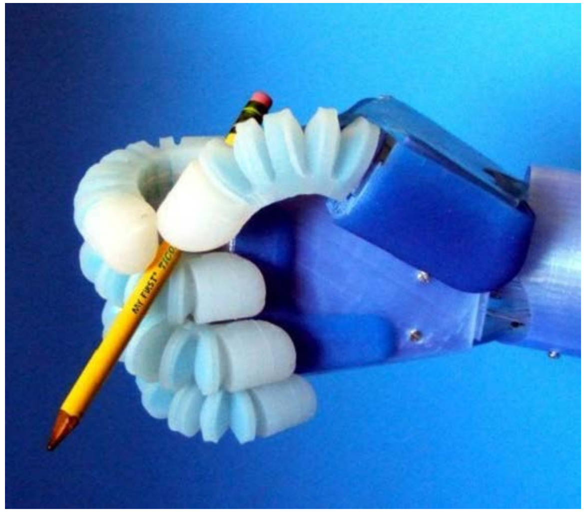
# High Force, Low Voltage Nano-scale Capacitor Actuator Performance in Dilute Salt Solutions

Lisanne de Groot, Carnegie Mellon University
James Pikul, Singh Center for Nanotechnology, University of Pennsylvania

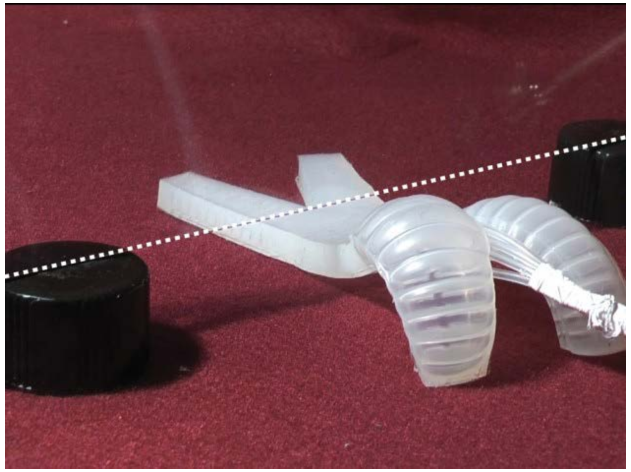
# Soft robotics provide versatile robots

http://www.trossenrobotics.com/p/phantomx-ax-12-reactor-robot-arm.aspx


https://tfwiki.net/wiki/Optimus_Prime_(G1)



http://techgenmag.com/2014/07/soft-robotics/



https://harvardmagazine.com/2011/12/soft-robots-starfish-variatio

# Flexible robots require new actuators

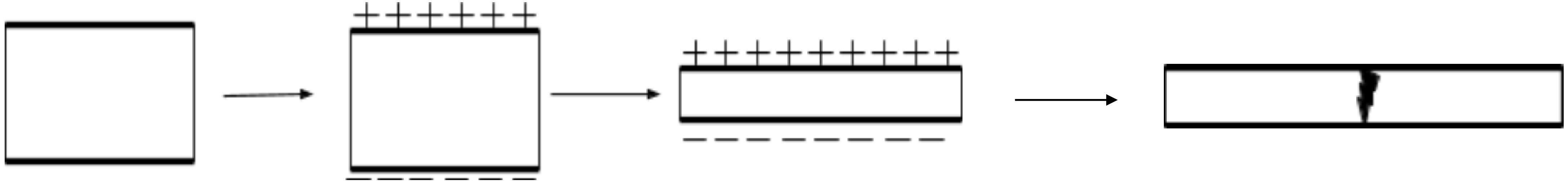
Power sources

Physical parts

Controlling System

Actuators

# Dielectric elastomeric actuators require high voltages and can break

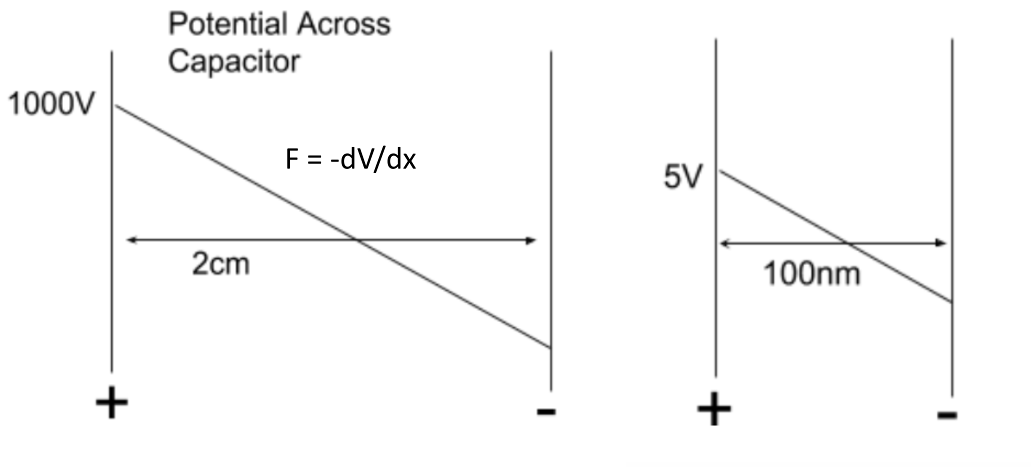


Irreversible polymer damage

Requires high voltages → Bulky power sources → Limited mobility

Smaller Actuators

# Smaller actuators require less voltage, but must be redesigned




Same force, less voltage!

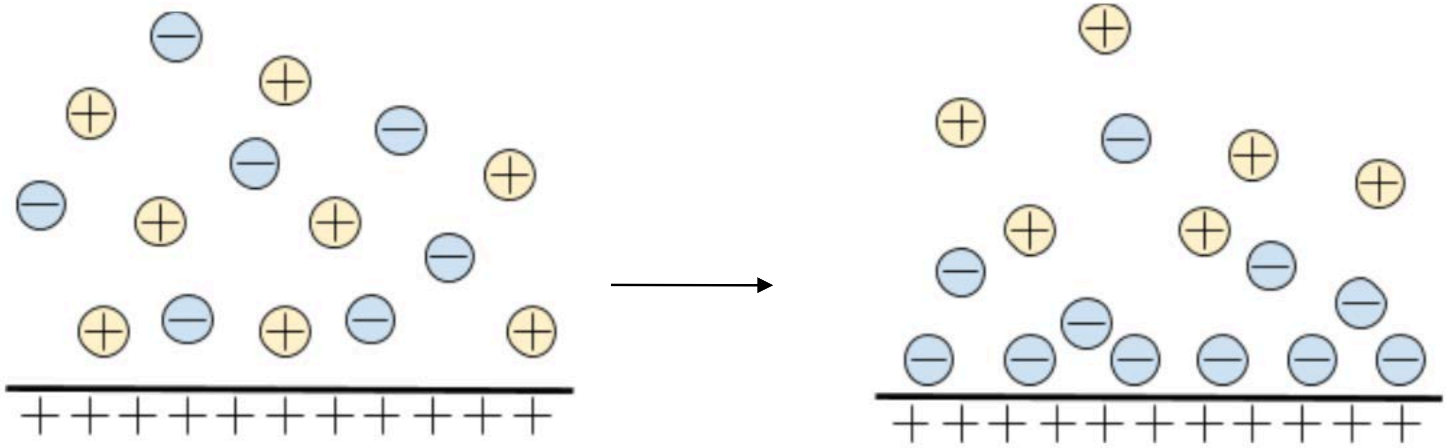
http://www.matai.co.jp/english/product/resin/resin1

https://hk3.weebly.com/the-chlorine-test.html

No thin, durable elastomers on the nano-sale thickness

Salt solution provides self-healing

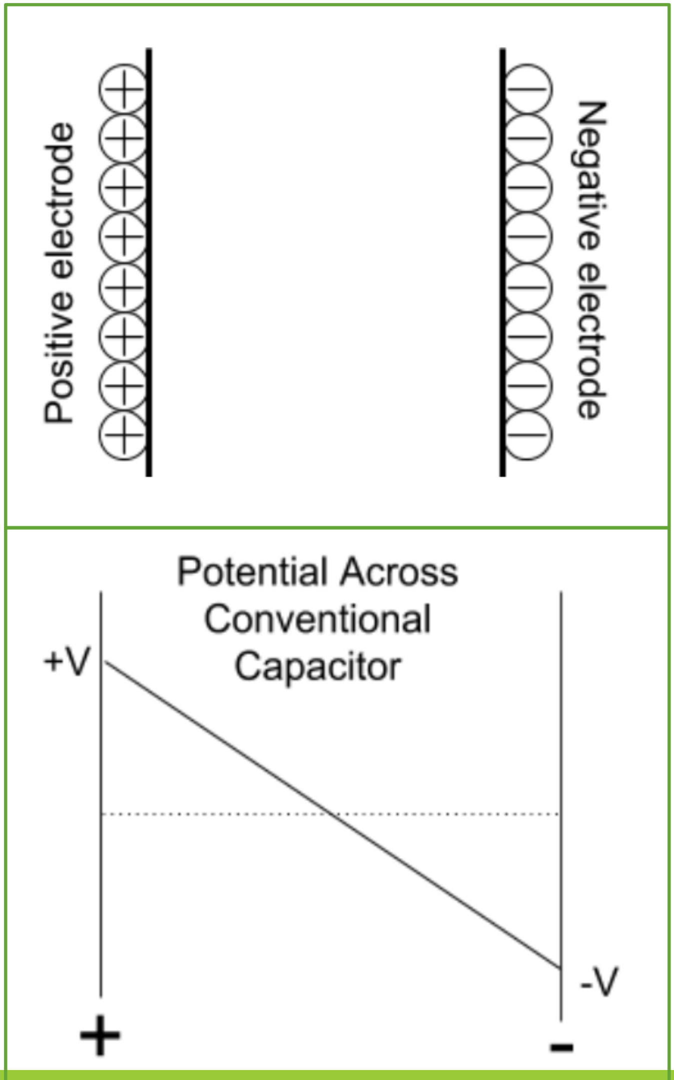
# Ions accumulate to charged surfaces to form a double layer in solutions



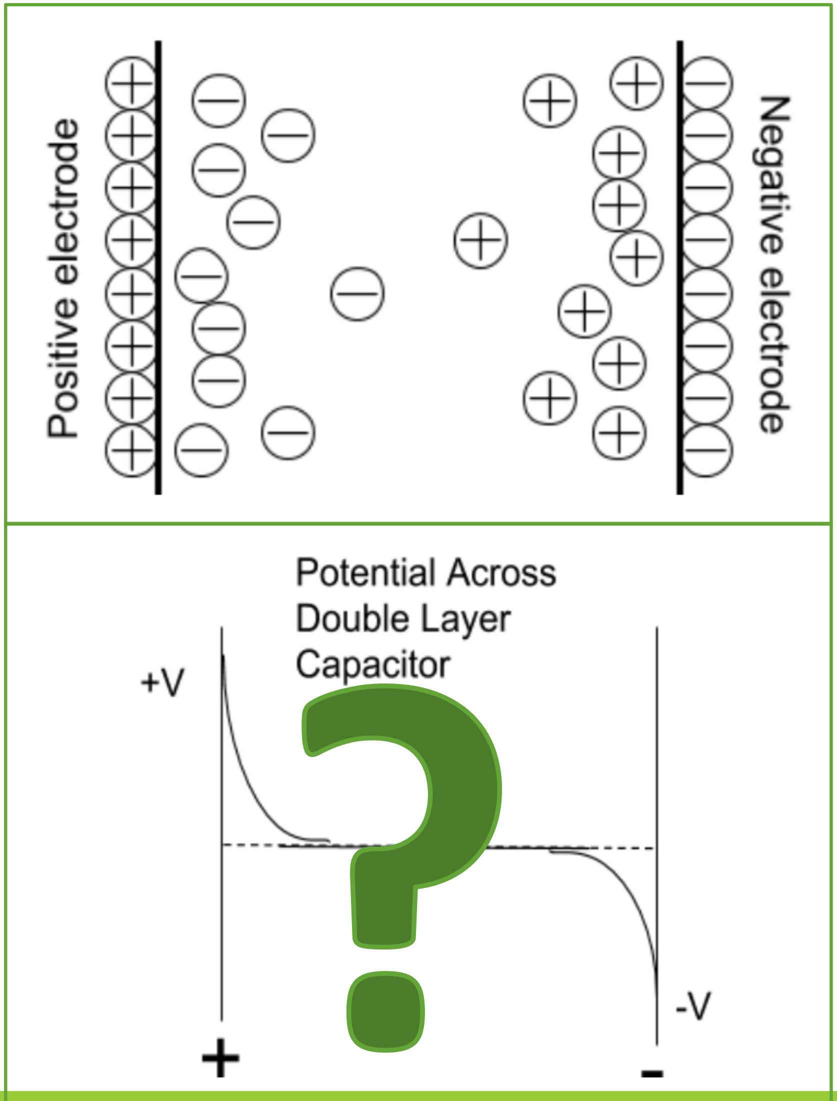
Counterions accumulate on charged surface

# Modelling double layers gives an idea of the forces involved

**Conventional Parallel Plate Capacitor**




**Double Layer Capacitor**




Theoretical model of the force from a double layer capacitor

# Theoretical electric field determined from potential energy equation

To get the force, we first need the capacitance and electric field:

$$F = E * Q$$

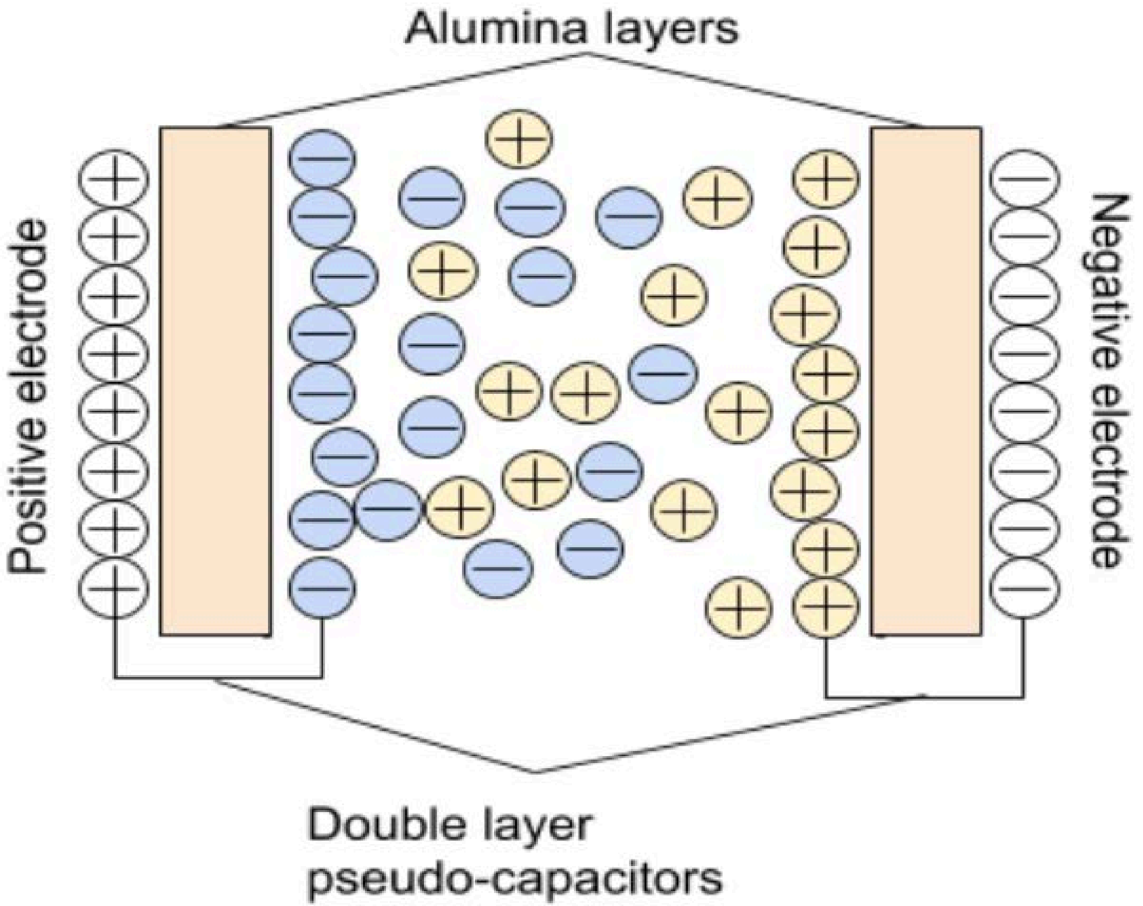
$$Q = C * V$$

- The electric field can be found:

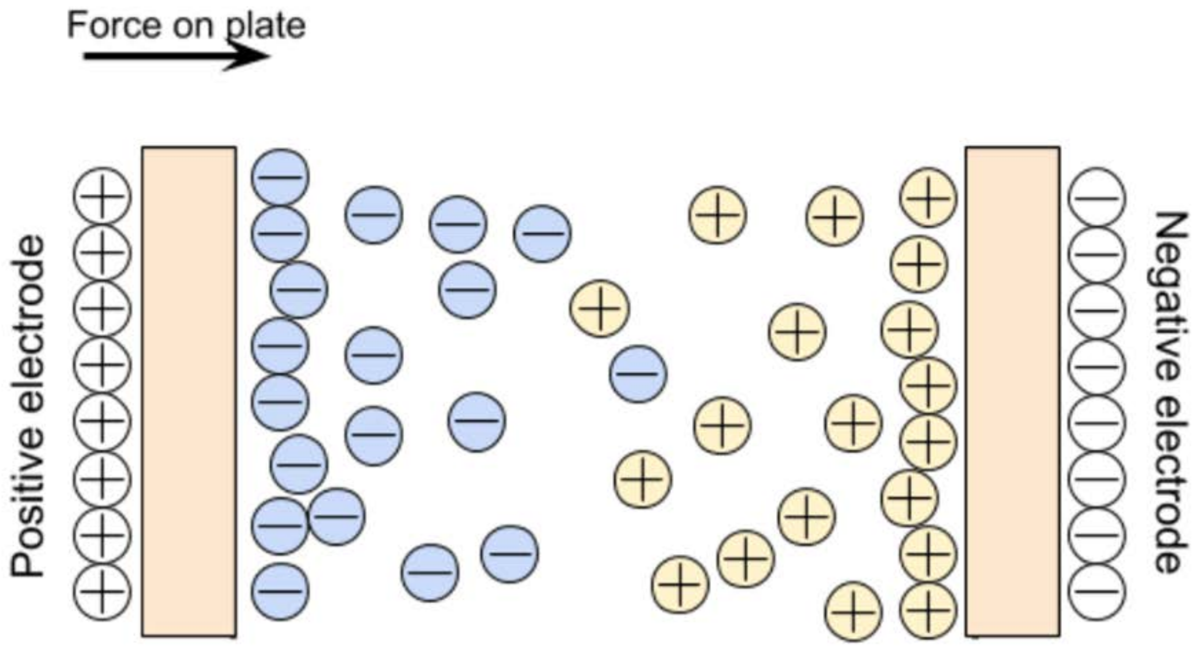
$$\mathrm{E(h)} = -\nabla\psi$$
$$= V\kappa(e^{-\kappa h} + e^{\kappa(d-h)})$$

$$C = \varepsilon\varepsilon_0 \frac{A}{d} * \frac{1}{2}$$

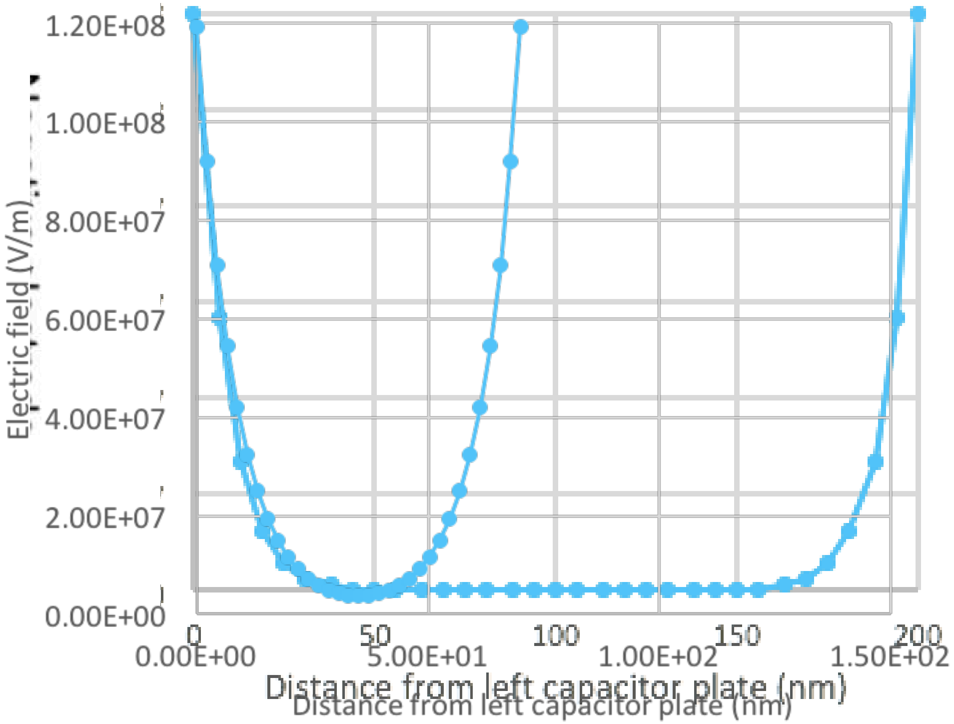
$$= 2.89 * 10^{-7}\ F$$



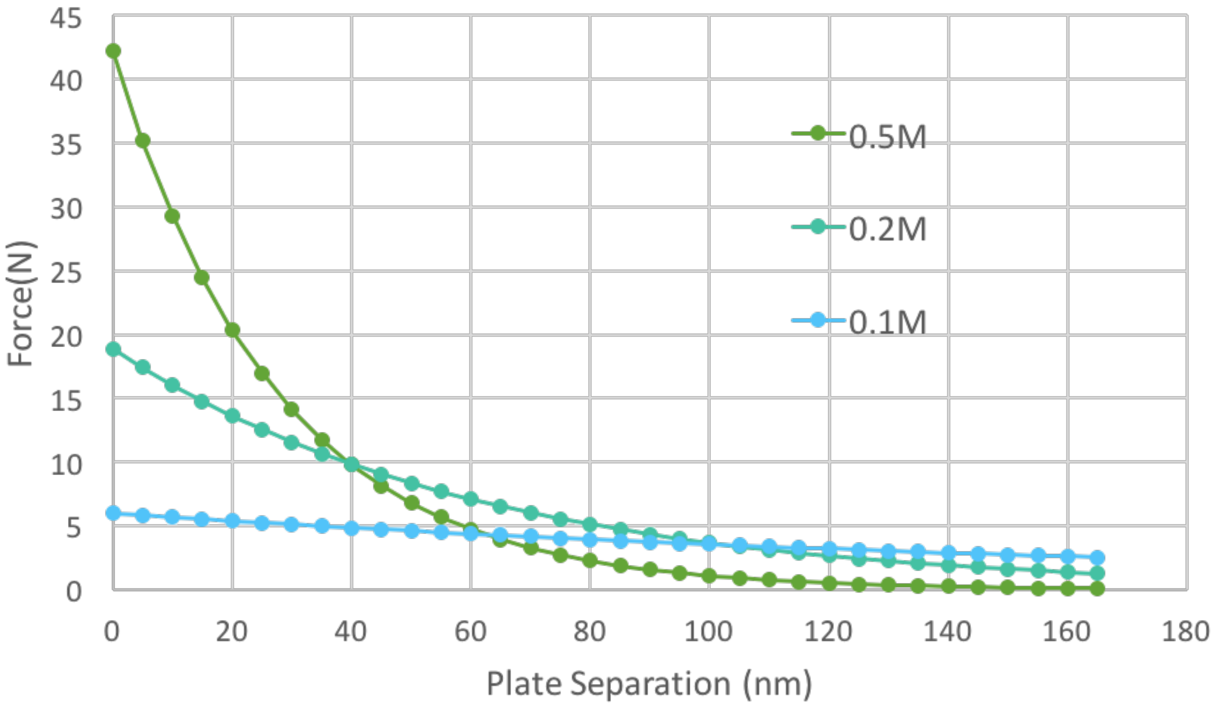
# Electric field evaluated at the midpoint to get the force

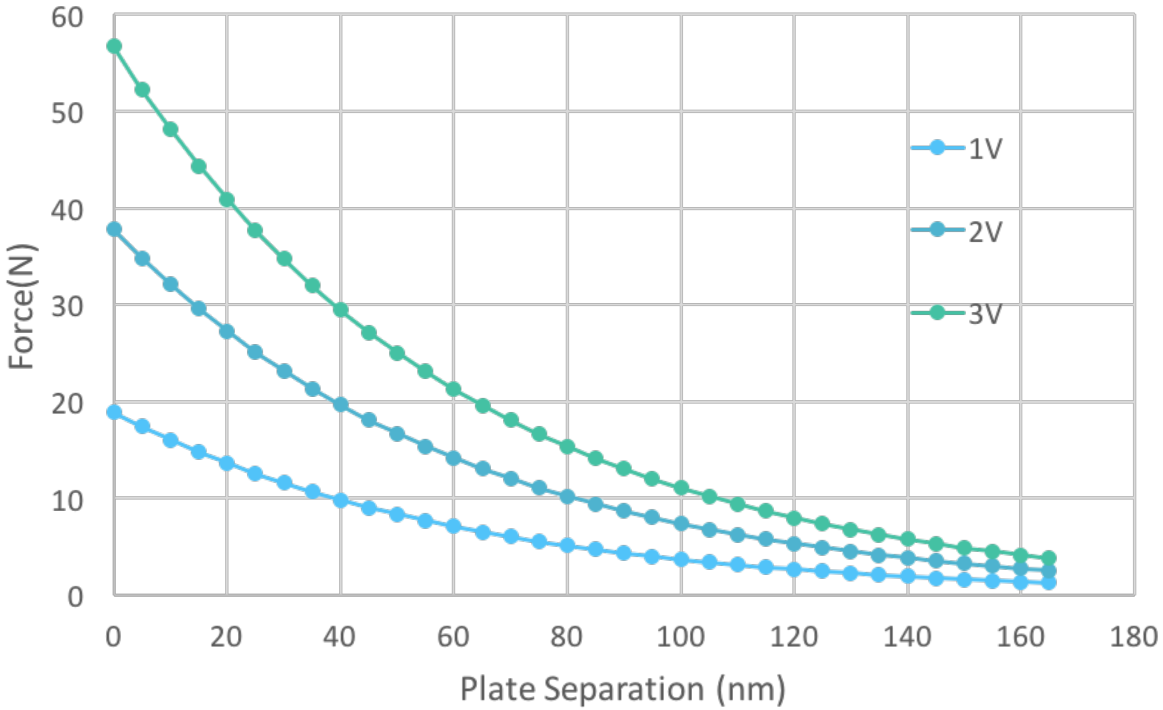



Net force on capacitor plate

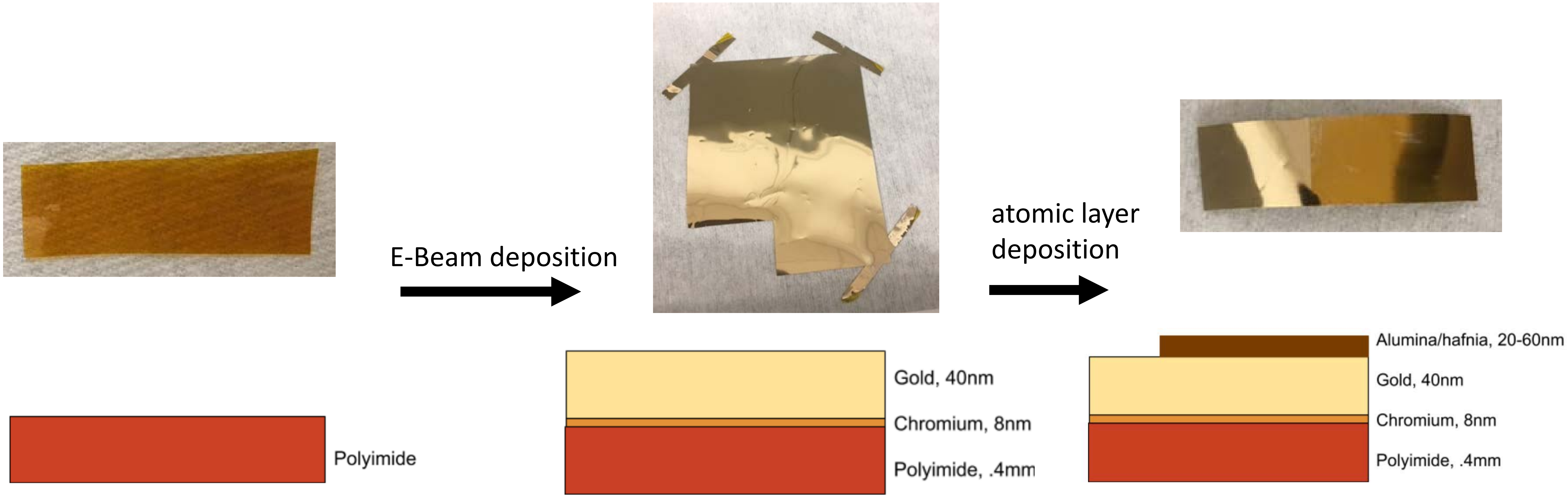


# Force increases with voltage, and changes shape with concentrations

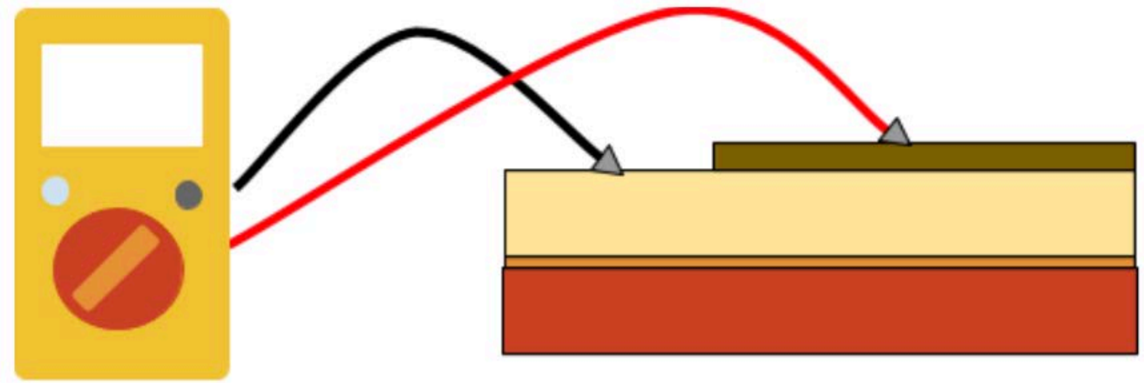


# Preliminary actuators made with gold on polyimide



# Resistance measurements tell insulating properties of alumina/hafnia layer

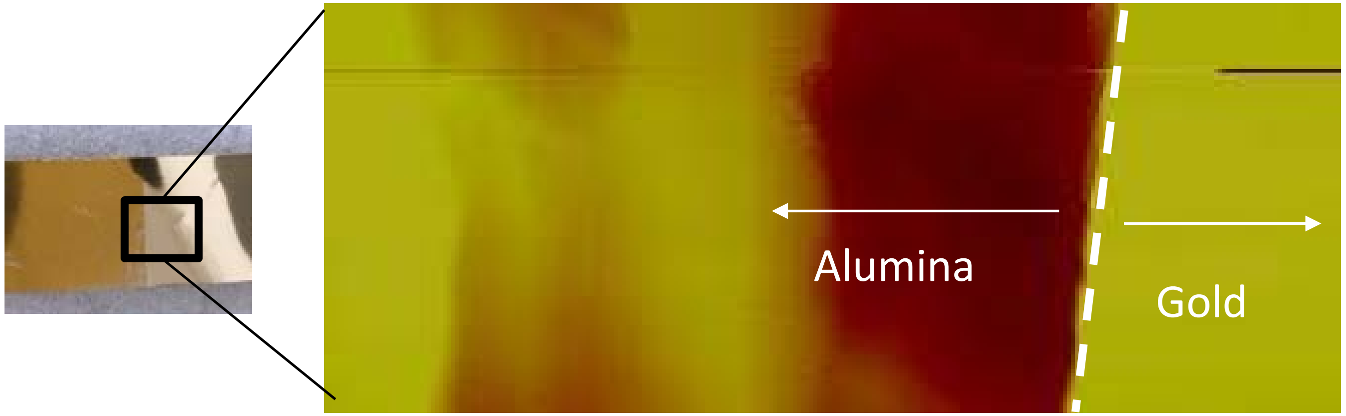


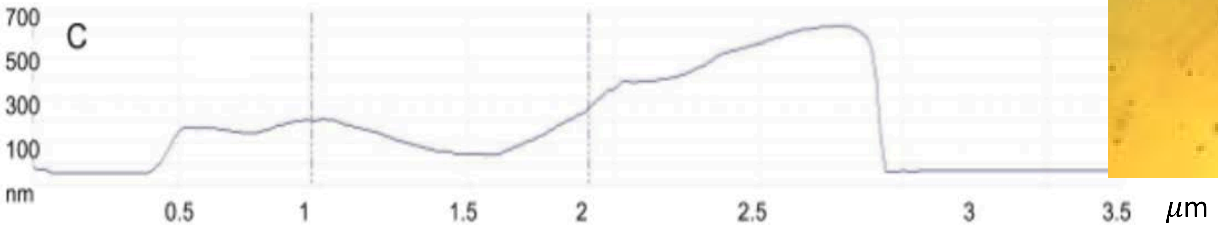
If a resistance is measured, the alumina/hafnia layer is shorting

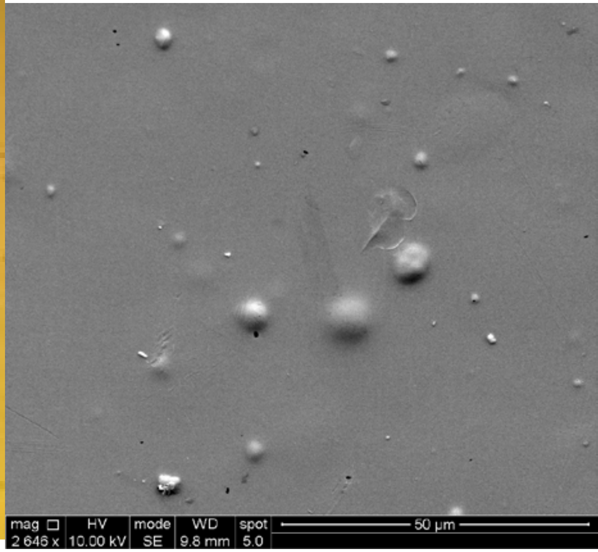
Higher resistance -> better insulator.

| Material | Thickness (nm) | Resistance (Ω) |
|---|---|---|
| Alumina | 30 | 9.6 ± 1.7 (N=6) |
| Hafnia | 15 | 10.0 ± 1.7 (N=6) |
| Alumina | 20 | 14.2 |
| Hafnia | 20 | 8.2 ± 2.4 (N=6) |
| Alumina | 60 | Not measurable |

# Samples had uneven and dirty coatings

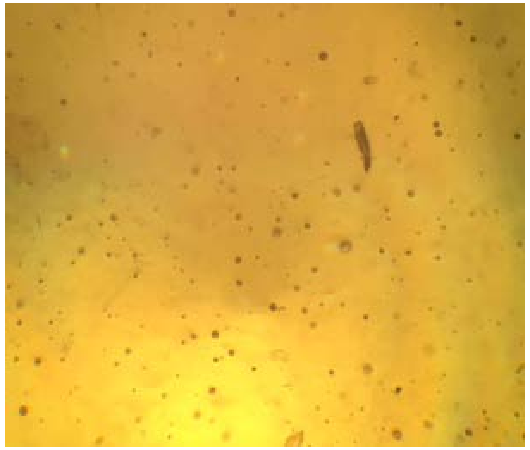


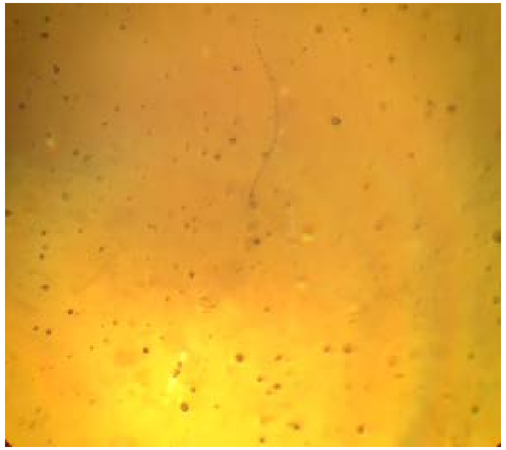



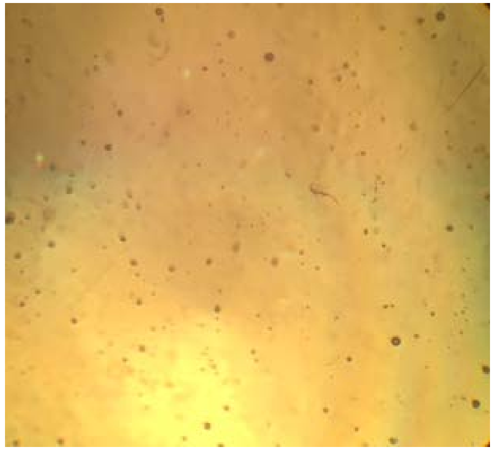



# By cleaning the samples in between each step, surface became somewhat cleaner

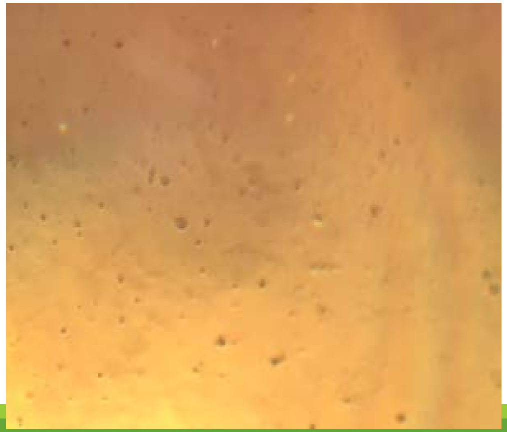
Samples without cleaning







Samples with cleaning



# Summary and future directions

- So far:
  - developed model for determining the expected force
  - Fabricated electrode sheets
- Clean up electrode surface
- Test in air
- Test in salt solution

# Acknowledgements

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