Center for Energy Efficient Electronics Science

Theme 2: Nanomechanics

Students: Zhixin Alice Ye, Benjamin Osoba, Urmita Sikder, Tsegereda Esatu, Xiaoer Hu
Postdocs: Sergio Almeida, Sara Fathipour, Rawan Naous
Professors: Junqiao Wu, Vladimir Stojanović, Tsu-Jae Liu
Interns: Kelsey Horace Herron (JSU), Wenyi Zhang (UCAS)

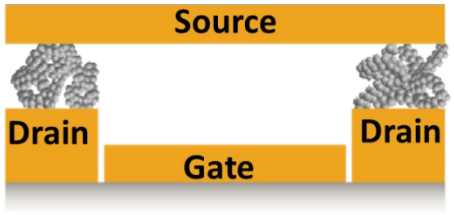
Student: Jinchi Han
Professors: Farnaz Niroui, Jeffrey Lang, Vladimir Bulović, Jing Kong, Timothy Swager

Students: Aldo Vidaña, Edgar Acosta, Robert Sifuentes, Mariana Martinez, Raquel Zubia
Professors: David Zubia, Dr. Jose Mireles (UACJ Mexico)

NSF Virtual Site Visit
February 8, 2019

A Science & Technology Center

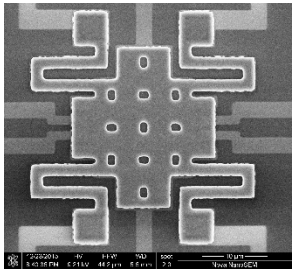
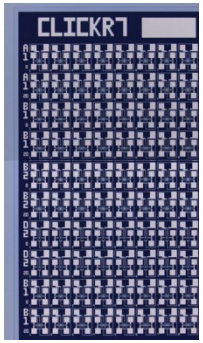
Theme II Projects & PIs

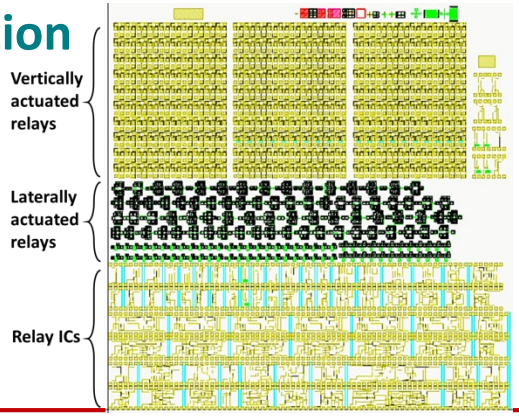


- **Squitch [Lang, Bulović, Kong, Swager]**
  - Compressible molecules
  - Multi-terminal design

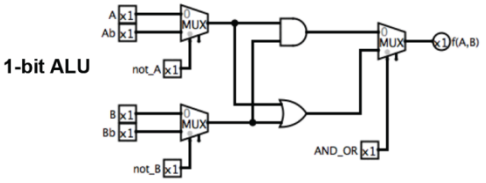



- **Low-Voltage Relay Integrated Circuits [Liu, Wu, Stojanović]**
  - Sub-100 mV circuit demonstration

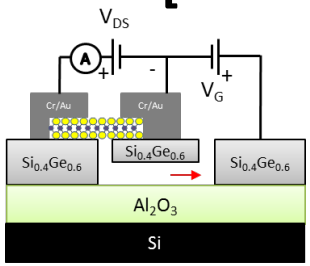



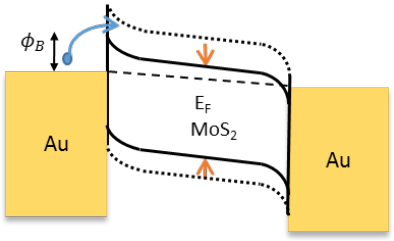


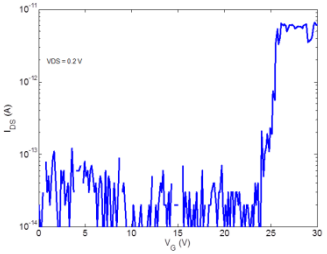




- **Stritch [Zubia]**
  - Low-voltage actuator design for inducing strain in 2-D materials



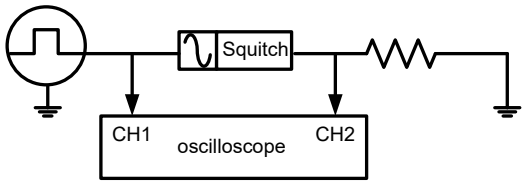


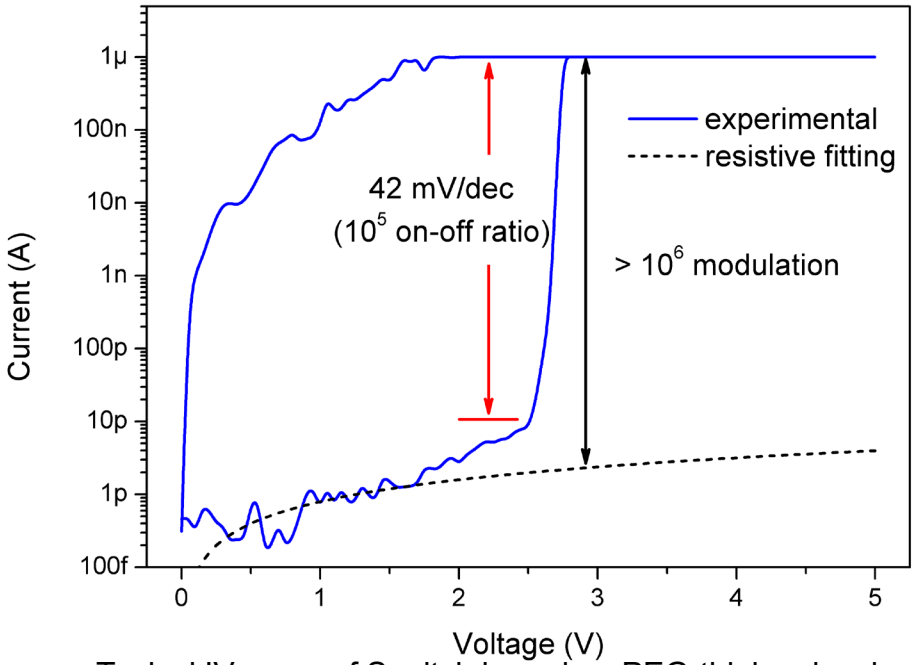


Squitch Update

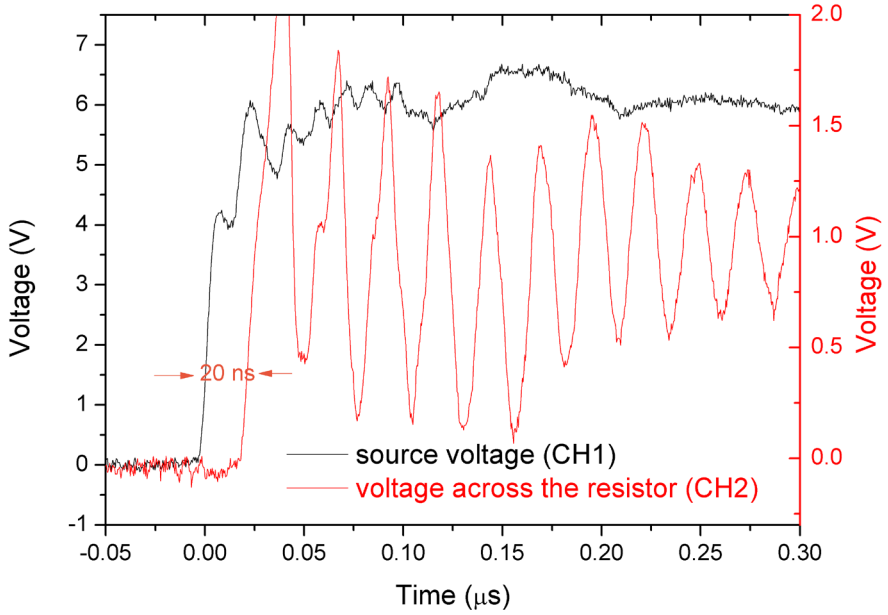
1. Two-terminal Squitches have been experimentally demonstrated with

- low actuation voltage (~ 2V)
- large on-off ratio (>10^5)
- small subthreshold slope (~ 40 mV/dec)
- negligible OFF-state leakge (< 1 pA)
- short switching delay (~15 ns, excluding delay from measurement circuit)





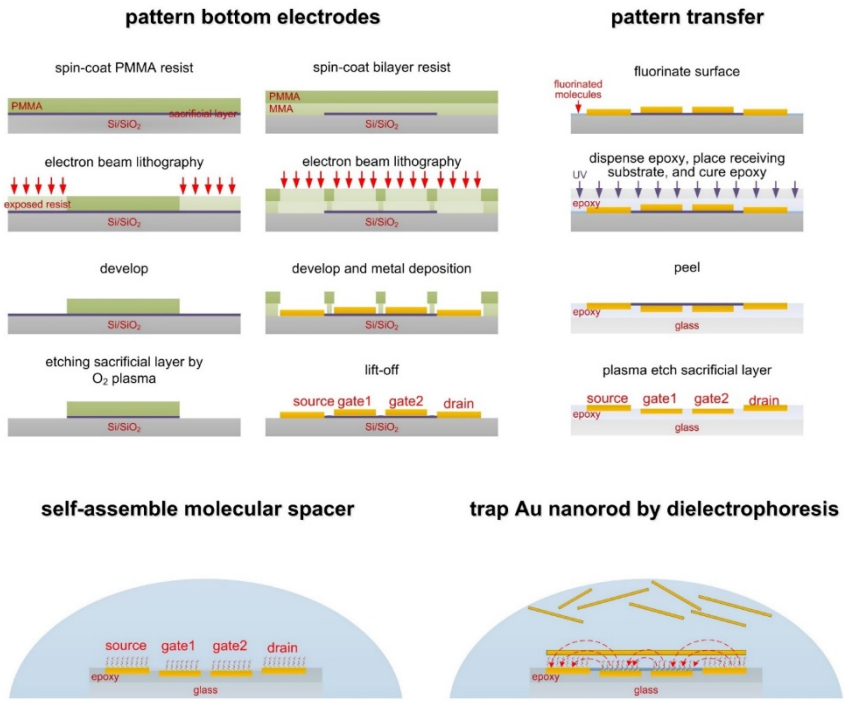
Typical IV curve of Squitch based on PEG-thiol molecules



Experimental result of dynamics of squitch

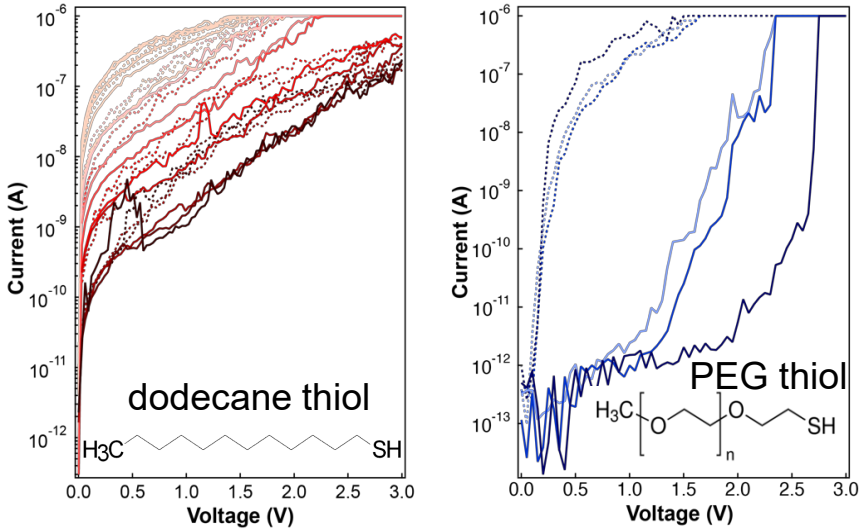
Squitch Update (continued)

2. nanofabrication process has been improved for a higher throughput (scalable) and a better yield (~40%, limited by DEP trapping)



Scalable nanofabrication process of squitches

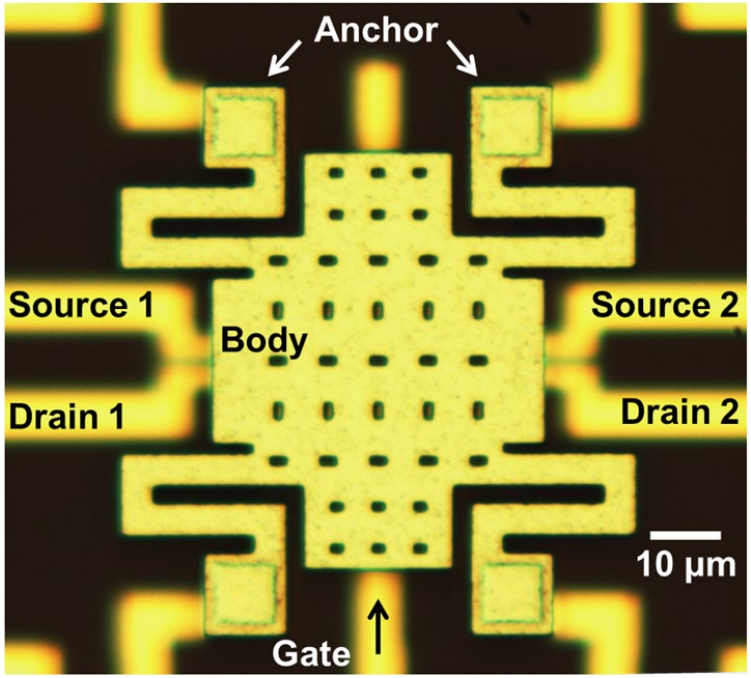
3. The significant role of molecules has been illuminated
   - behavior of squitches can be designed by engineering the molecules
   - squitch can perform as a useful metrology platform to study the mechanics of molecules



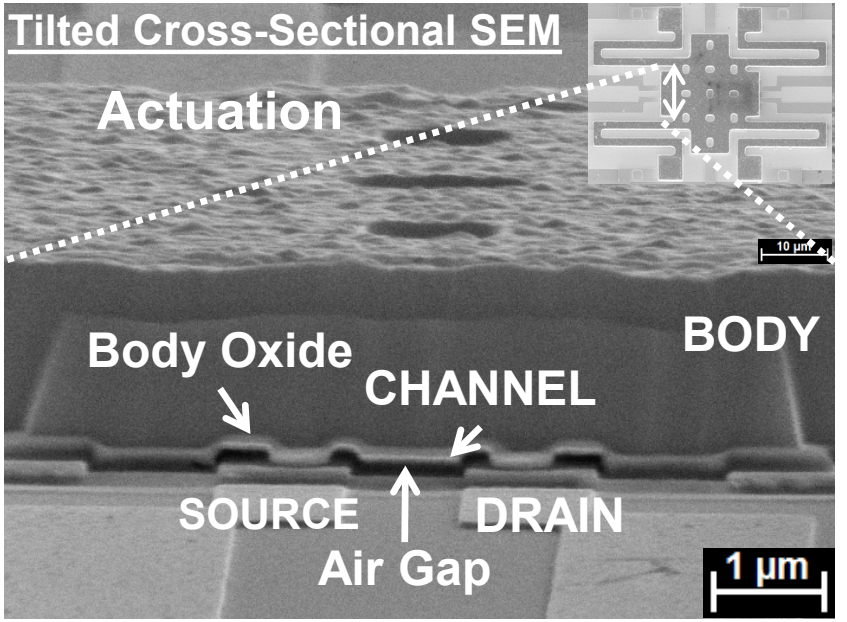
IV curves of squitches based on dodecane-thiol molecules and PEG-thiol molecules over cycles of switching

Body-Biased Relay Structure and Operation

Plan-View Microscopic Image

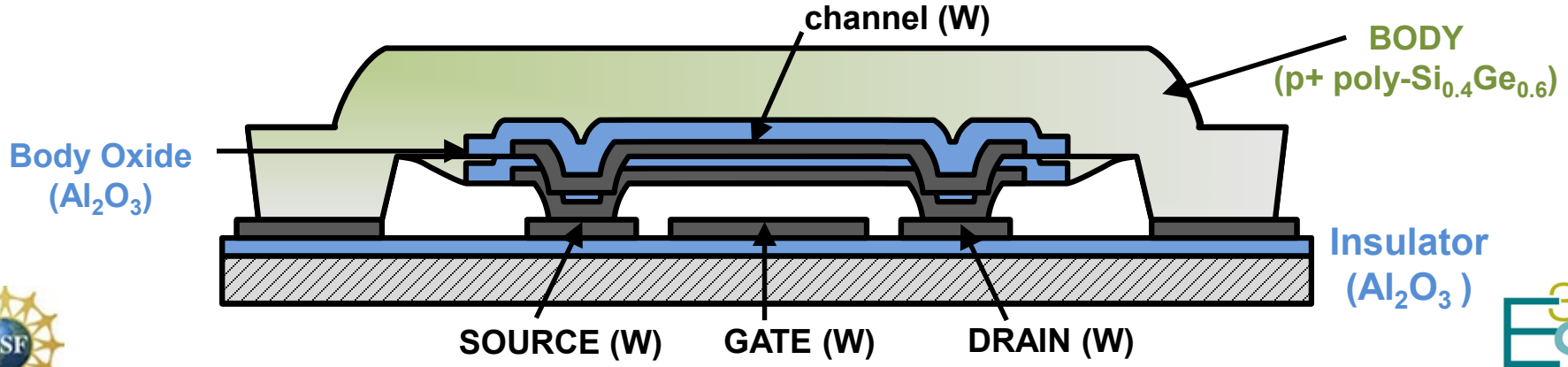


Plan-View SEM



I-R. Chen *et al*. (UCB), *Transducers* 2013

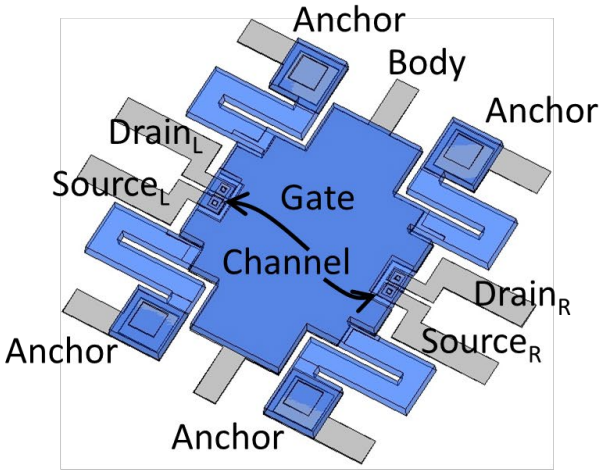
Schematic Cross-section



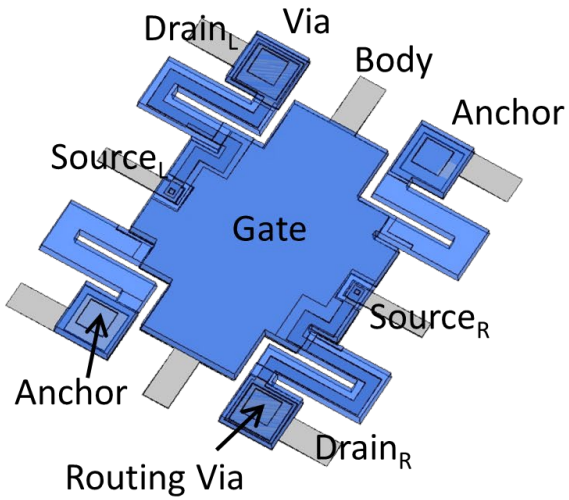
Improved Body-Biased Relay Design

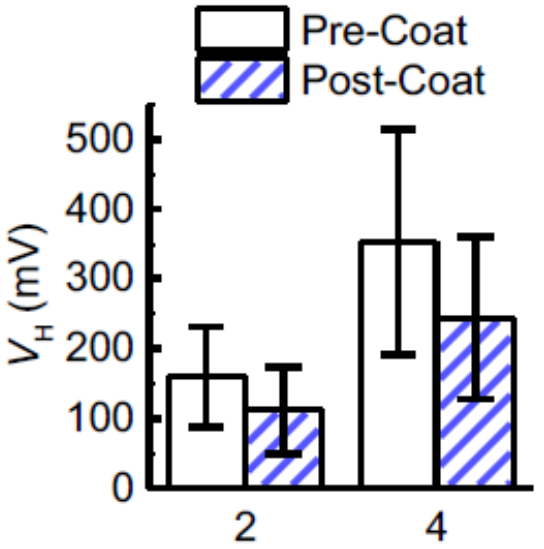
Z. A. Ye *et al.*, presented at the *2018 IEEE International Electron Devices Meeting*

4-Contact Design



2-Contact Design

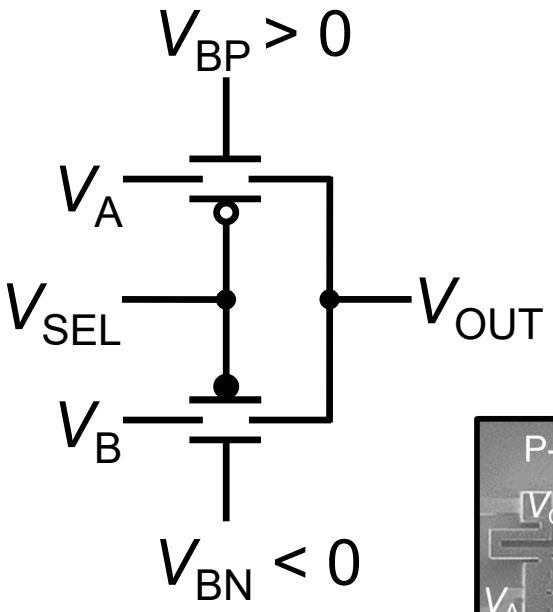




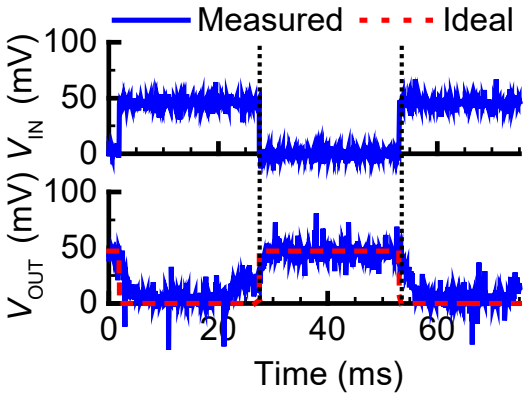
50 mV Relay Integrated Circuit Demos

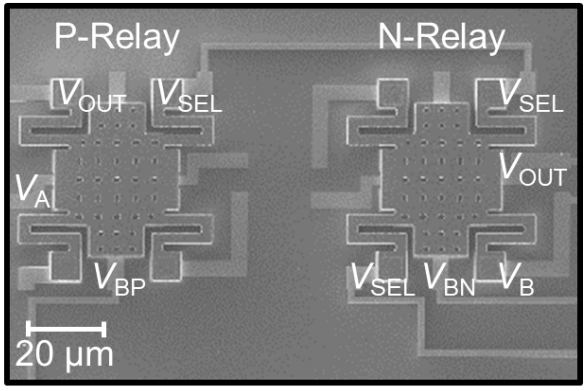
Z. A. Ye *et al.*, presented at the *2018 IEEE International Electron Devices Meeting*

Circuit Diagram

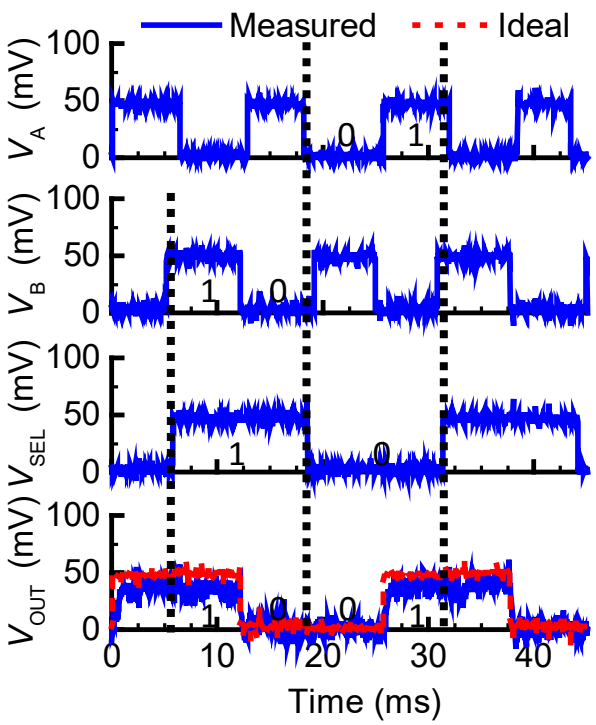


Inverter Waveforms





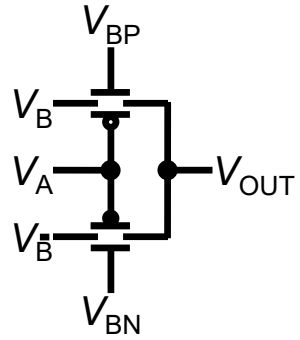
2:1 MUX Waveforms

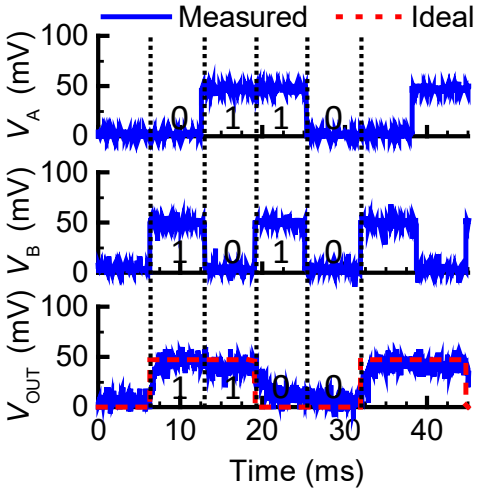


50 mV Relay Logic Gate Demos

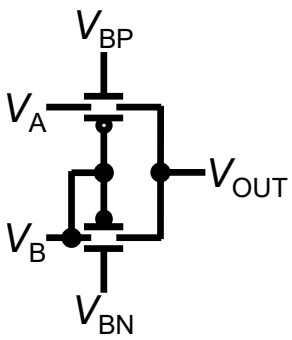
Z. A. Ye *et al.*, presented at the *2018 IEEE International Electron Devices Meeting*

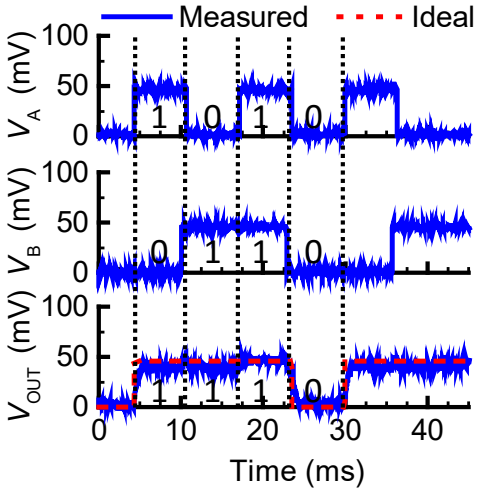
XOR GATE



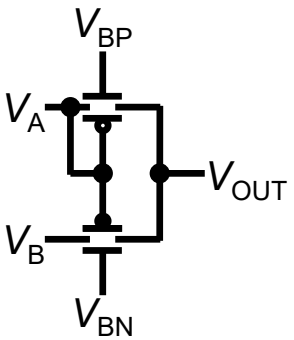


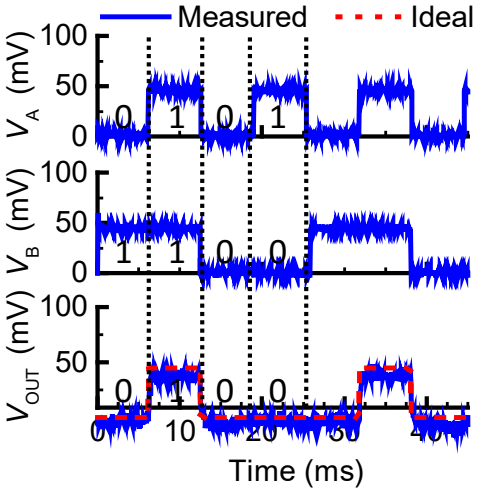
OR GATE



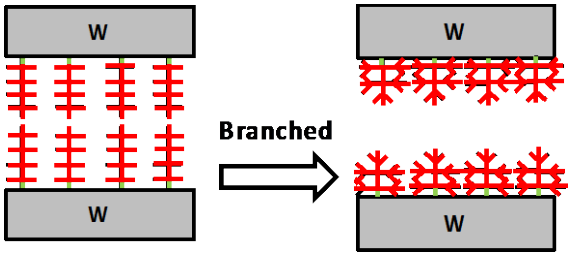


AND GATE

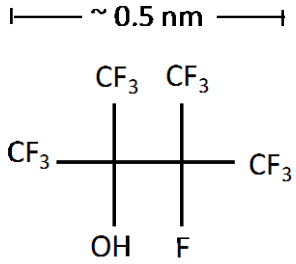




Self-Assembled Molecular (SAM) Coatings

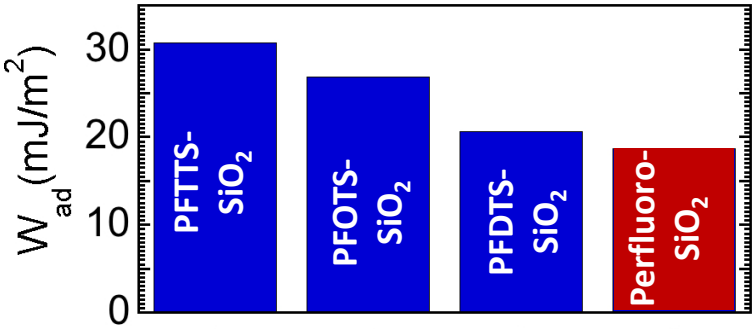


Perfluoro(2,3-dimethylbutan-2-ol)

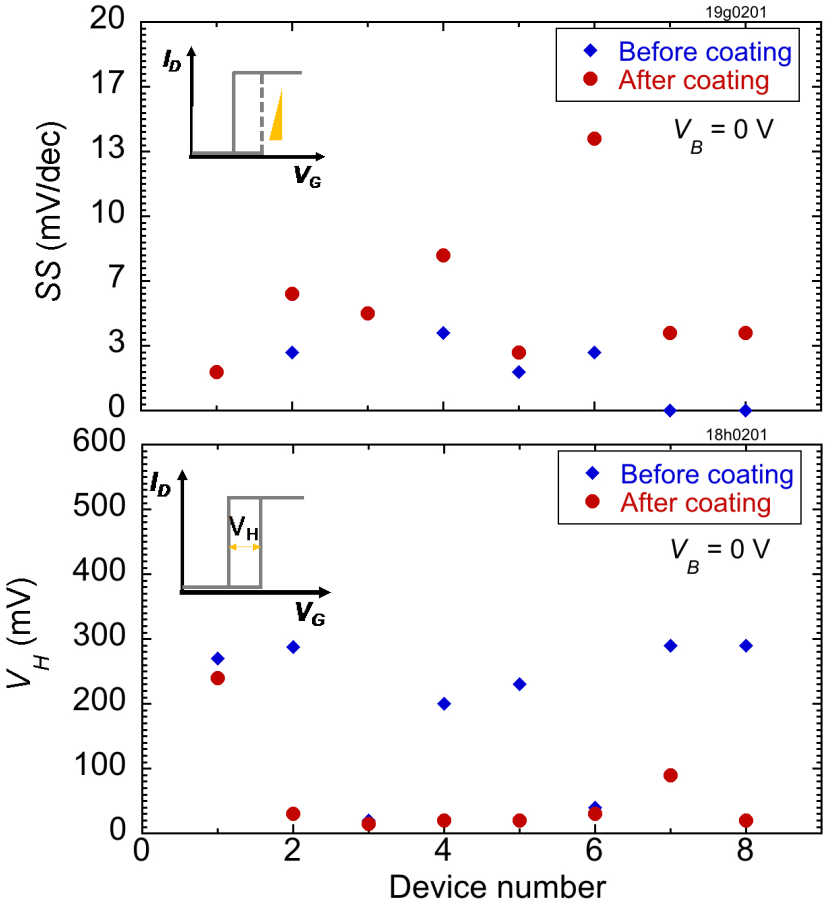


Motivation: reducing adhesion (more F atoms) without sacrificing electrical conduction (short molecule).

Perfluro has ~24 F atoms/nm vs. ~10 F atoms/nm in PFOTES

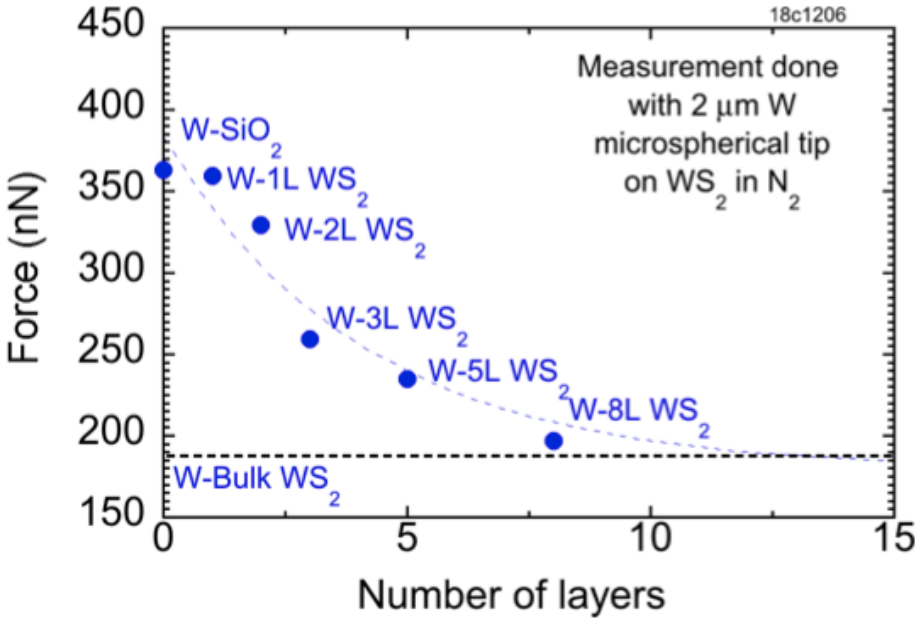


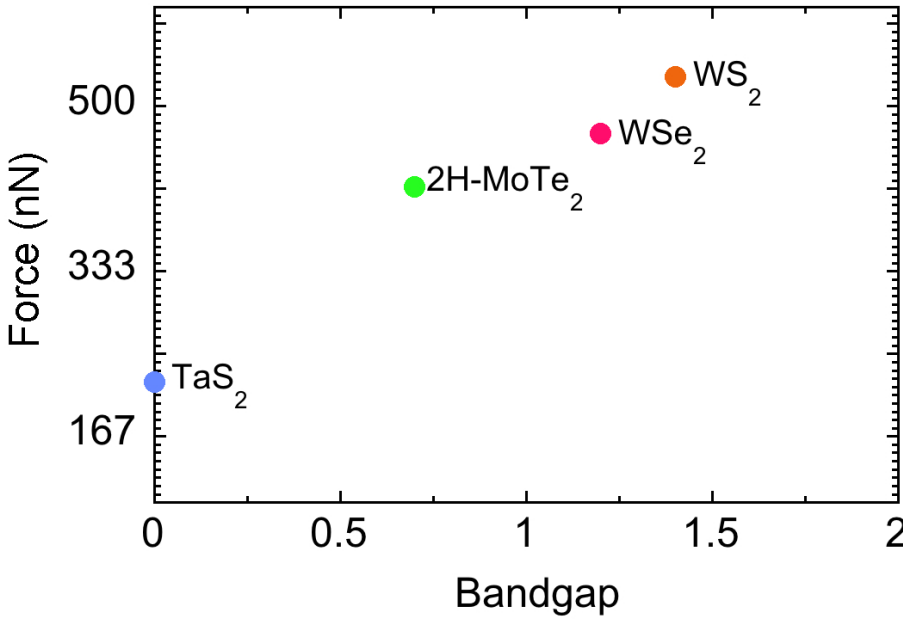
Lower adhesion energy with Perfluro coating



Reduced hysteresis while maintaining low subthreshold swing

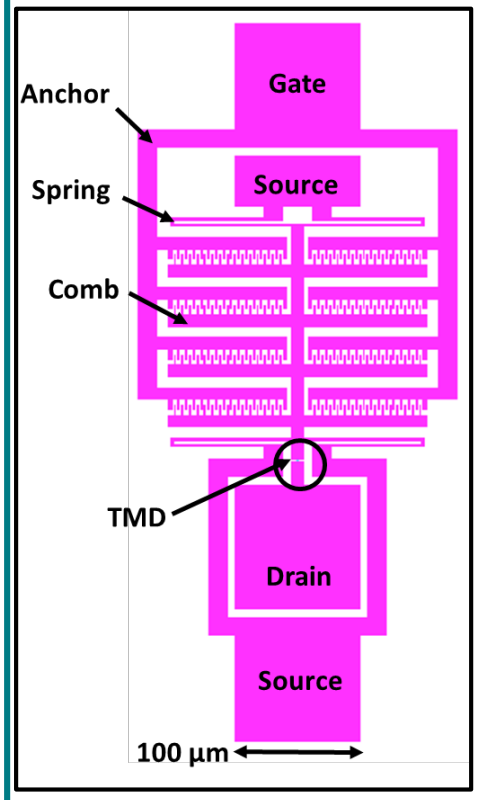
Transition-Metal Dichalcogenide Adhesive Force

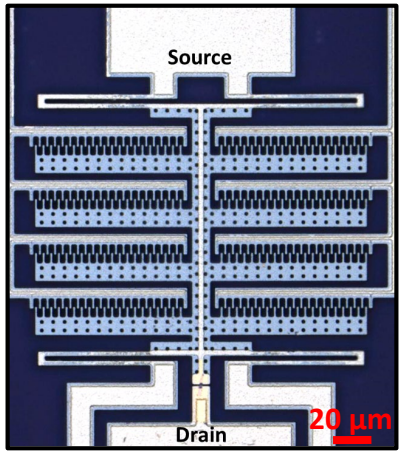


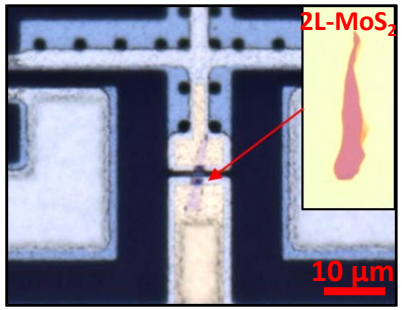


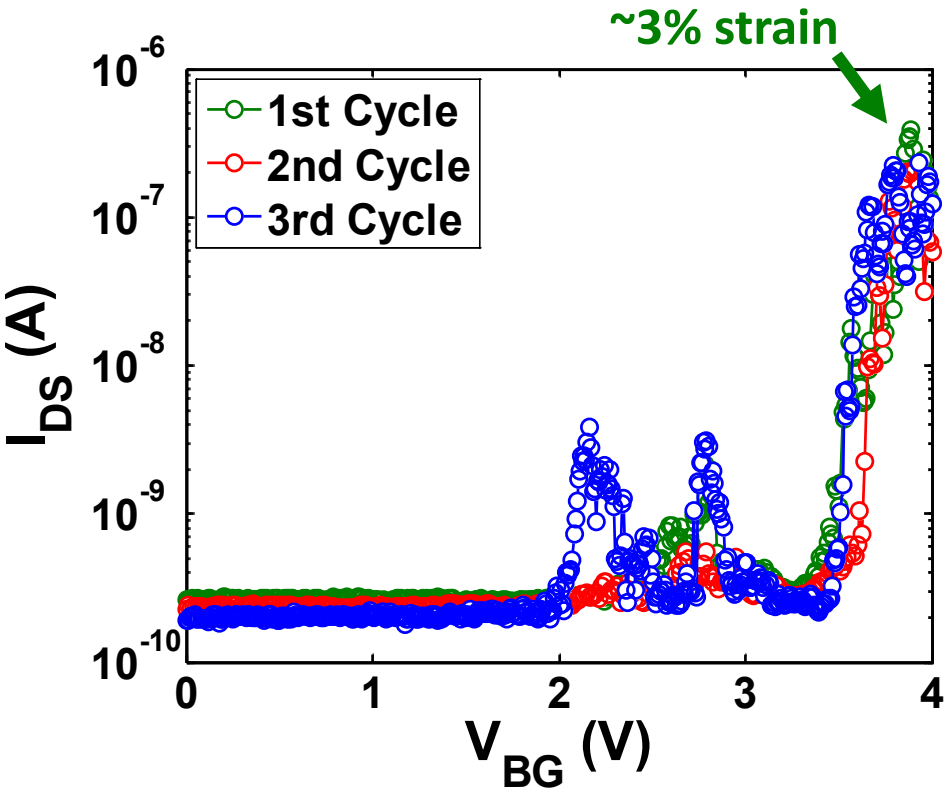
Adhesive force decreases with bandgap of bulk TMD: as bandgap decreases, electron density increases, and the screening of adhesive force by electrons becomes more pronounced.

Stritch Update



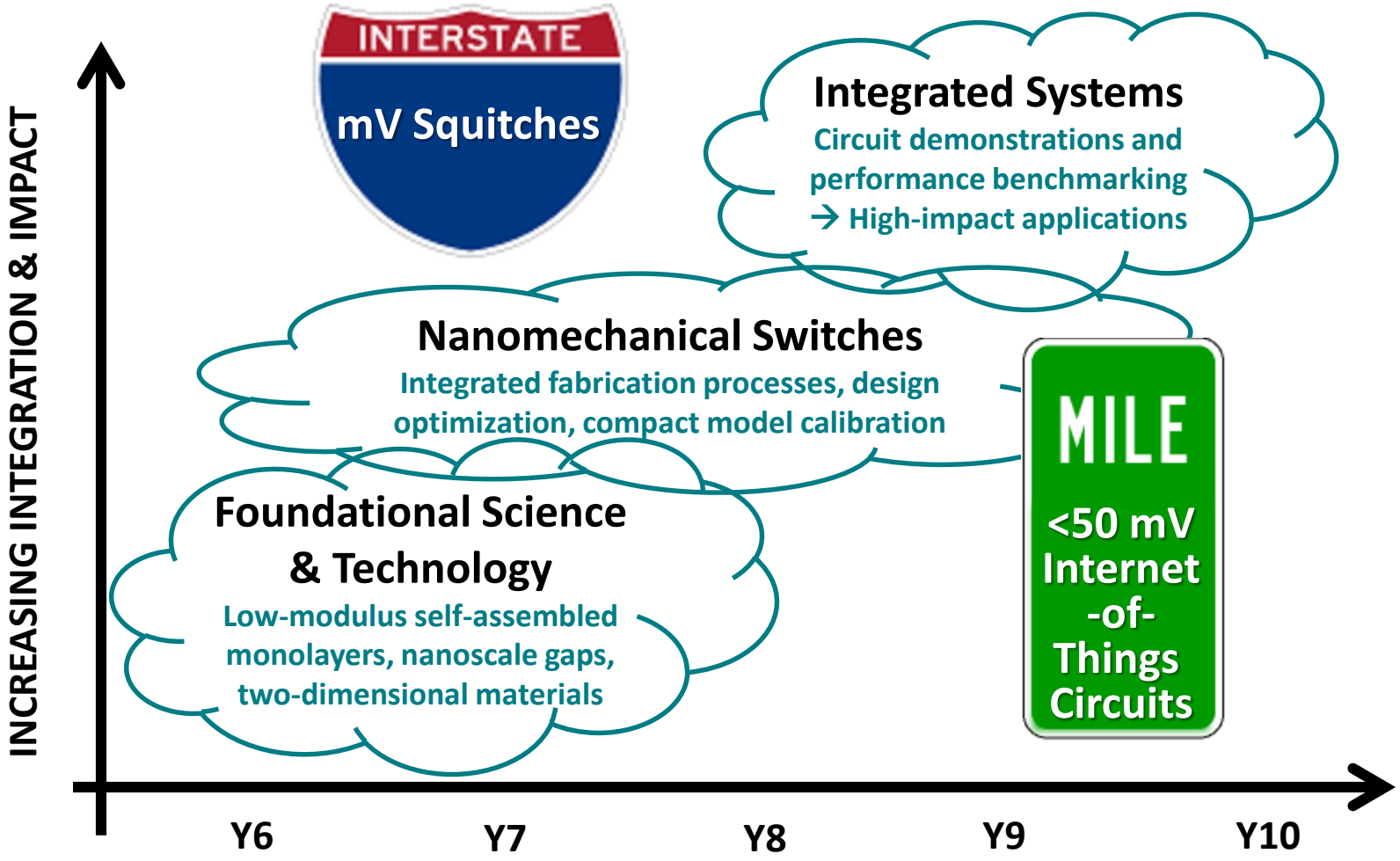






- Comb-drive actuator was designed and fabricated @UCB using poly-$Si_{0.35}Ge_{0.65}$
- Strain-induced conductivity modulation in bi-layer MoS_2 flake demonstrated
- **~3000x increase in conductivity measured over multiple cycles!**

Theme II (Nanomechanics) Roadmap



Theme II Legacy

- milliVolt nanomechanical digital computation
  across a wide range of operating conditions
- Stritch
- Squitch
- BEOL switches (reconfigurable interconnects)
- E-book