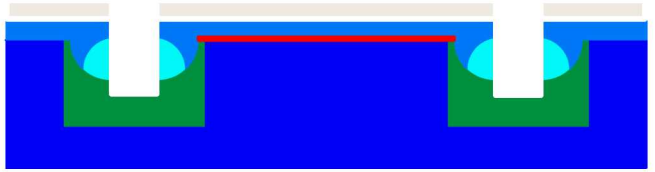
Si Substrate SiO_2 Epi-Si Oxide

Arsenic Implant δ Layer Aluminum

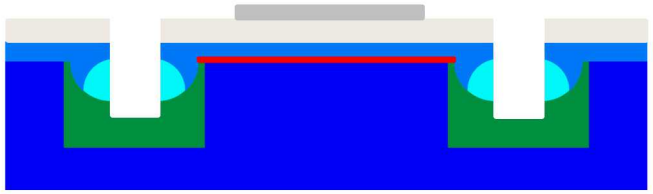


1. Device as it arrives in BEOL after STM

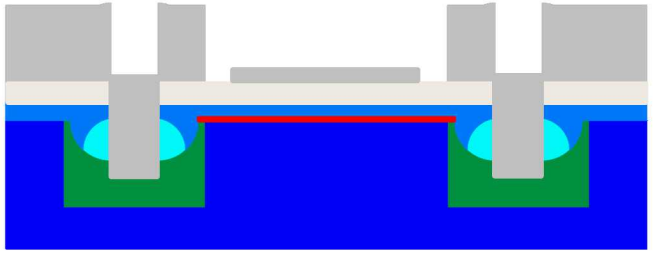
2. Low temperature oxide deposition (many choices)



3. Vias are etched through oxide, Si Cap, remaining oxide, and into the implanted region



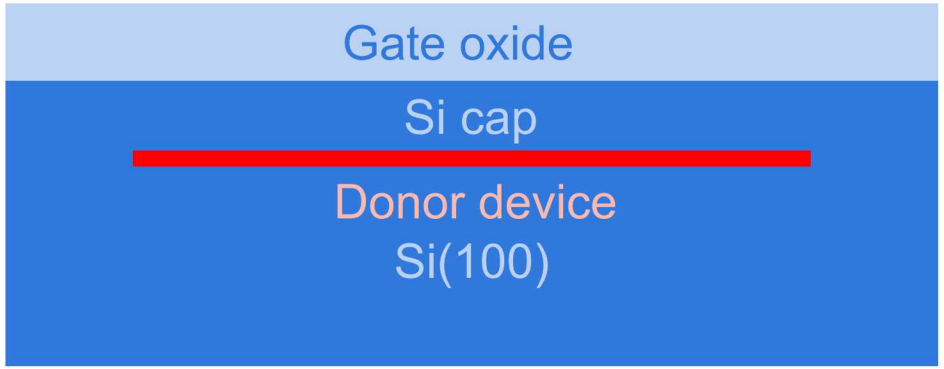
4. Aluminum top gate defined by EBL is deposited over patterned device.

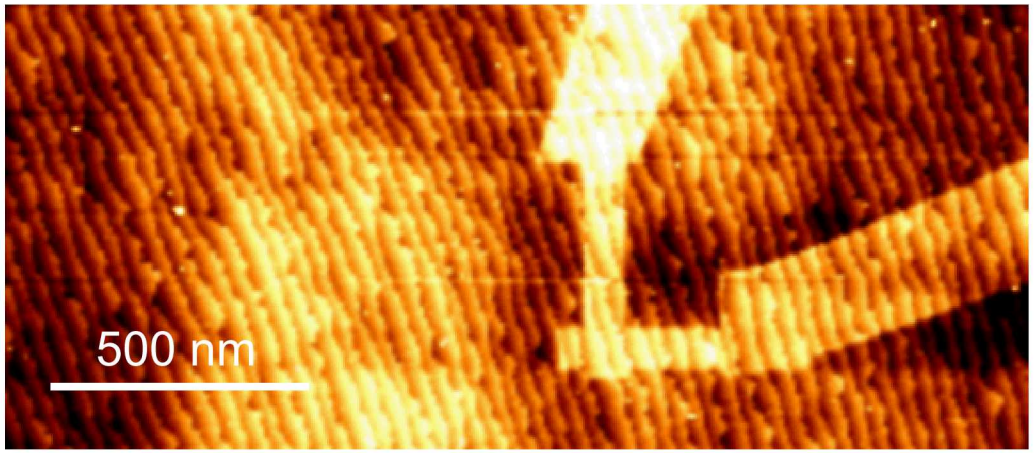


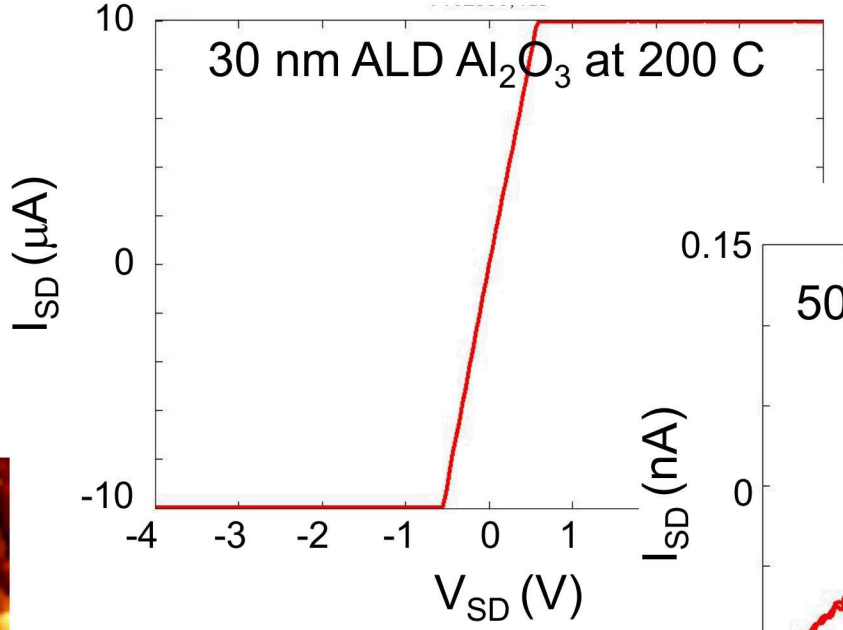
5. Aluminum contacts are deposited into vias and connect to macroscopic bond pads

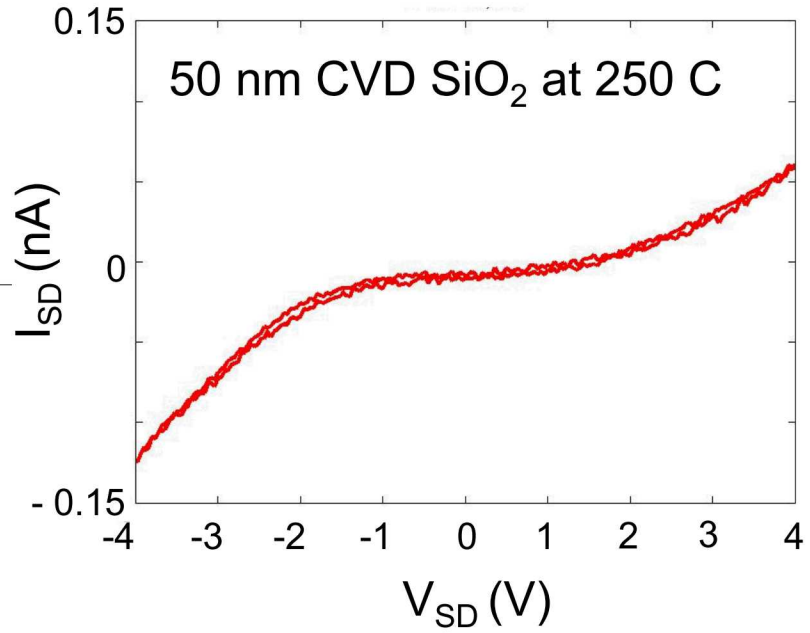
Nanowires for gate oxide evaluation

1. Pattern nanowire.
2. Deposit range of dielectrics with a range of recipes.
3. If nanowire no longer conducts, discard recipe.



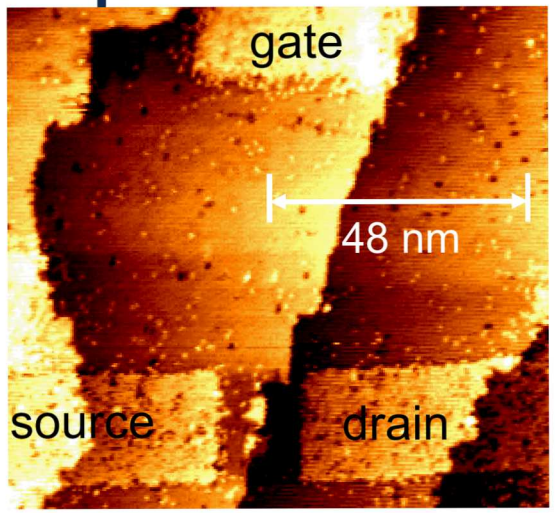




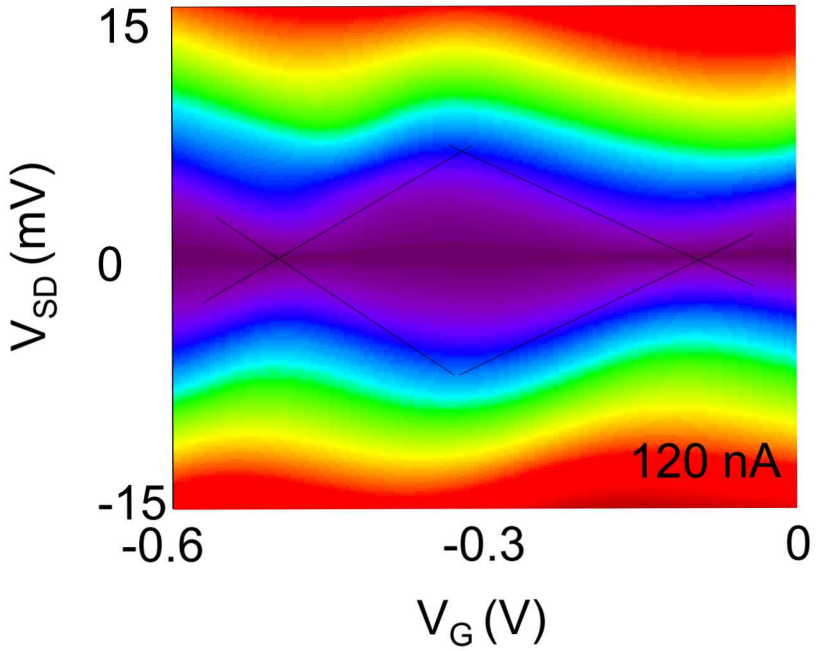


Wire survives, for ALD Al_2O_3

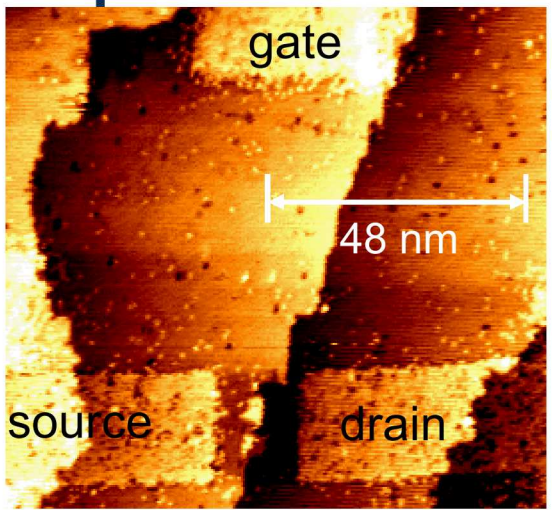
In-plane and surface gates qualitatively similar

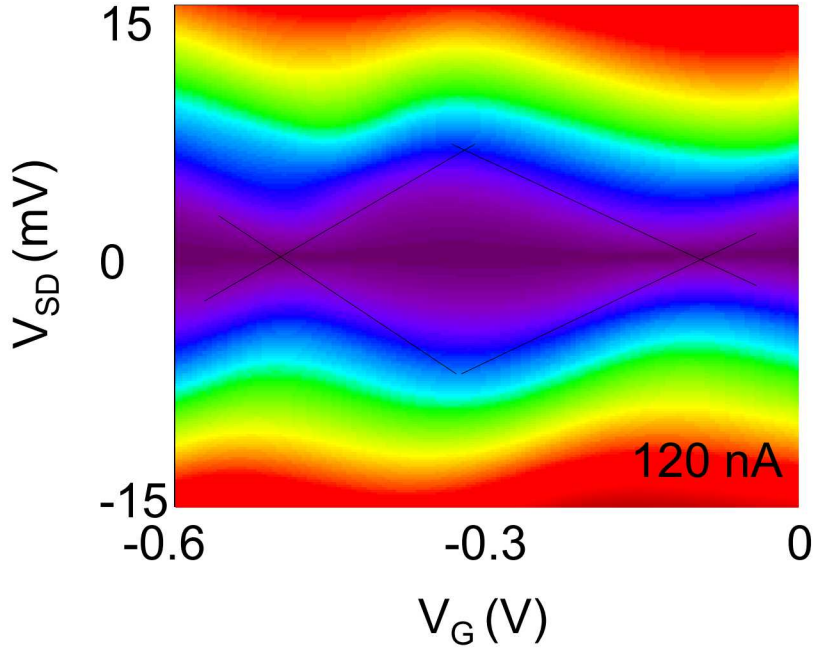


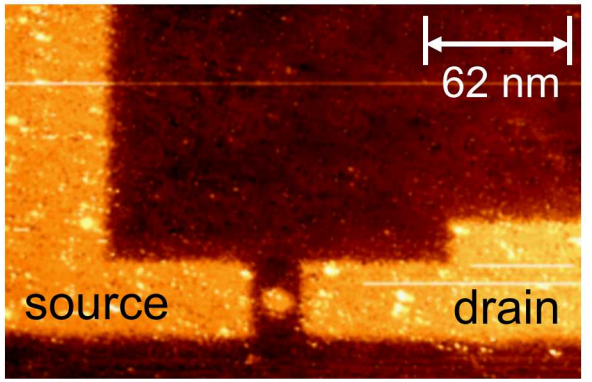
Gate SET. Strongly coupled to lead.

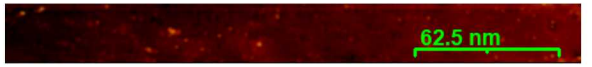


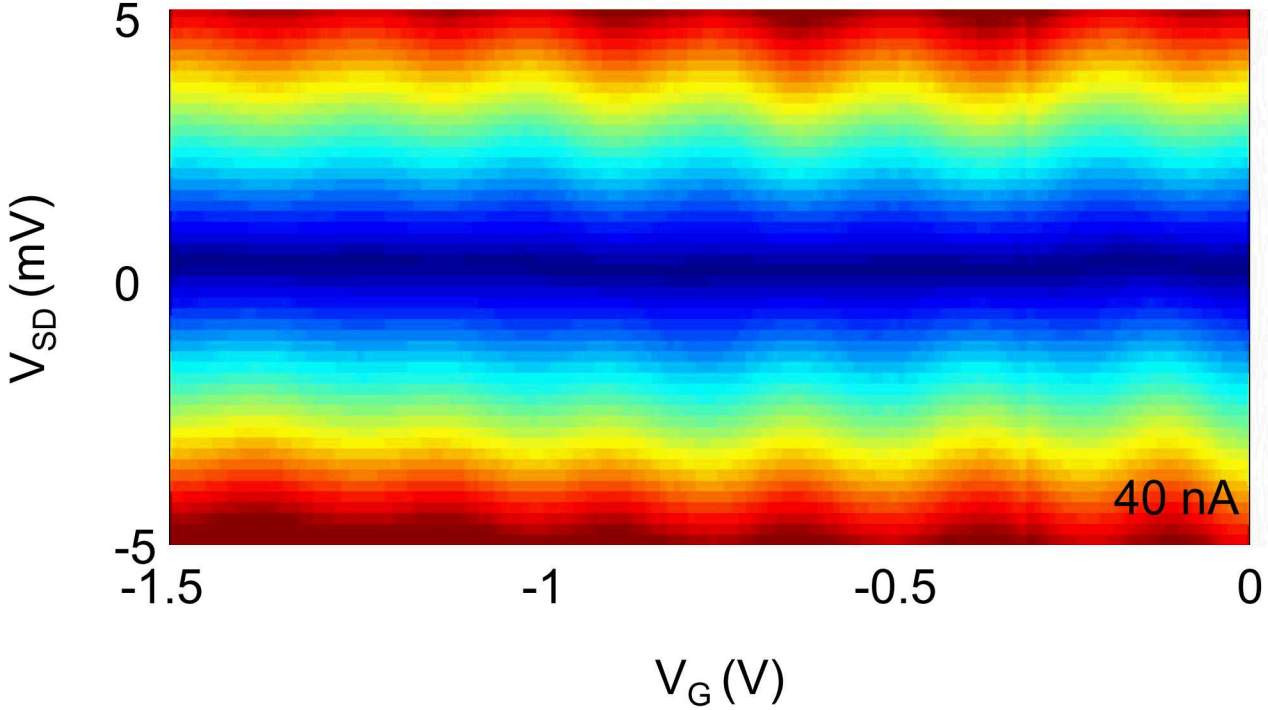
In-plane and surface gates qualitatively similar





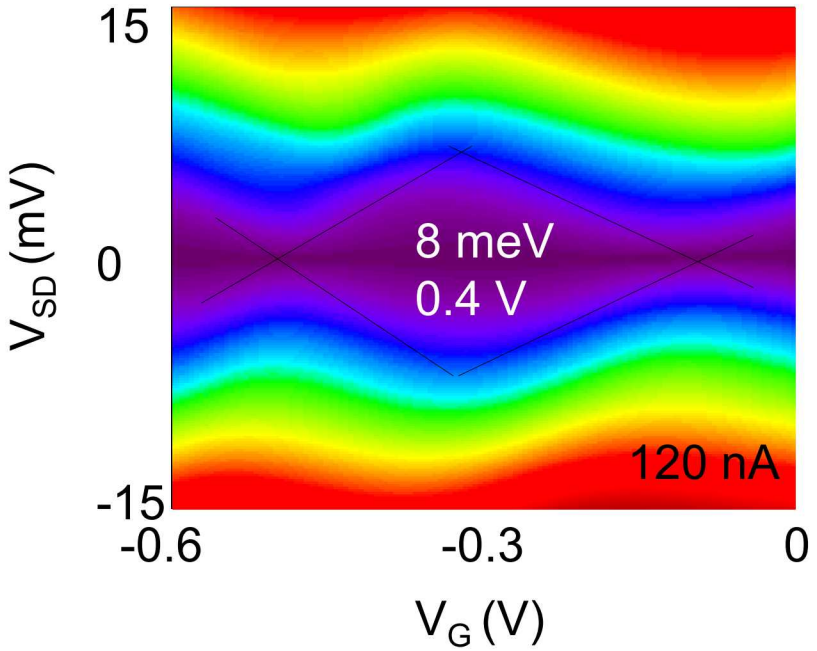


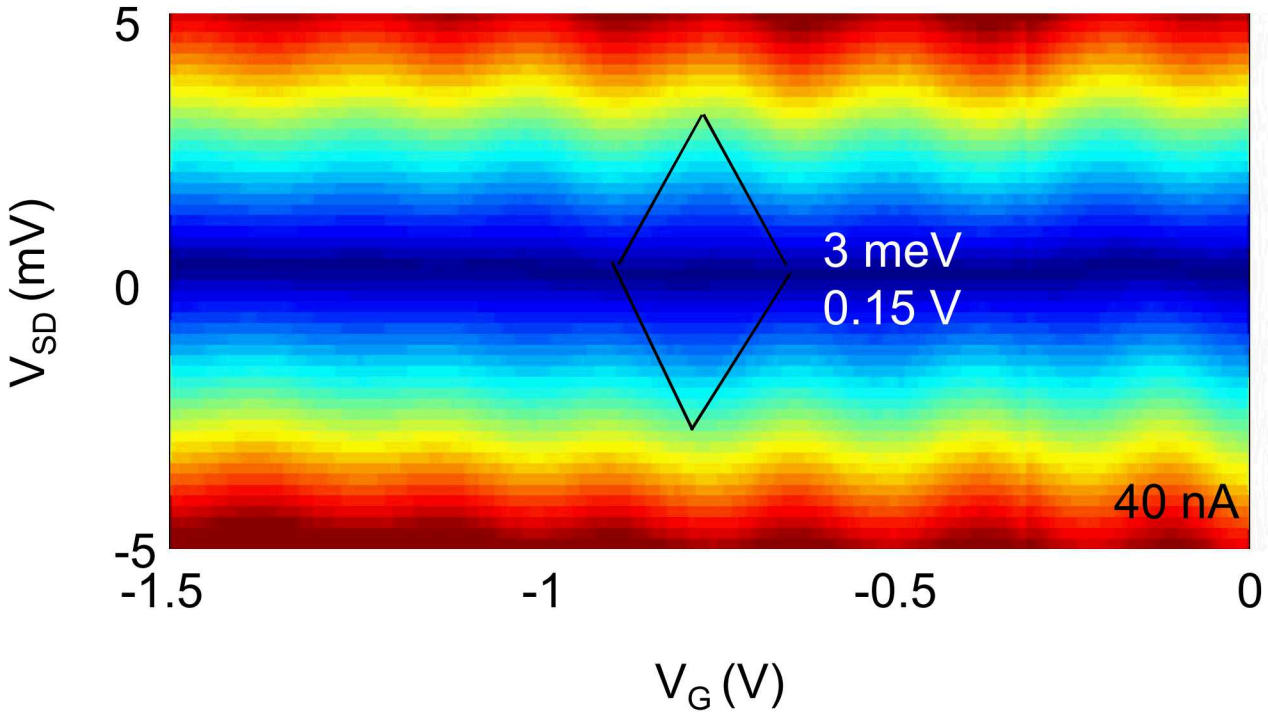




In-plane and surface gates qualitatively similar

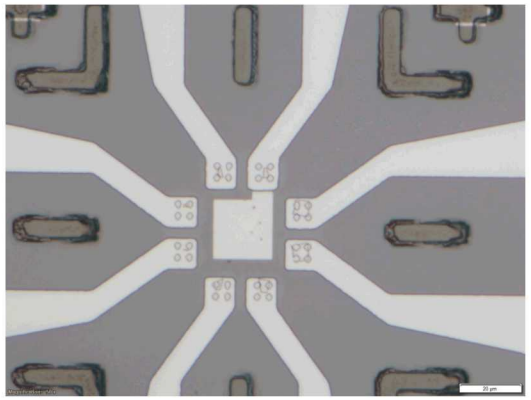
Unclear why these are so similar

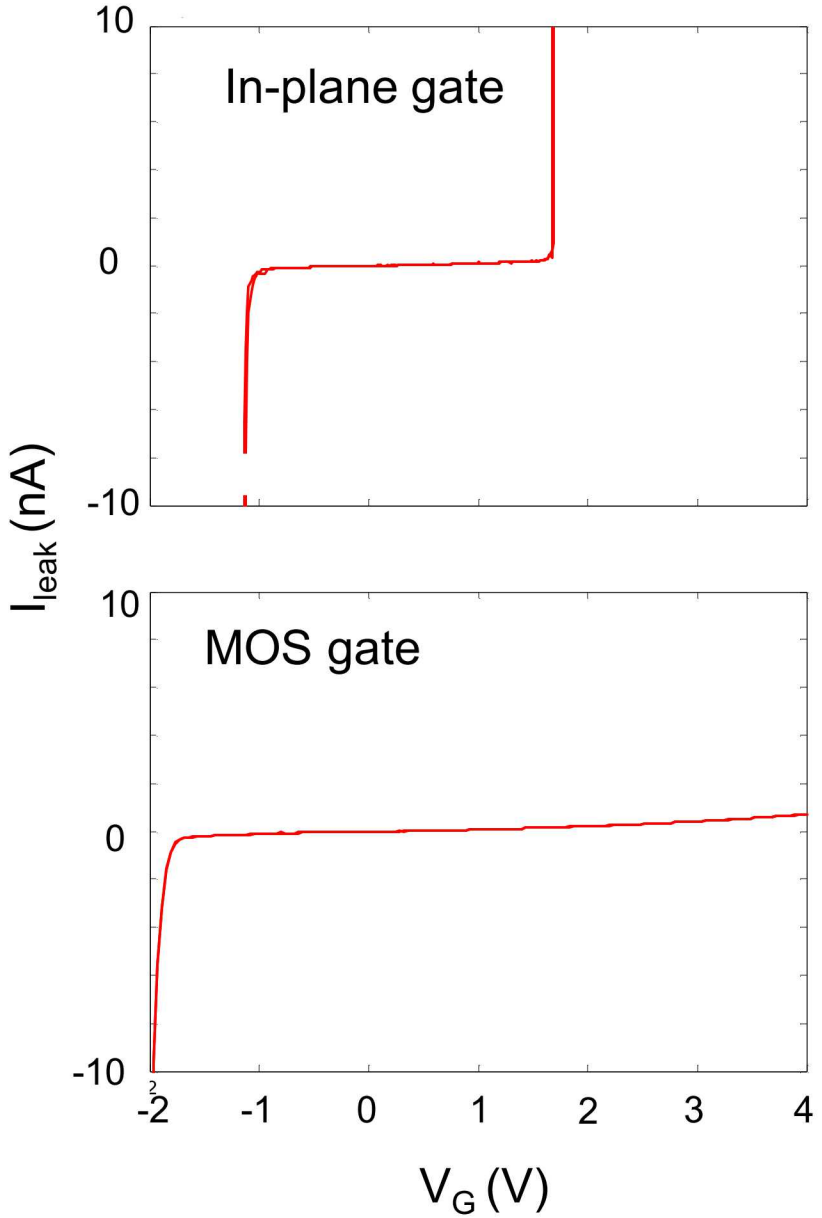




Improved gate range

MOS Gate



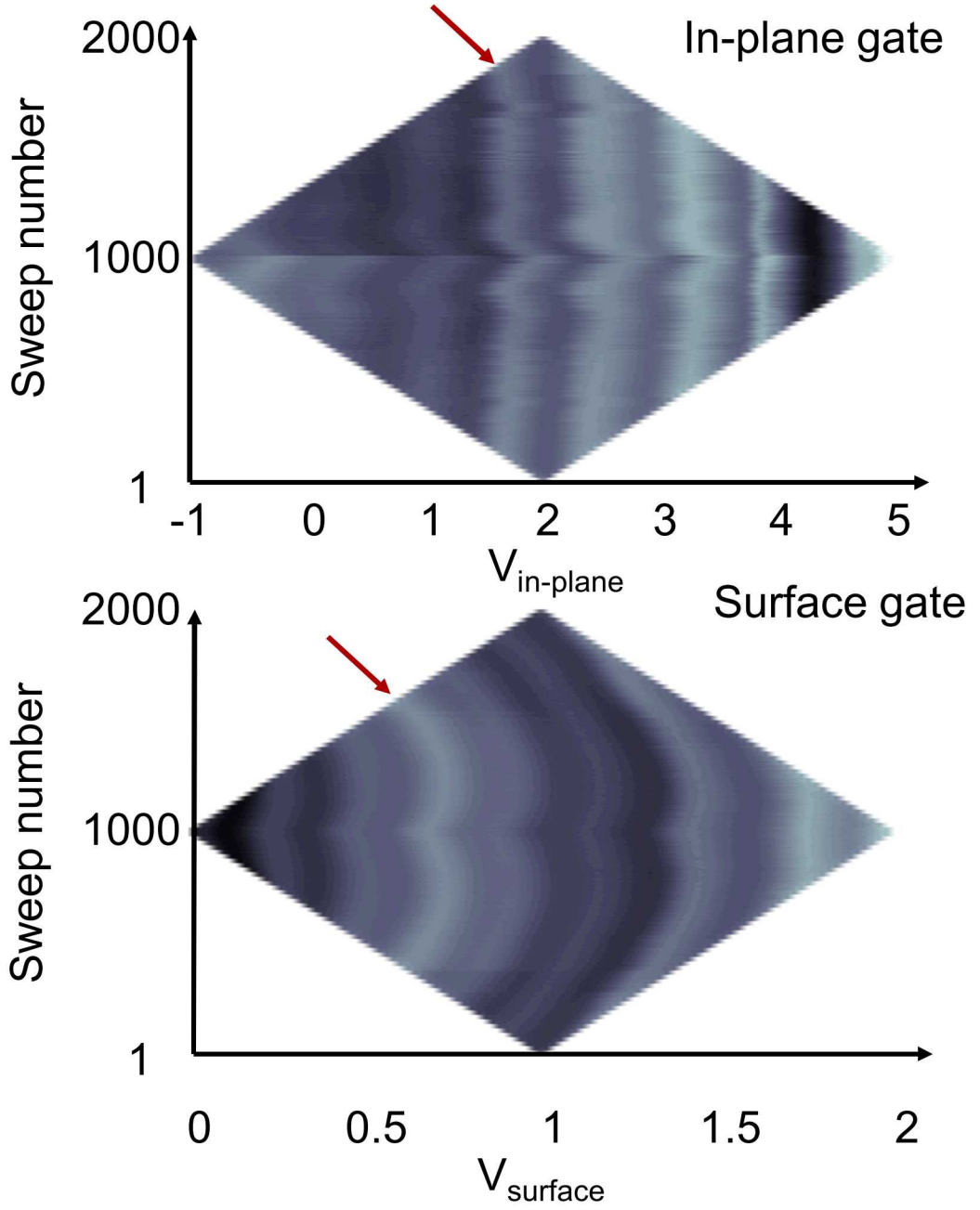


Expect low leakage to +/- 10 V in next design (need to isolate metal from silicon)

Gate hysteresis

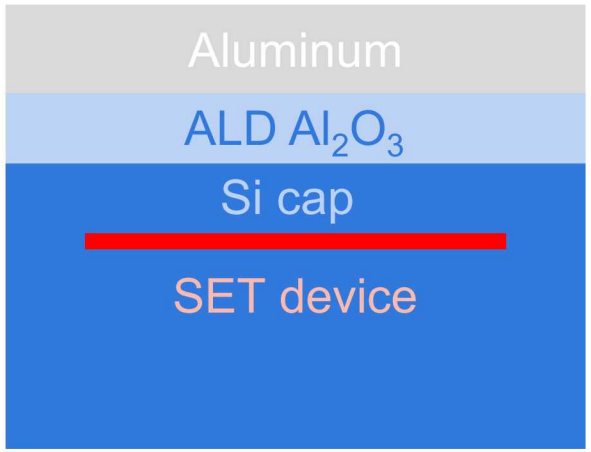
Repeat gate sweep across charge lines – should be straight

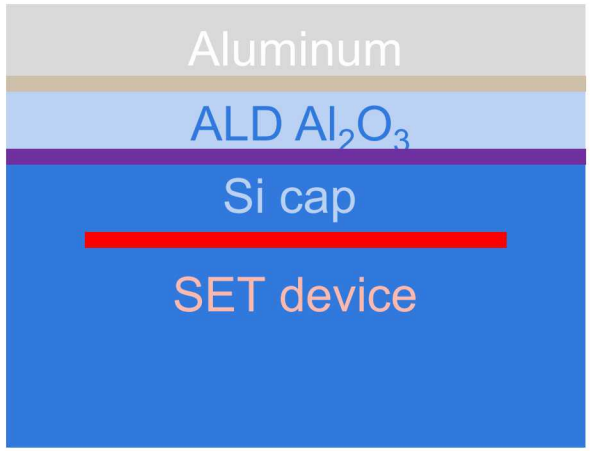
Surface gate is less ‘glitchy’
Surface gate is more hysteretic



What's next?

1. Diffusion barriers to improve interface quality





TiN barrier

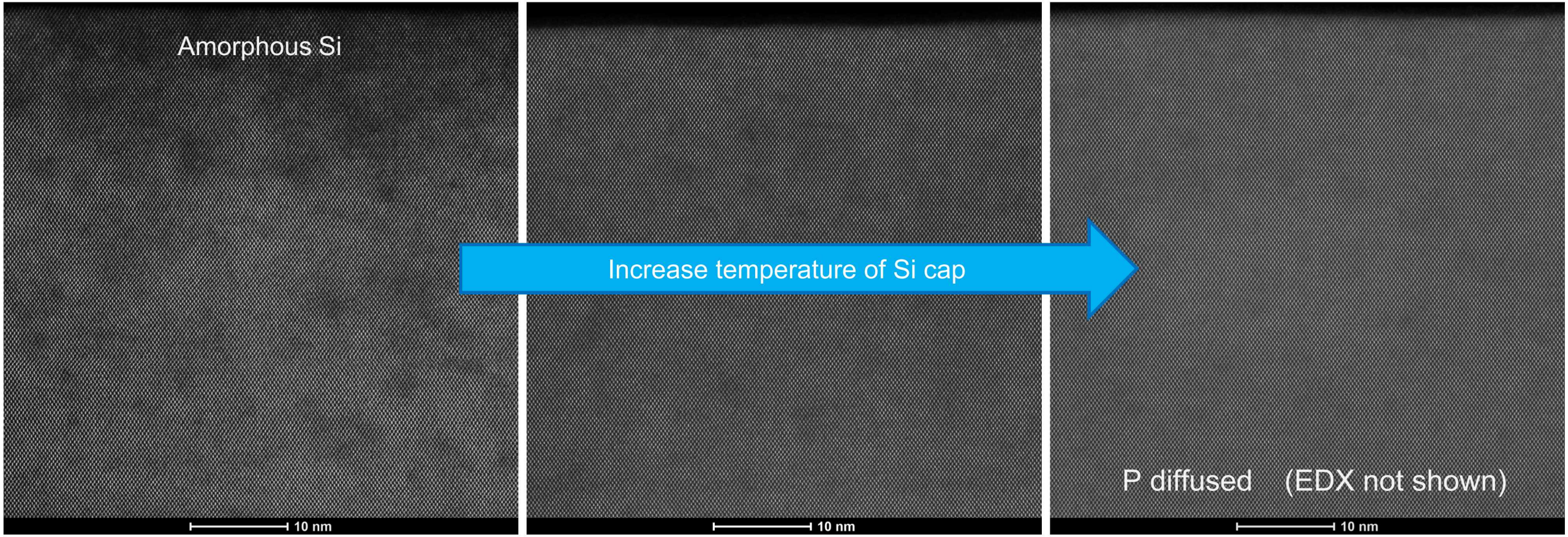
SiO_2 barrier

Requires significant process development:

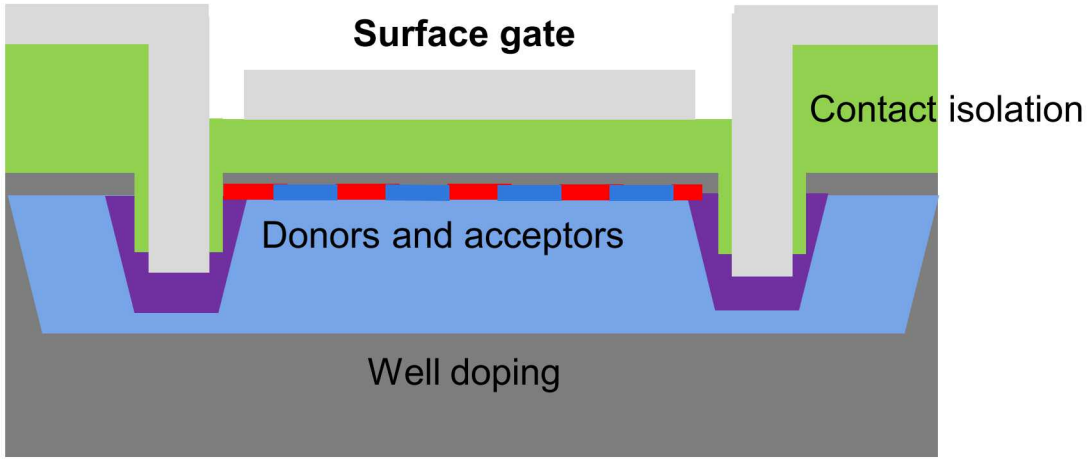
- Low temperature SiO_2
- Dual evaporation of metal
- Etched metal (not liftoff0

What's next?

2. Quality of low temperature materials – e.g. Si cap, oxide



Conclusion



Device cross section

Surface gate applicable to both APAM physics-focused devices and ultra-scaled transistors

Some of this work is supported by the Laboratory Directed Research and Development Program at Sandia National Laboratories, and was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525