Massachusetts Institute of Technology

Multi-Terminal NEM Switch Based On Compressible Molecules (Squitch)

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Collaborators: Prof. Timothy M. Swager
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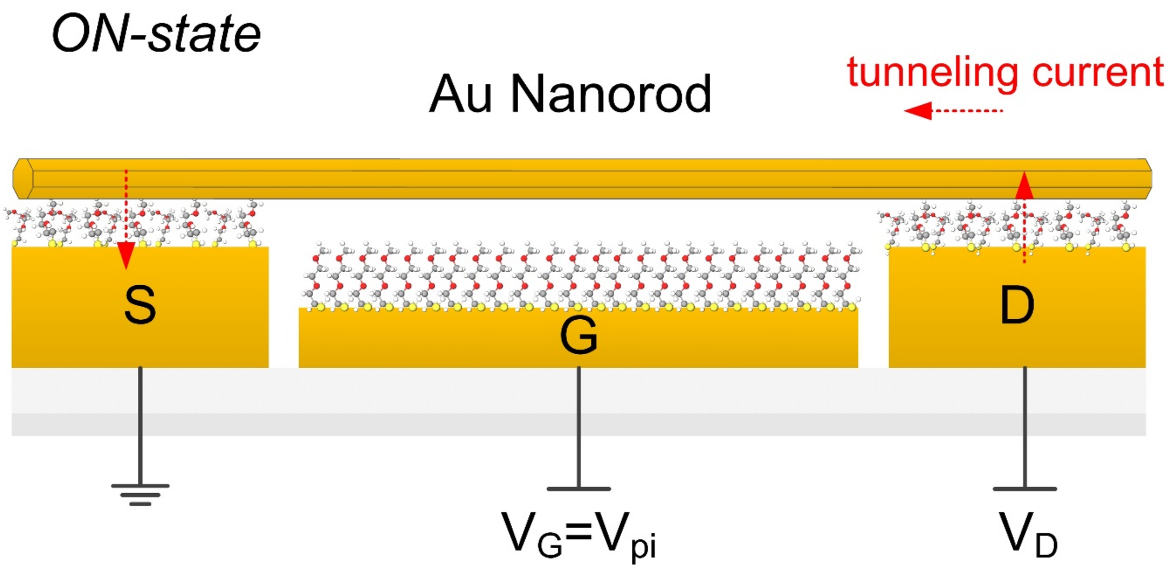
Multi-terminal NEM switch based on compressible molecules



sub-5 nm displacement

- low actuation voltage (<3 V)
- negligible OFF-state leakage (pA level)
- >5 orders of magnitude on-off ratio
- a high switching speed (100 MHz ~ 1 GHz)

no metal-metal contact

- low hysteresis (<1 V)
- reduced risk of stiction failure

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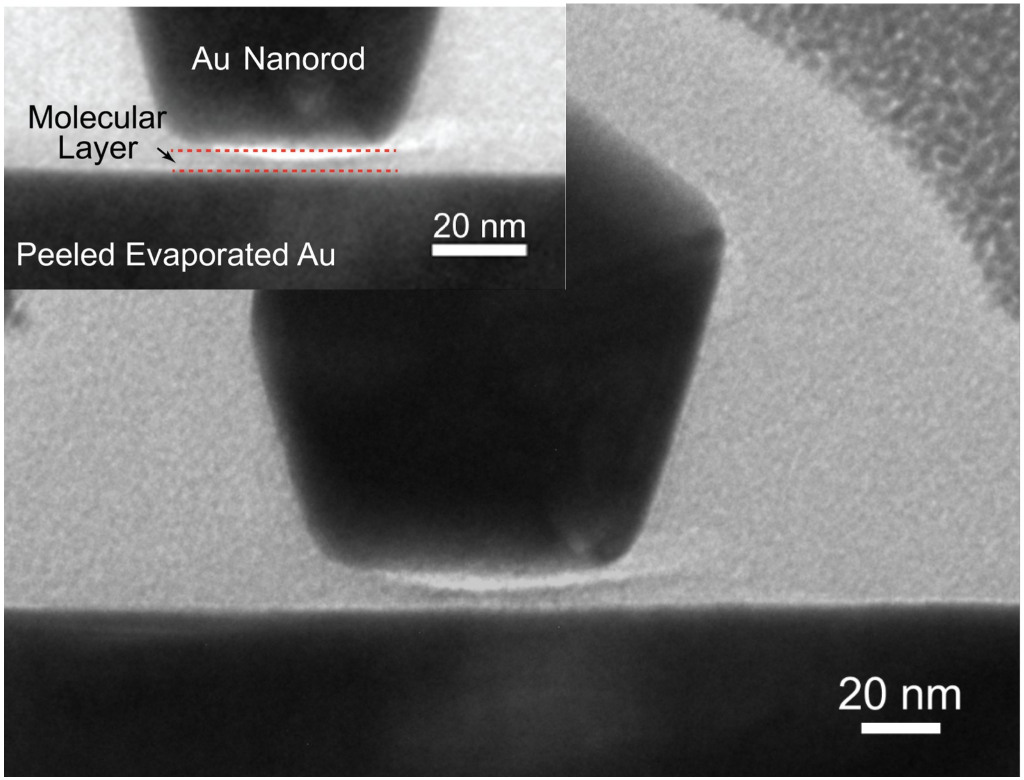
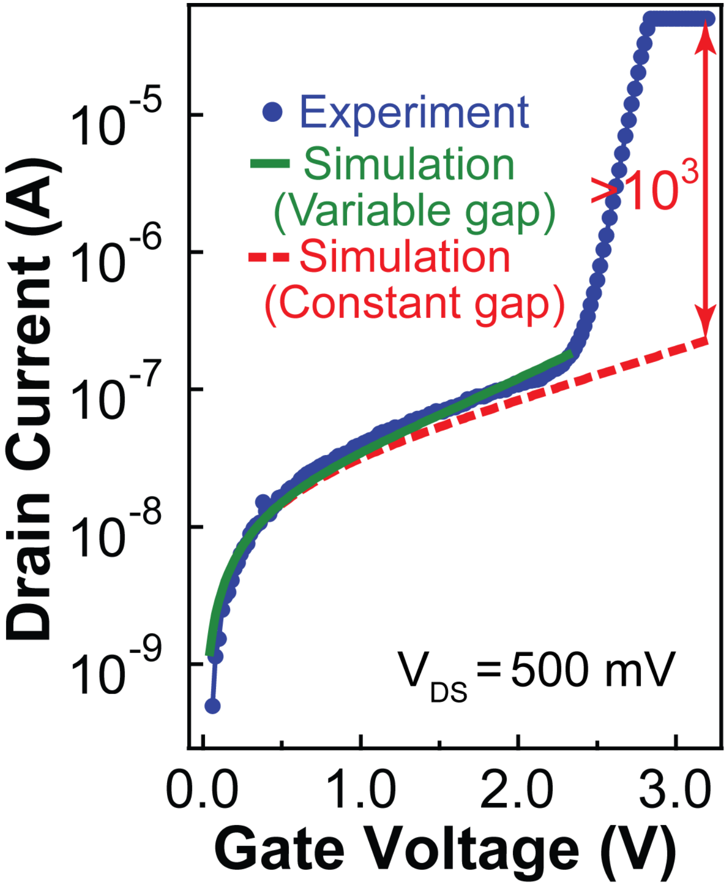
Previous results on a multi-terminal squitch



TEM image of the tunneling junction



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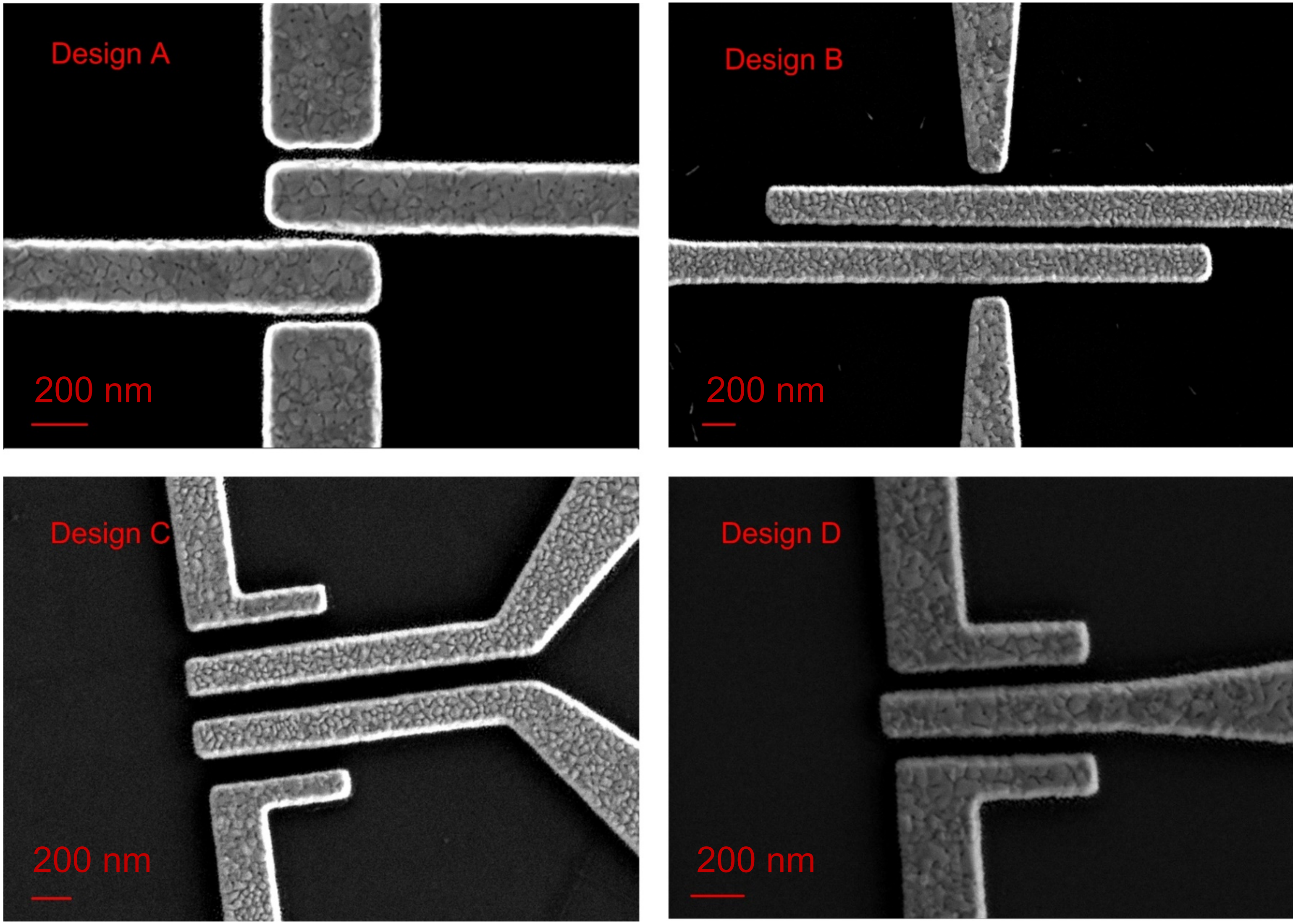
Step 1 – patterning bottom electrodes **Yield** – 90%~100%



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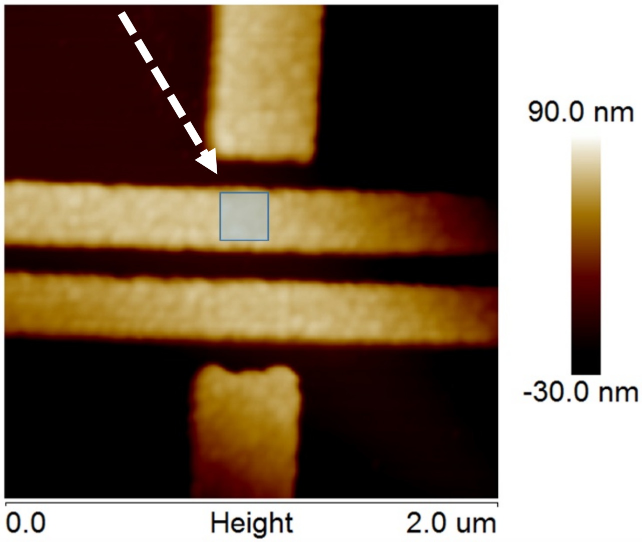
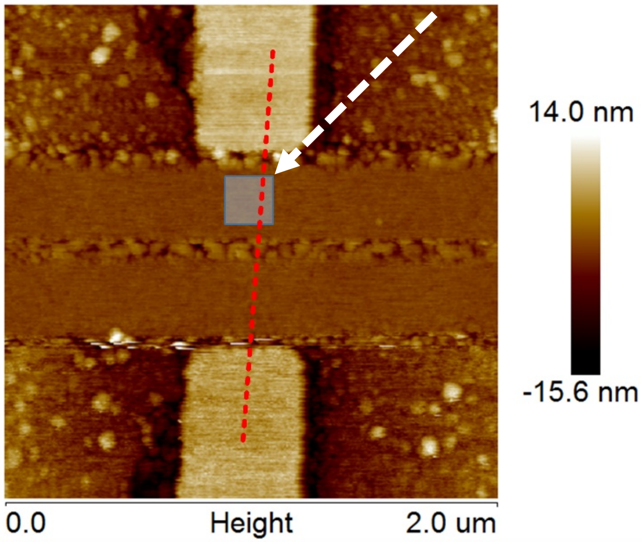
Step 2 – pattern transfer by peeling

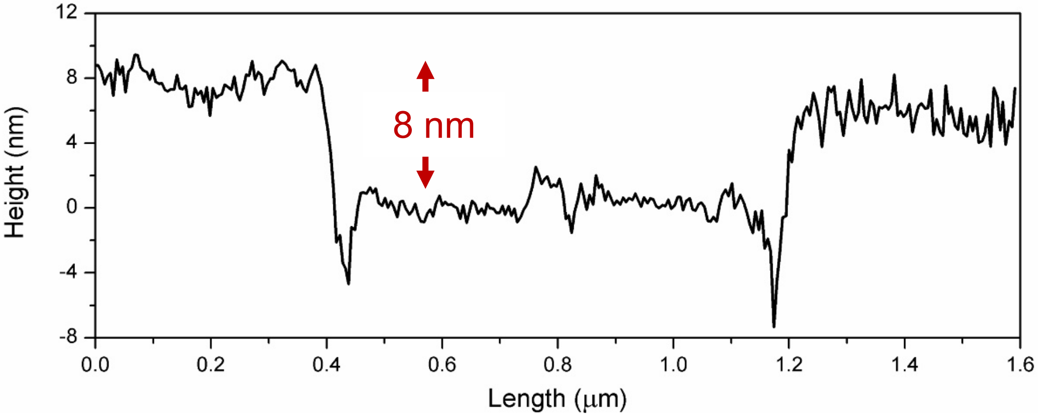
Yield – 90%~100%

Roughness:
2.58 nm (RMS)

Roughness:
0.44 nm (RMS)







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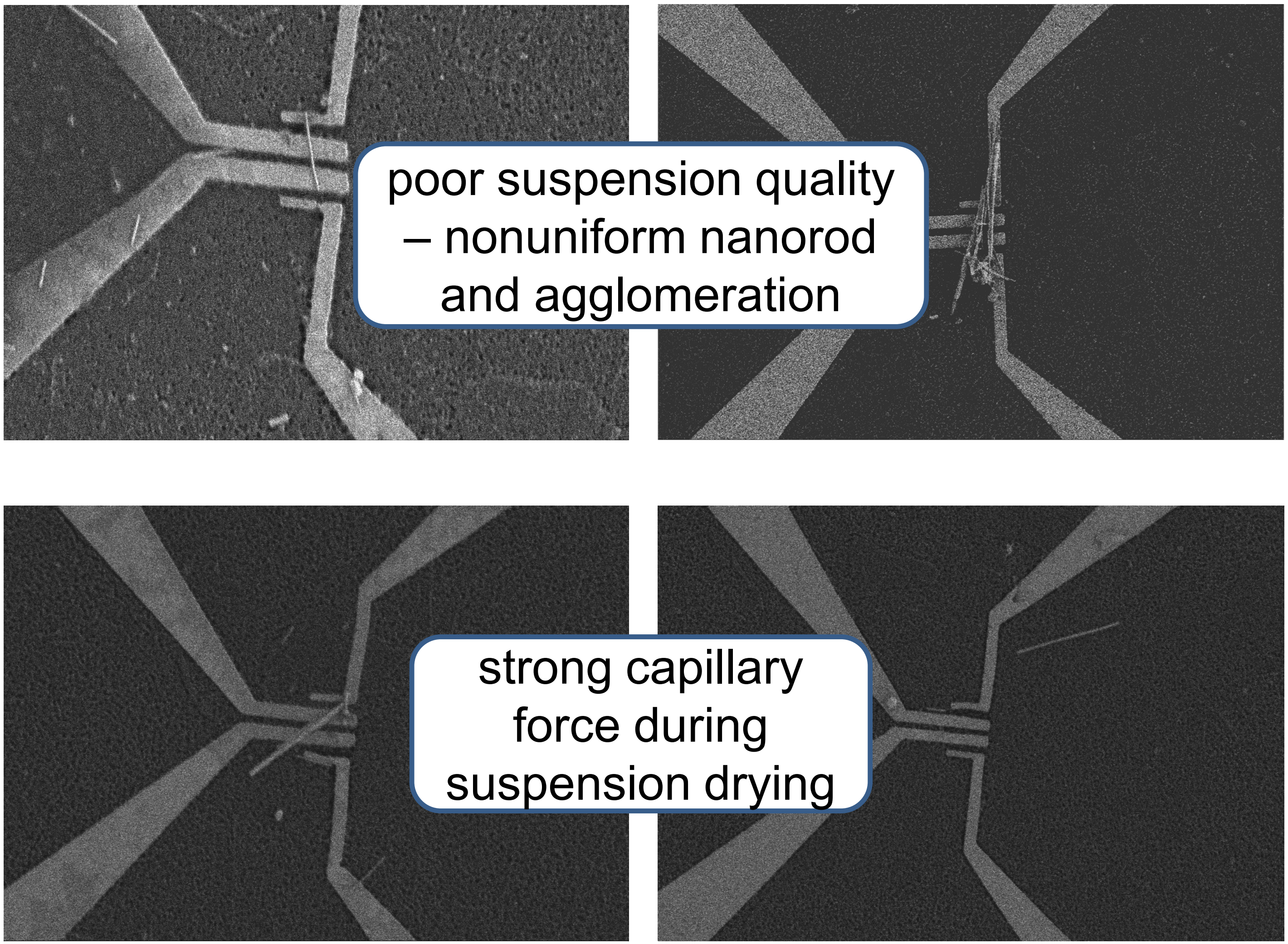
Step 4 – dielectrophoretic trapping top electrode



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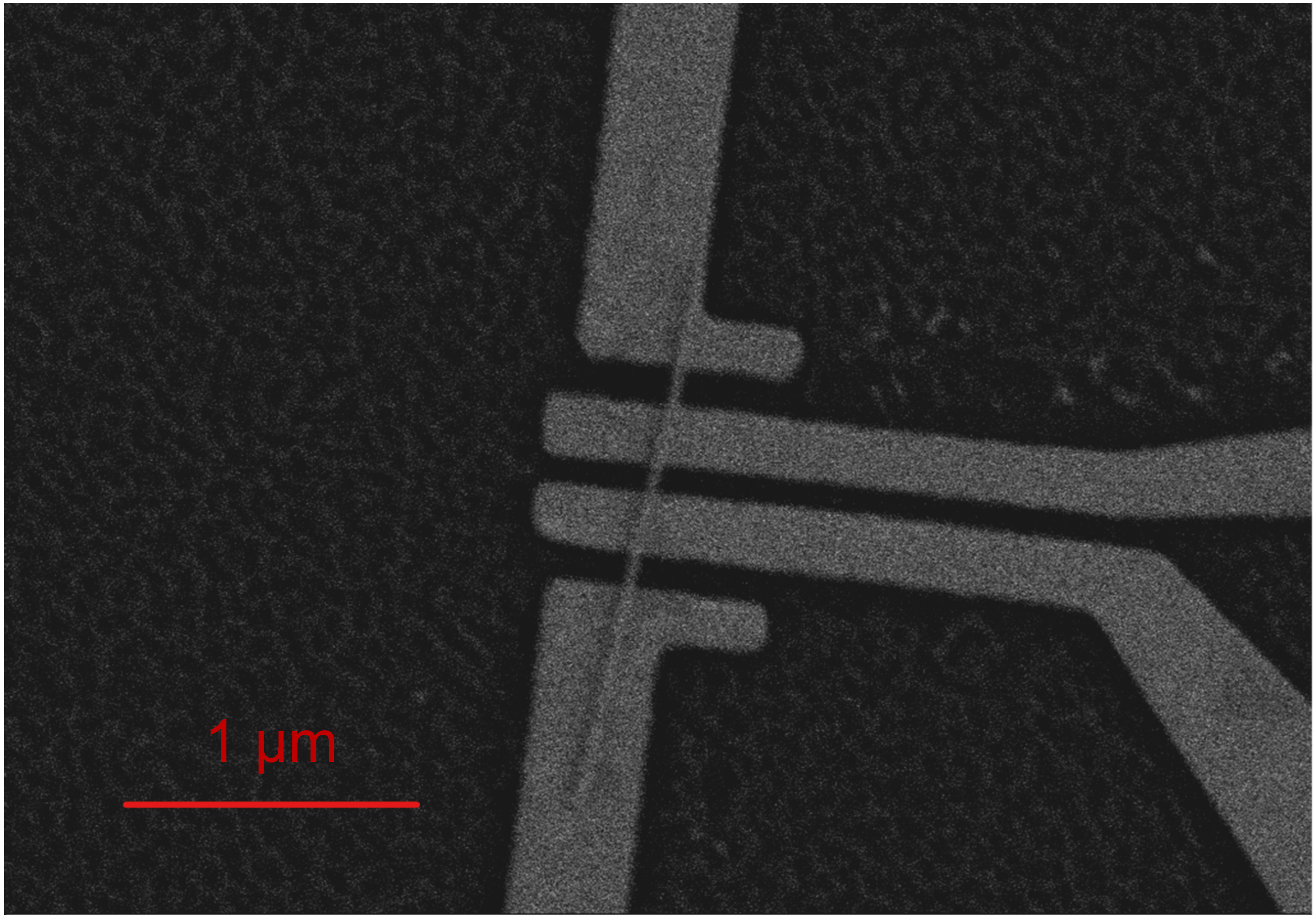
Step 4 – dielectrophoretic trapping top electrode



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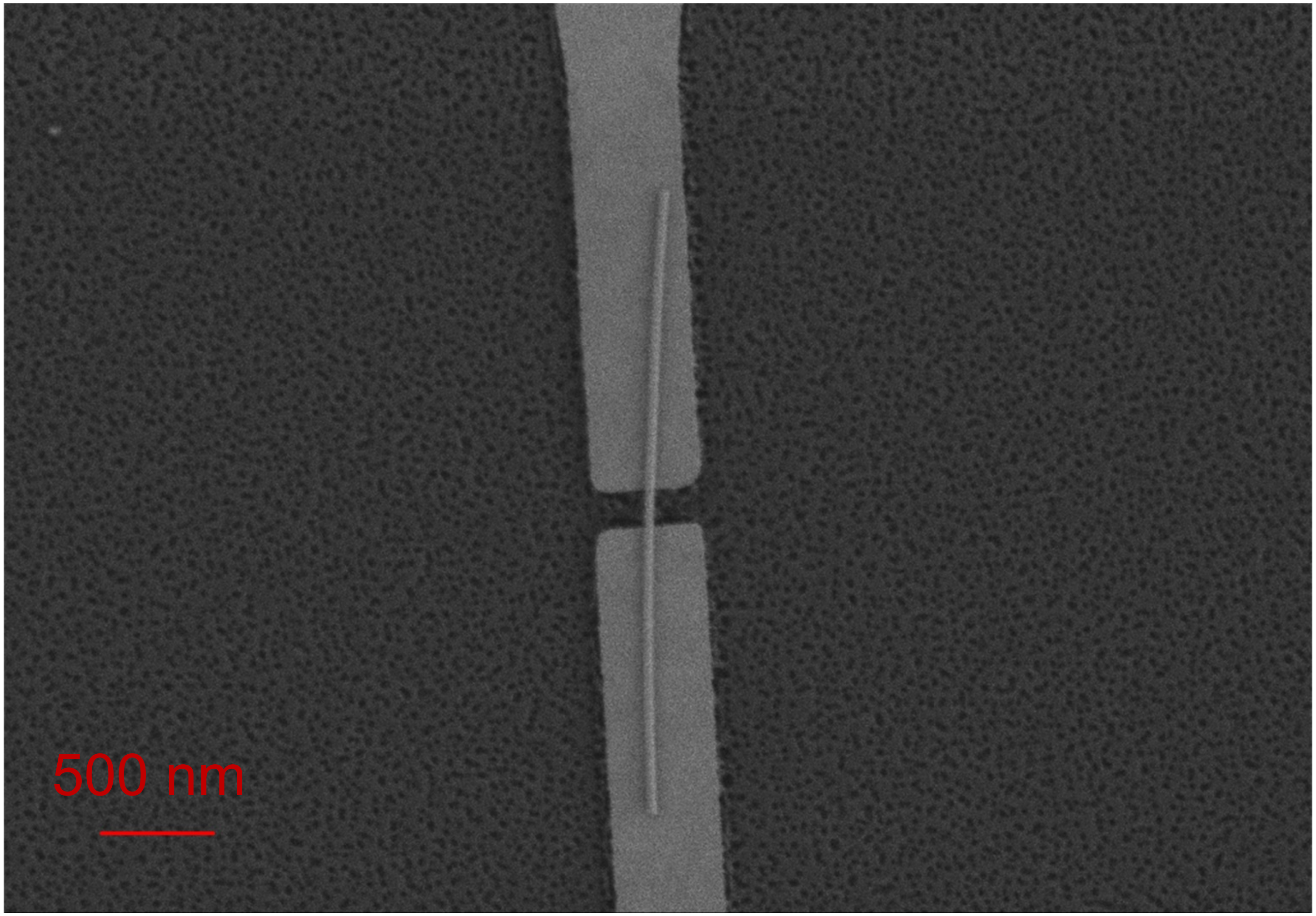
Experiments on two-terminal squitches



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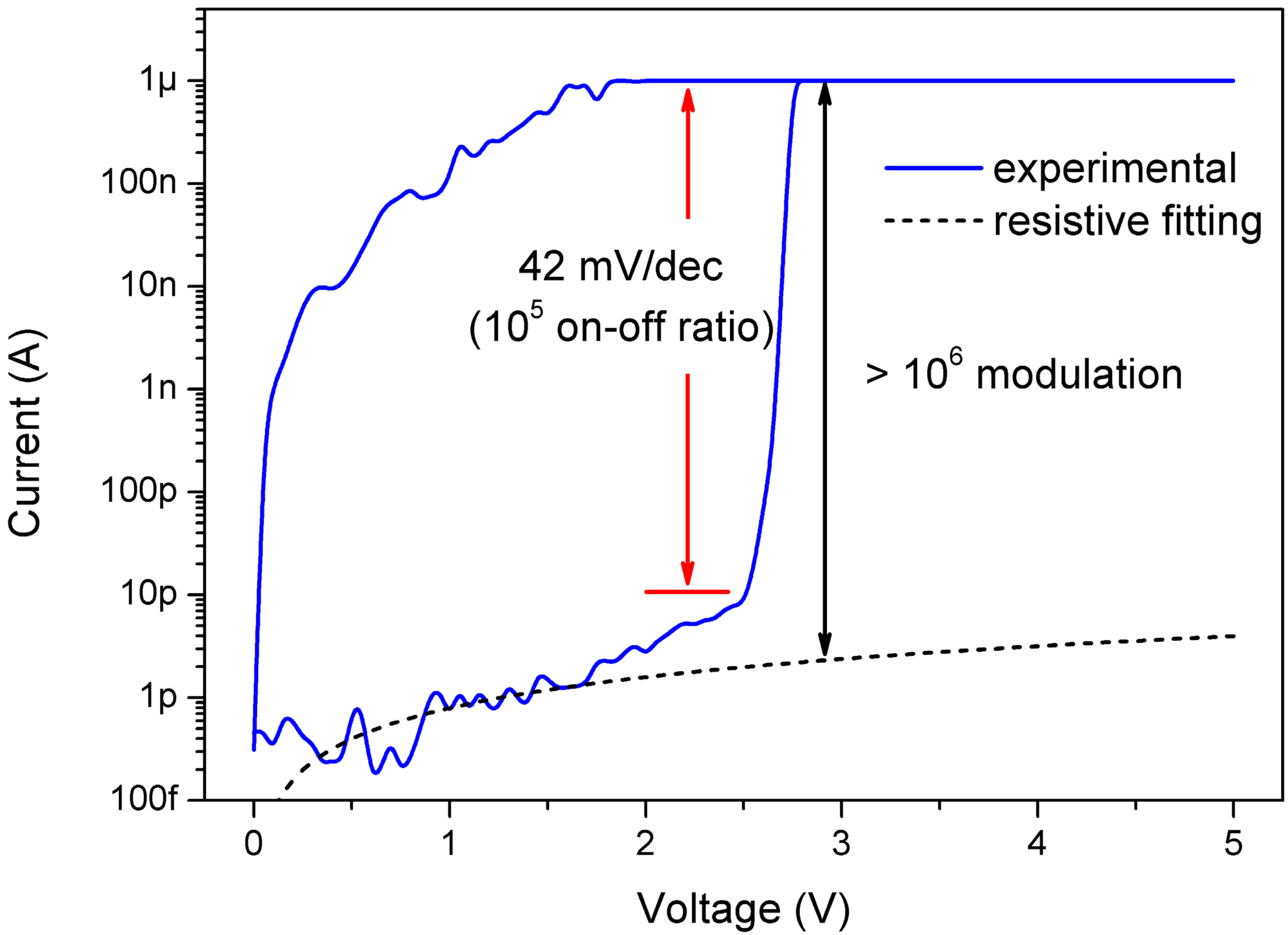
IV curve of two-terminal squitch



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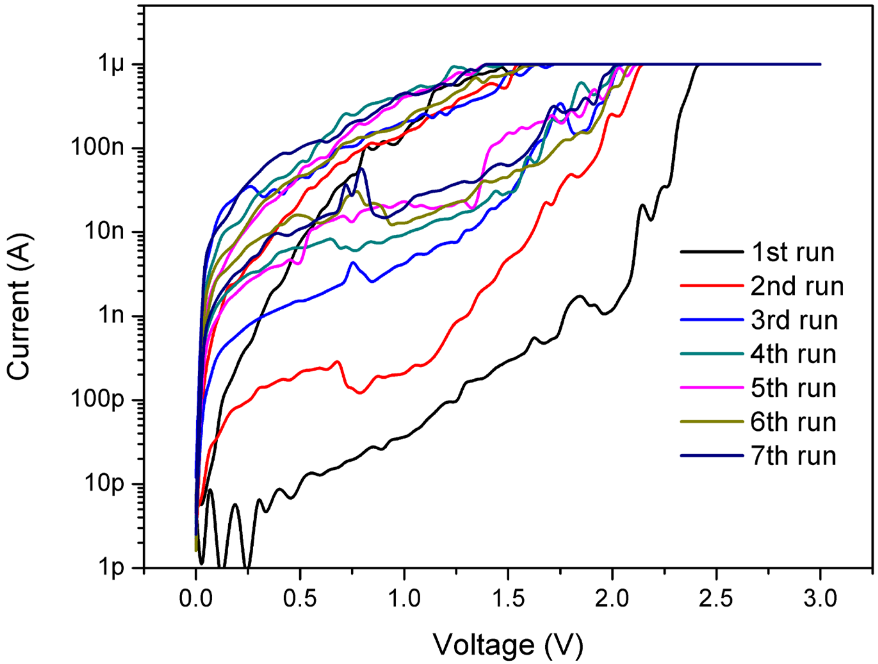
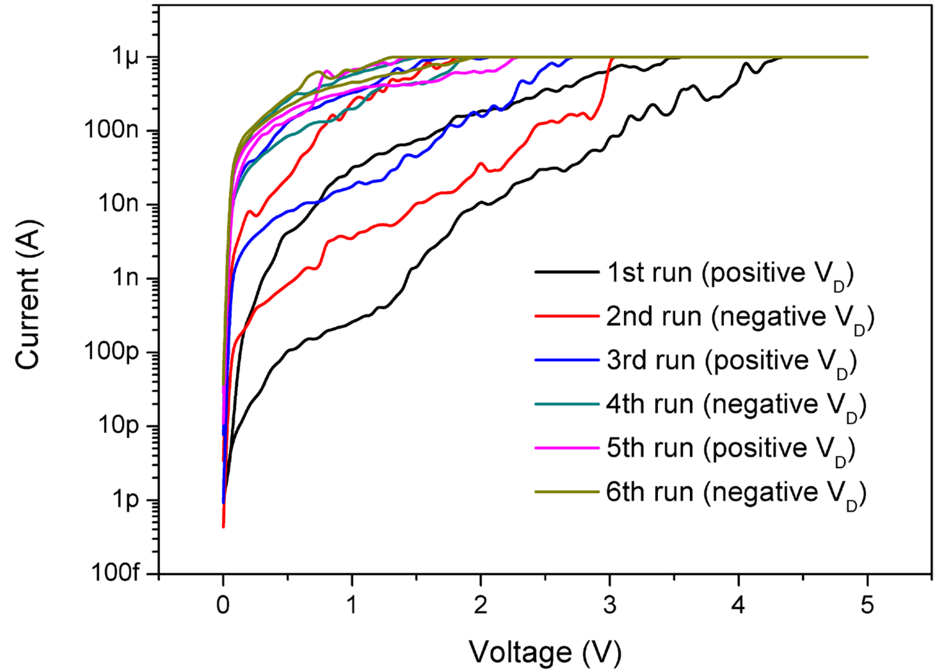
Degradation in performance over cycles

- IV curves move towards upper left over cycles until stabilized or stiction due to change in

the elastic property, and the thickness of molecular layer

after cycles of compression





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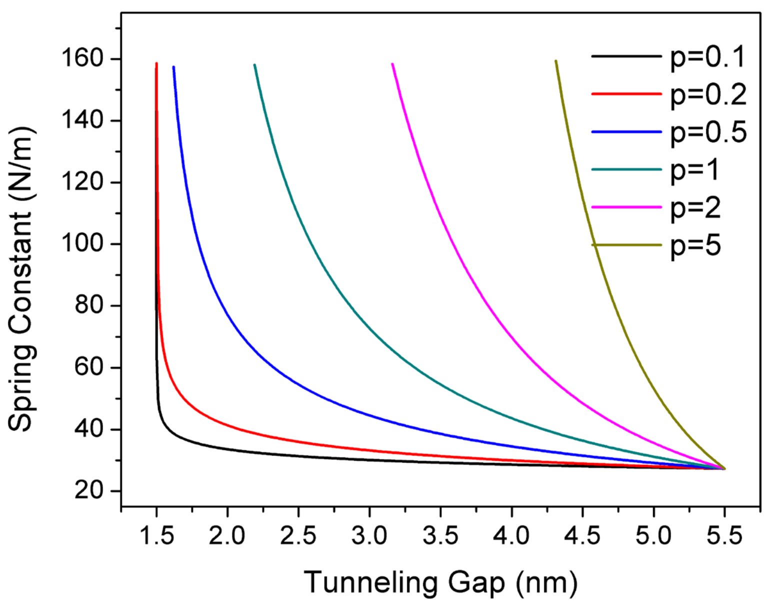
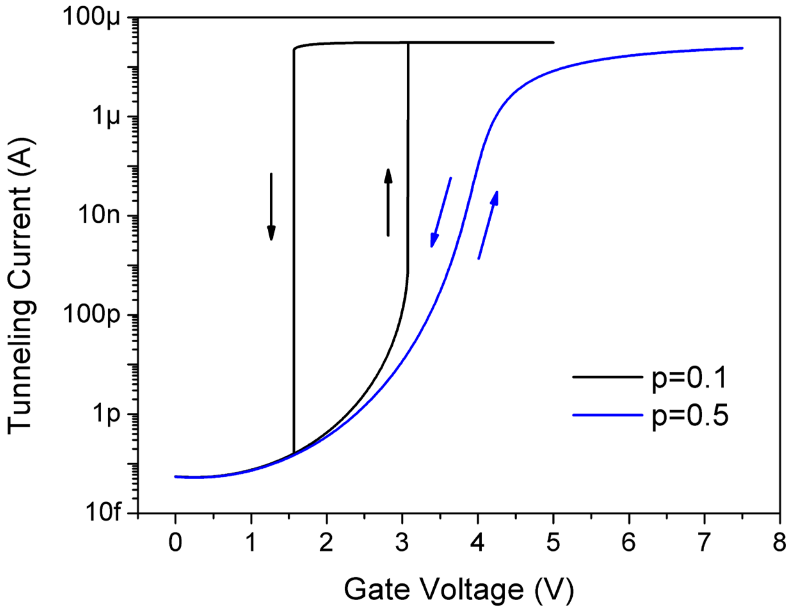
Squitch modeling

equivalent spring constant of molecular layer

$$k_{\mathrm{f}}(d_{\mathrm{S,D}}) = \left(\frac{d_0 - d_{\mathrm{thr}}}{d_{\mathrm{S,D}} - d_{\mathrm{thr}}}\right)^p \frac{E_{\mathrm{m}} S_{\mathrm{S,D}}}{d_0}$$

k_f : equivalent spring constant of molecular layer
$d_{S,D}$: thickness of molecular layer at the source (S) or the drain (D) under compression
d_0 : initial thickness of molecular layer
d_{thr} : critical thickness when abrupt stiffening occurs
E_m : Young's modulus of uncompressed molecules
$S_{S,D}$: area of the source (S) or the drain (D)





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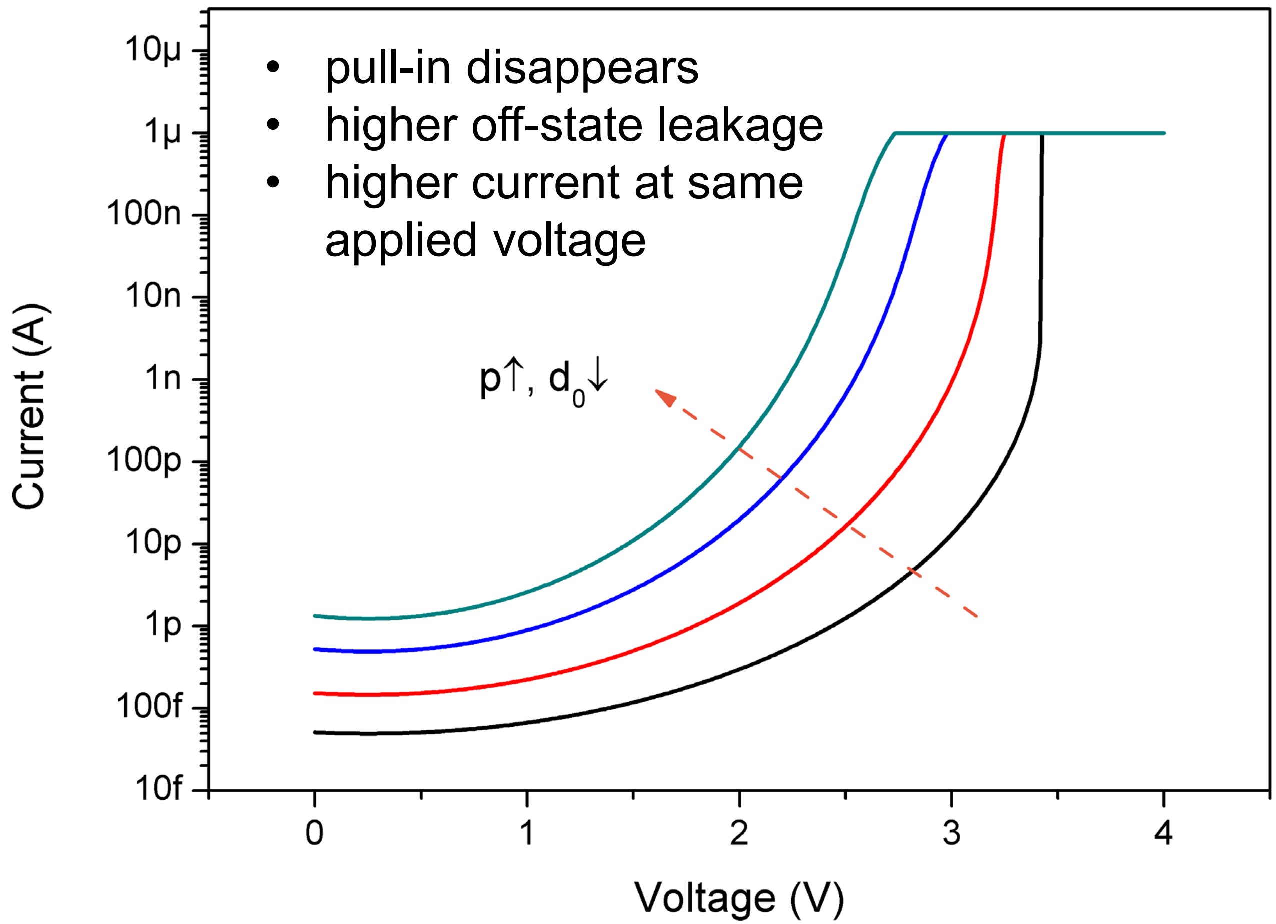
Squitch modeling

Over cycles of compression, molecular layer becomes thinner ($d_0\downarrow$) and molecules stiffen gradually ($p\uparrow$)



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Future work

1. Further investigation on degradation of molecular layer – factors include quality of assembly, accumulative joule heating, oxidization, effect of moisture, etc.

2. Graphene-based multi-terminal squitch – replace Au nanorod with graphene and eliminate the trapping step towards a high throughput (permits more rapid experimentation on molecular behavior and circuit implementation)

3. Study on dynamics of squitch – theoretical and experimental evaluation of switching delay

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Thanks!

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