Corrosion resistant ALD coatings

EE412 Final Presentation

Joey Doll
Alex Haemmerli
Mentor: J Provine

Electrochemical Corrosion

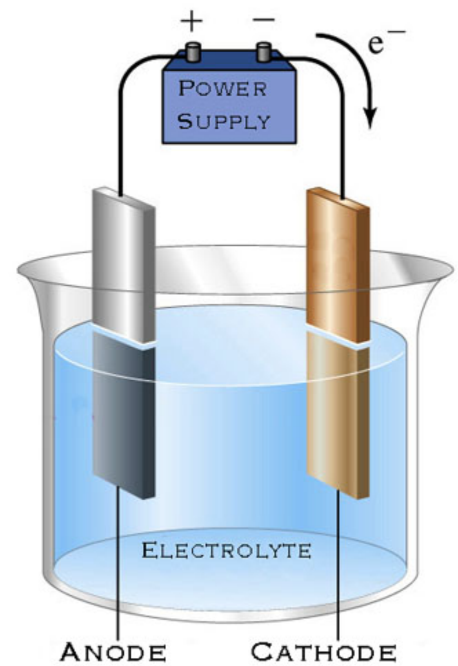
Anode reaction:

$$yM + xH_2O \rightarrow M_yO_x + aH_2 \uparrow + bH^+ + be^- \qquad (1)$$

Cathode reaction:

$$2H_2O + 2e^- \rightarrow H_2 \uparrow + 2(OH)^- \qquad (2)$$

$$O_2 + 2H_2O + 4e^- \rightarrow 4(OH)^-. \qquad (3)$$

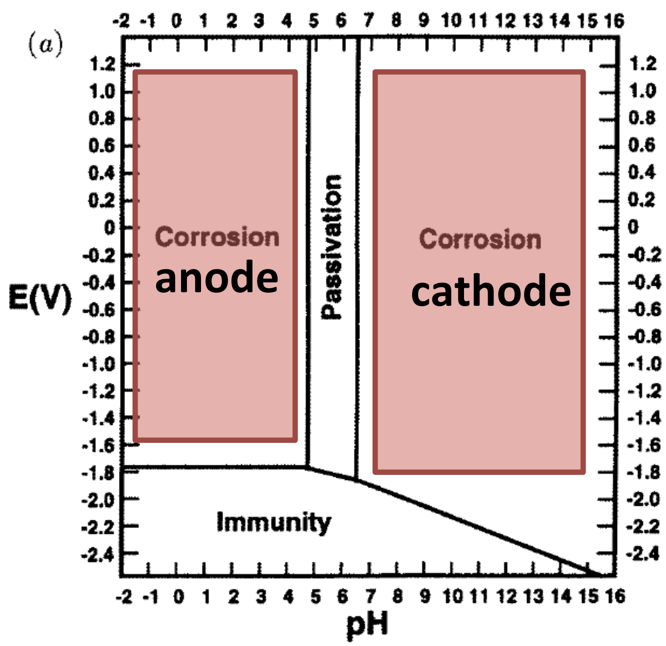


1) Oxidation and proton production at the anode
2) Hydroxide ions produced at cathode
3) Electrochemical corrosion requires current flow

From "Corrosion-induced degradation of microelectronic devices", Osenbach

Electrochemical Corrosion

Pourbaix diagram for Al



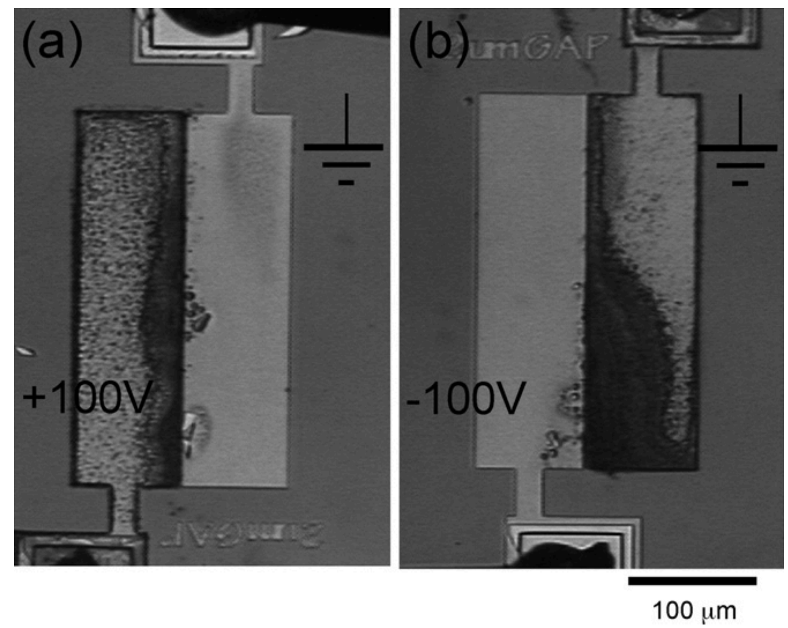
Al cathode reaction:

$$2Al + 6H^{+} \rightarrow 2Al^{+3} + 3H_2\uparrow$$

$$2Al^{+3} + 3H_2O \rightarrow 2Al(OH)_3 + 3H_2O\uparrow.$$

(Al corrodes at the anode or cathode)

Poly-Si cathodic corrosion



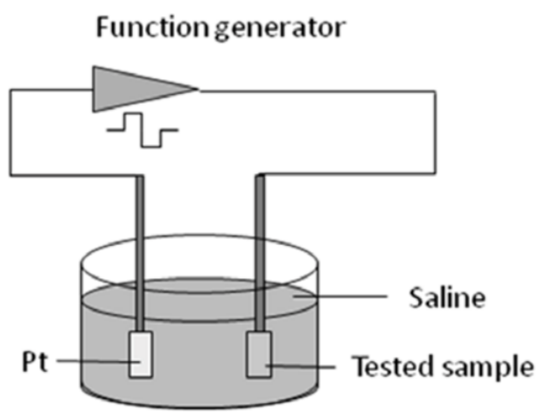
Corrosion isn't limited to non-nobel metals…

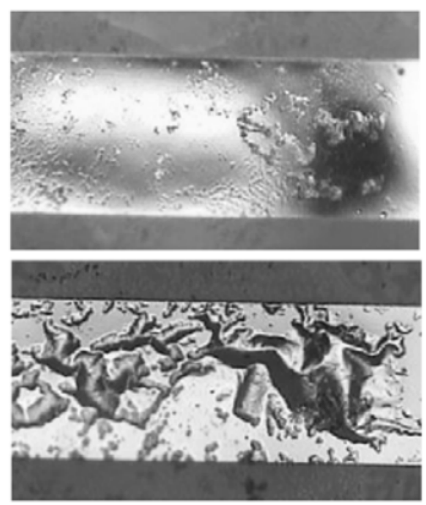
M. Hon et al. Sens. and Act. A (2008)

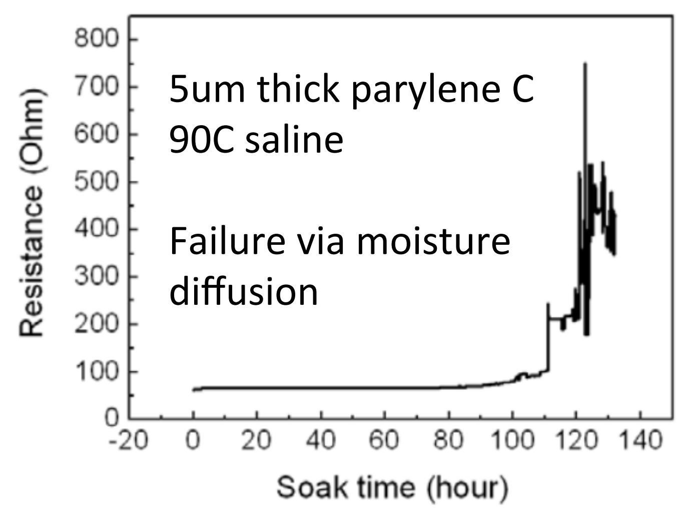
Common Passivation Options

- LPCVD dielectrics
- PECVD dielectrics
- LPCVD polymers (parylene)

- Considerations
  - Deposition temperature
  - Conformality/thickness/mechanics
  - Electrical properties (breakdown, leakage)
  - Moisture permeability

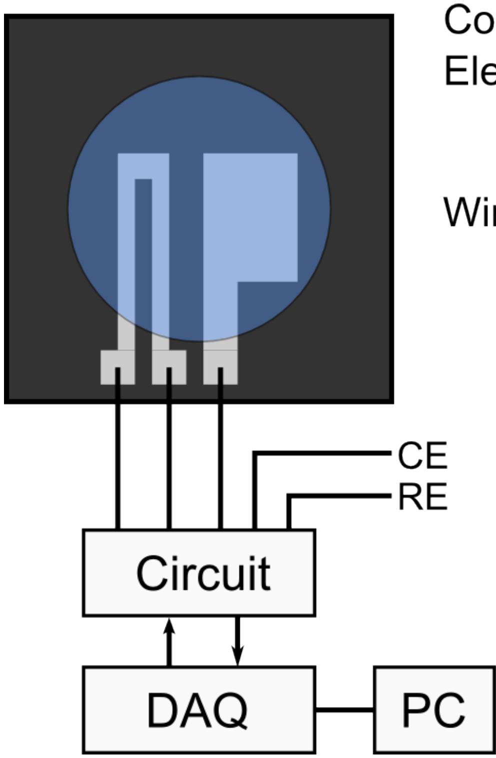


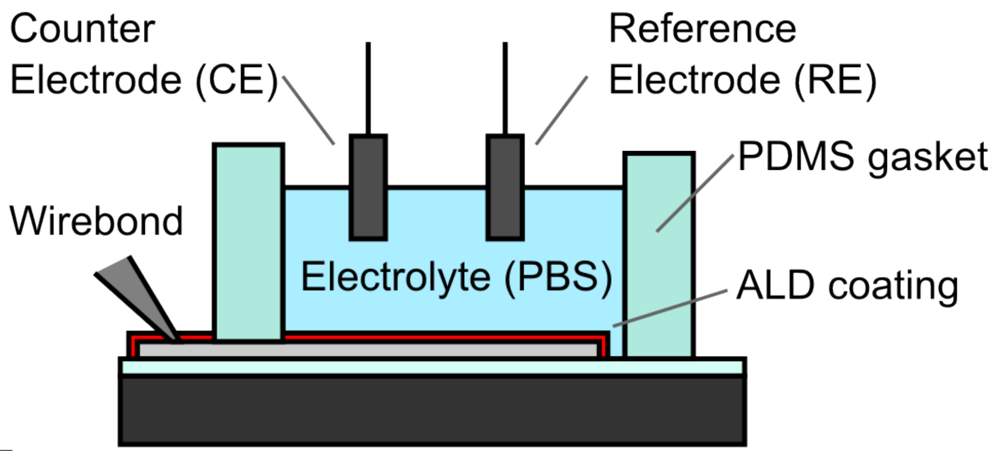




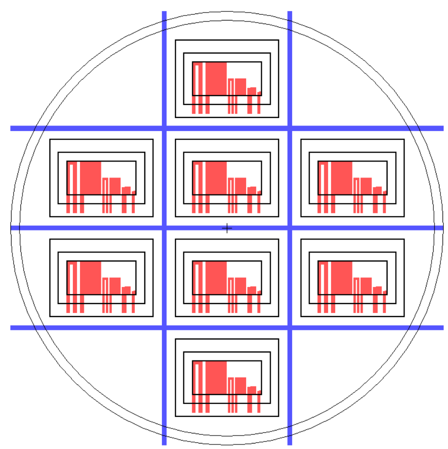
From “Corrosion behavior of parylene-metal-parylene thin films in saline”, W. Li et al, ECS Transactions (2008)

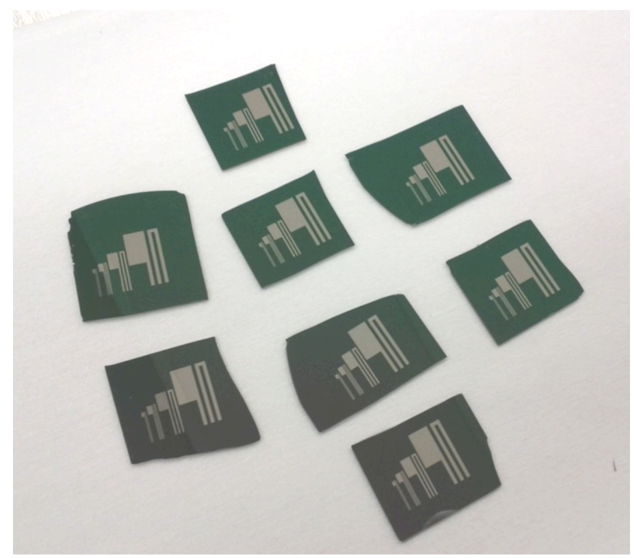
Our Approach



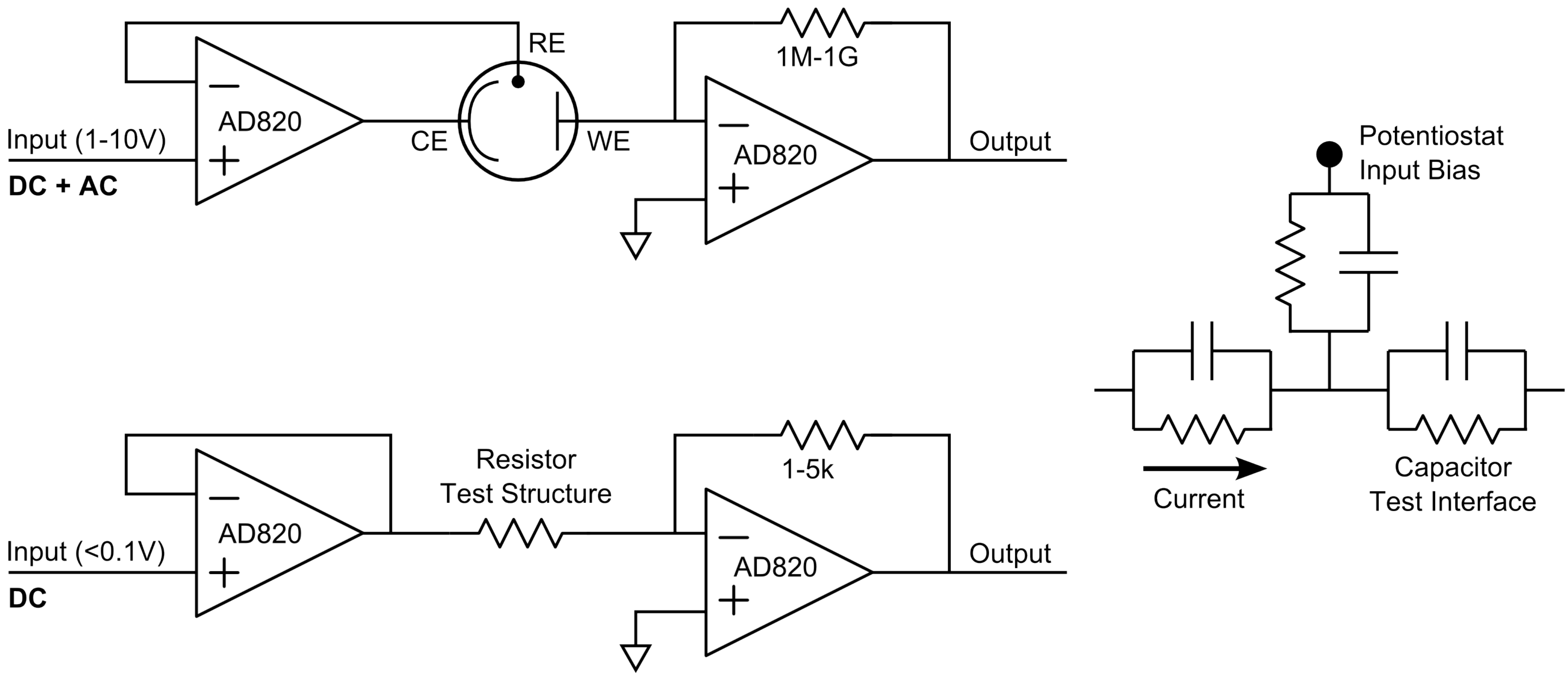


Performance metrics:
1) Capacitor leakage current
2) Capacitor interface stability
3) Time to resistor failure





Measurement Circuit

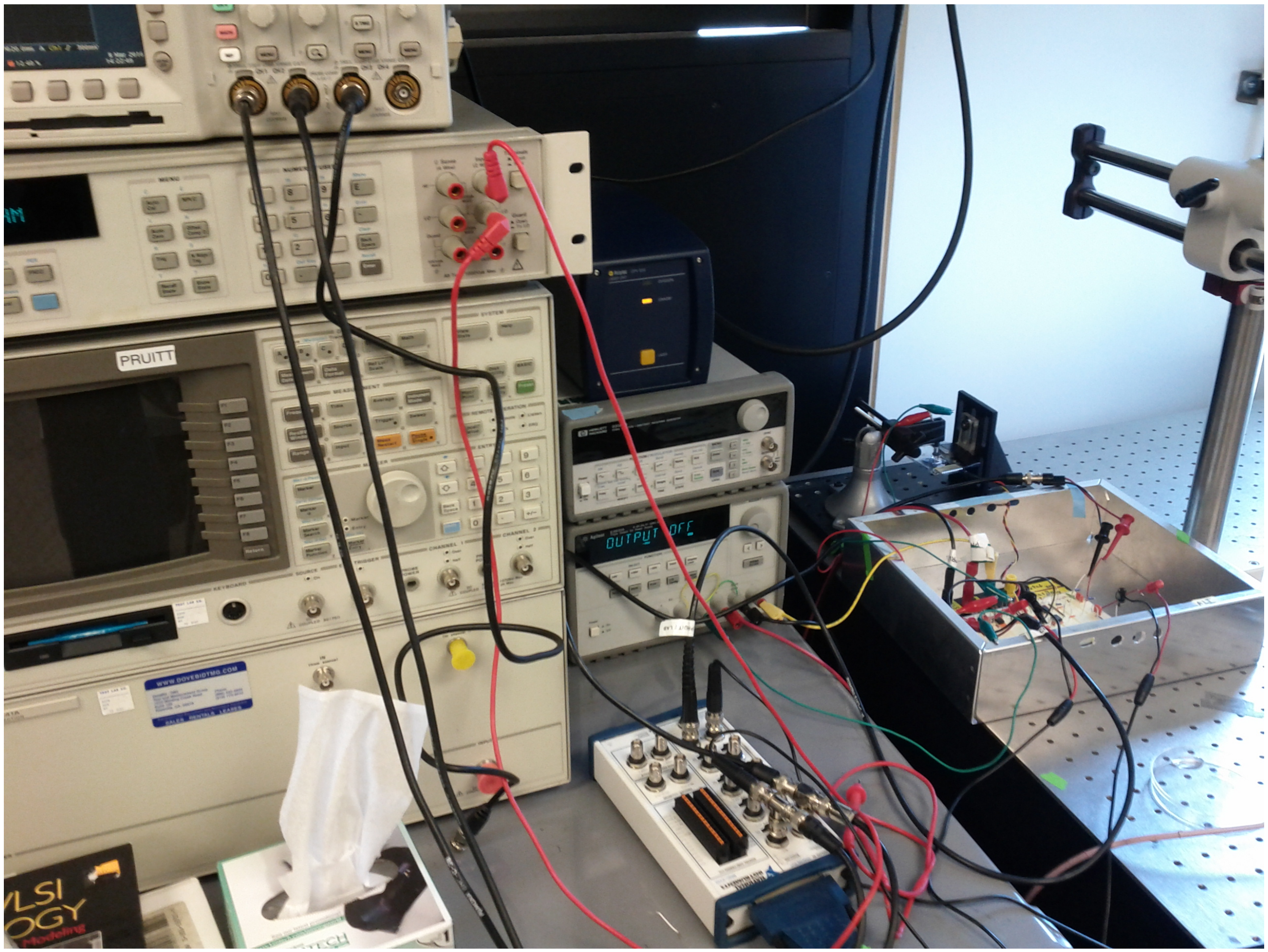


Experiments:

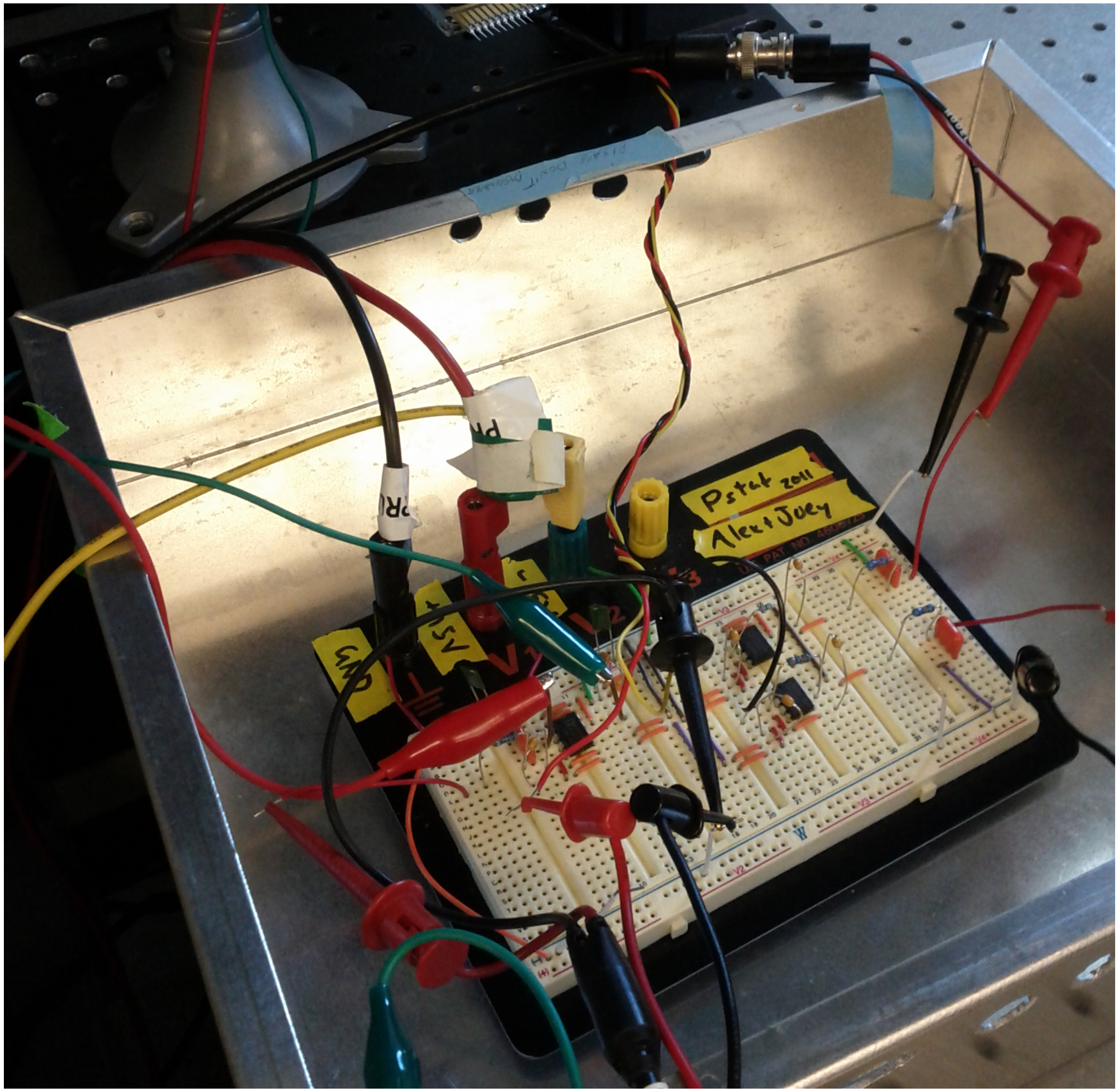
1) Long-term corrosion test

2) Ramped breakdown test

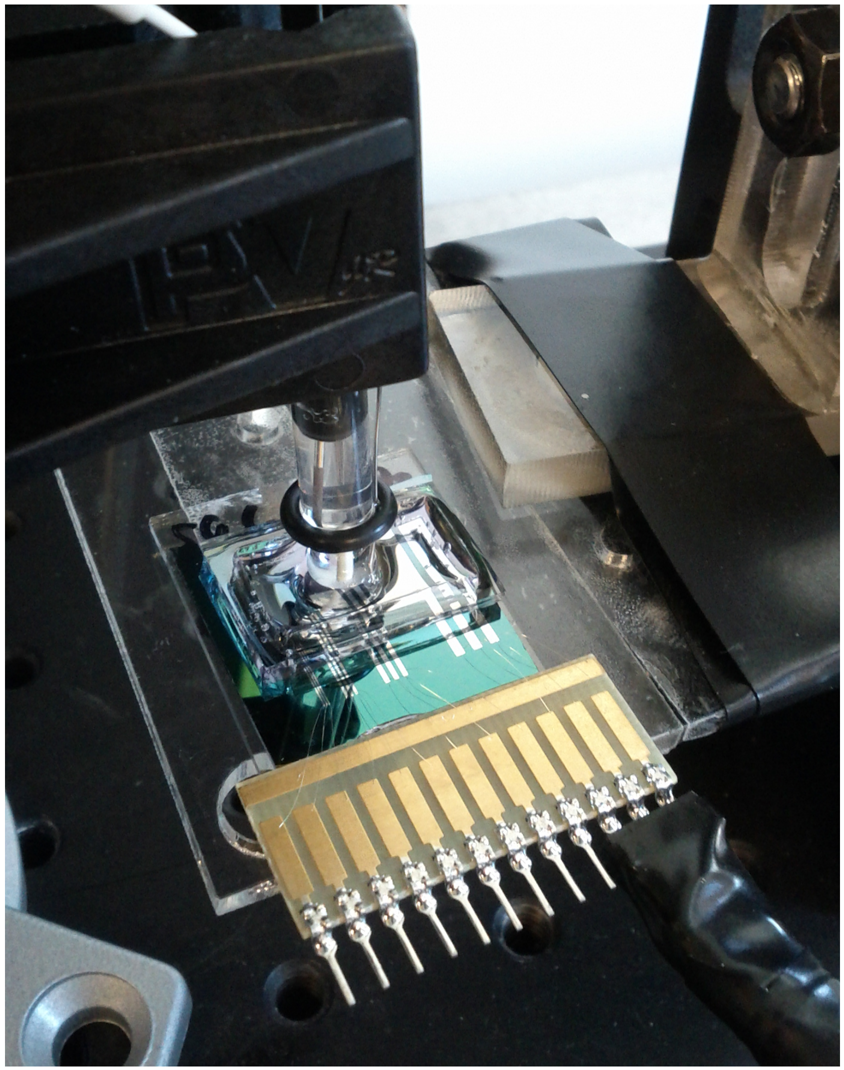
Experimental setup



Experimental setup

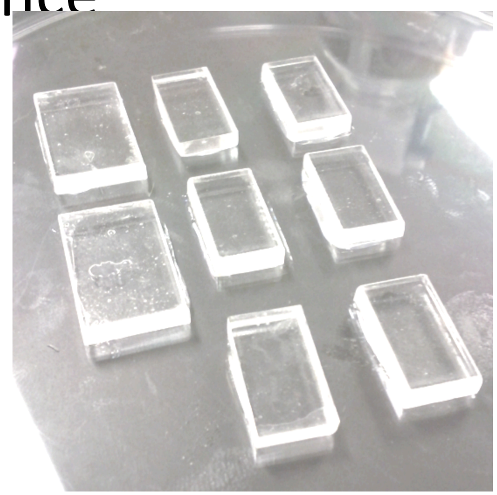


Experimental setup

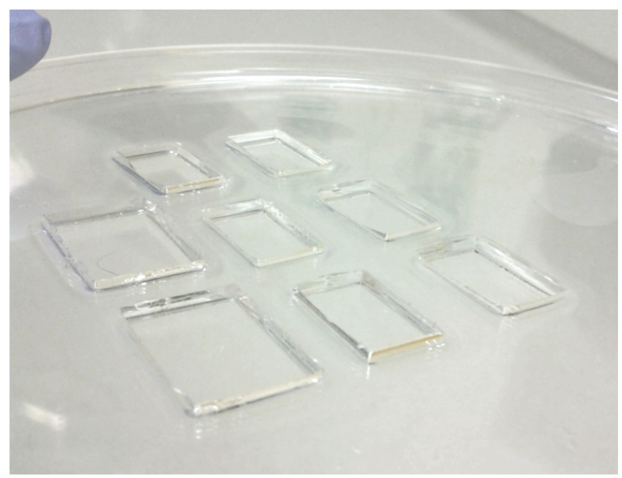


PDMS Gasket Fabrication

- Cut acrylic blocks using a laser cutter
- Pour PDMS around the blocks and cure
- Peel out and place on the sample
  - PDMS leaves a hydrophobic residue, so just place once



Acrylic squares



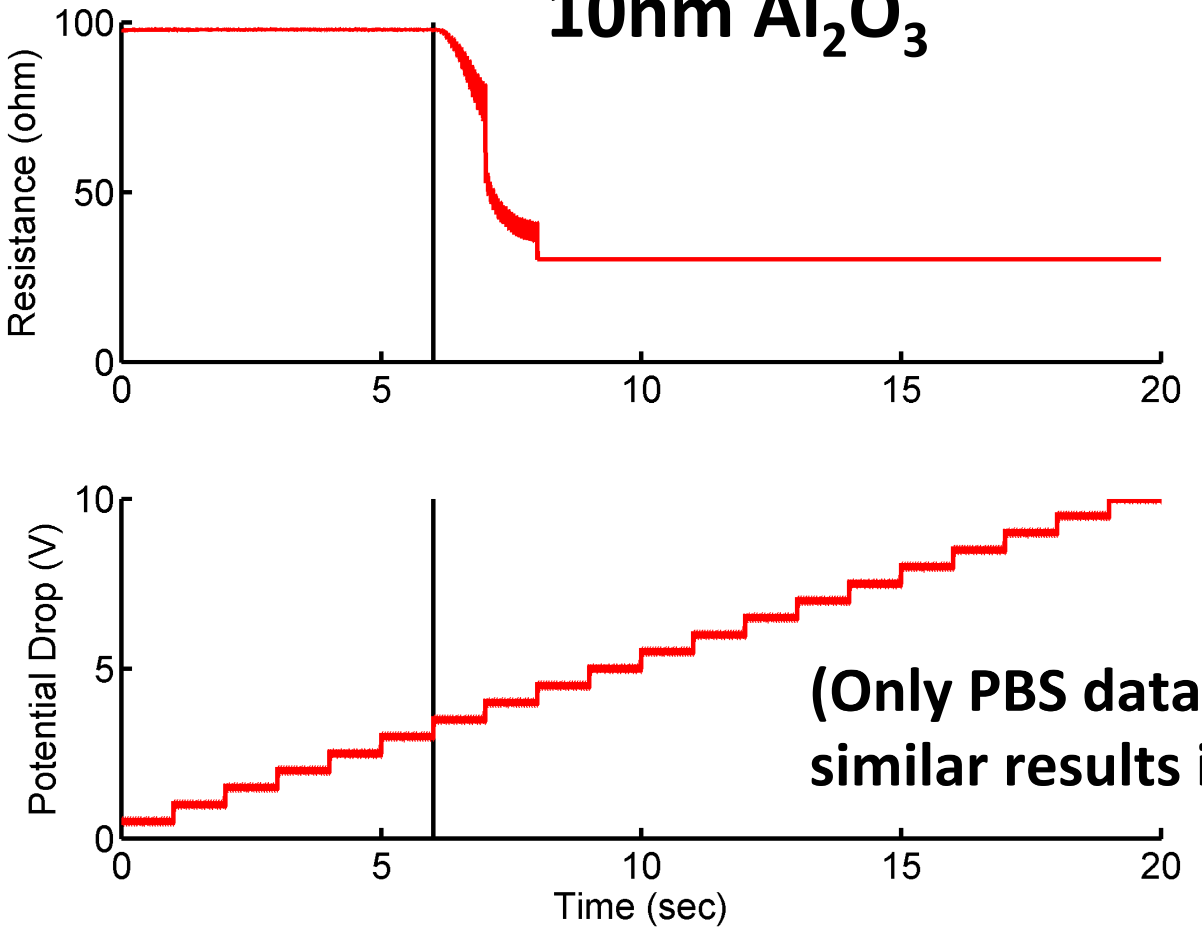
After PDMS curing

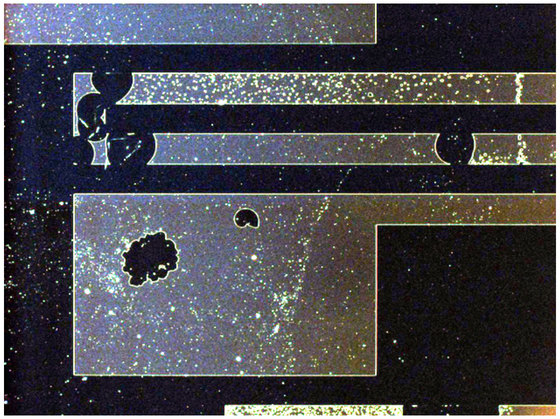
Film Investigations

- Films: Al_2O_3, HfO_2, ZrO_2
  - Electrical properties: $Al_2O_3 > HfO_2 \overset{?}{>} ZrO_2$
    - From EE412 Fall 2010 (Yi Wu, Shimeng Yu, Shuang Li)
  - Corrosion properties: $Al_2O_3 < HfO_2 \overset{?}{<} ZrO_2$
- Thicknesses: 5nm – 20nm
  - Single and multilayer films
- 8 samples tested to date, 22 more prepped

Ramped Breakdown Test

10nm Al_2O_3

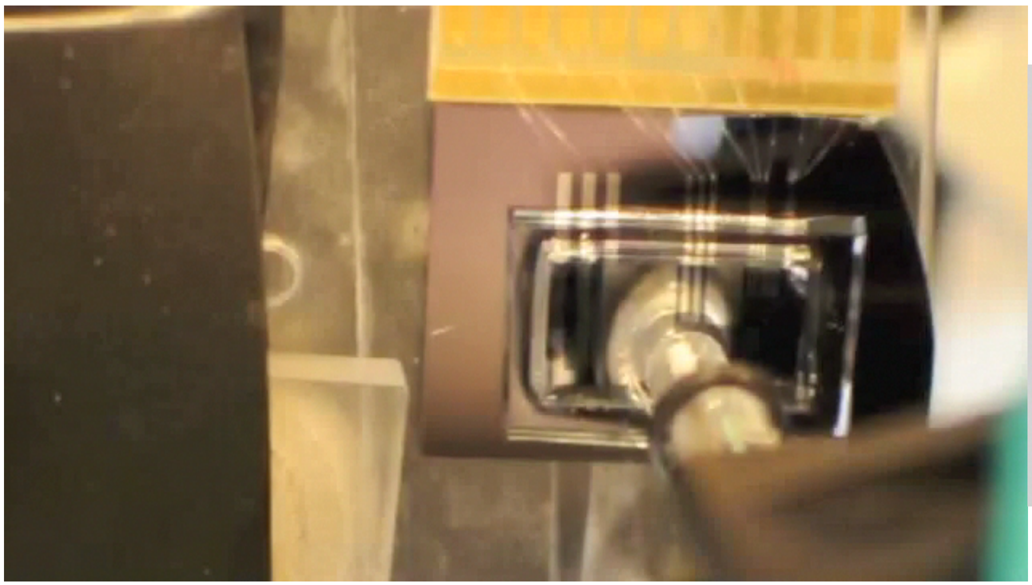


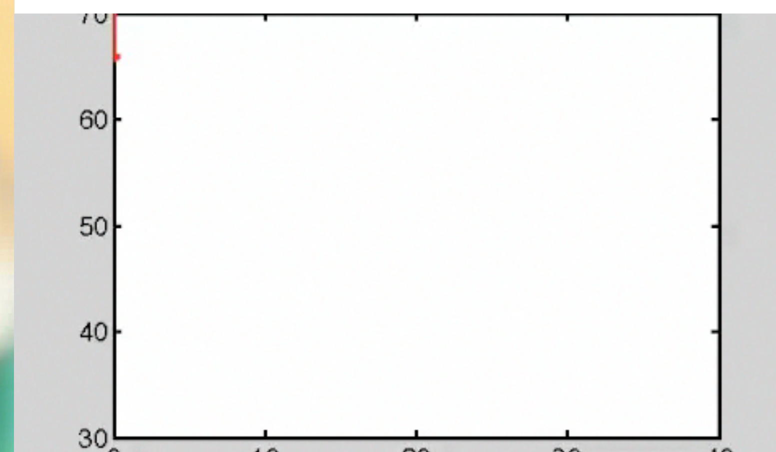


(Only PBS data shown, similar results in DI water)

1) **The resistor shorts out when corroded (due to the 3-wire setup)**
2) **The capacitor is more sensitive to defects due to its higher impedance**

Illustration of failure





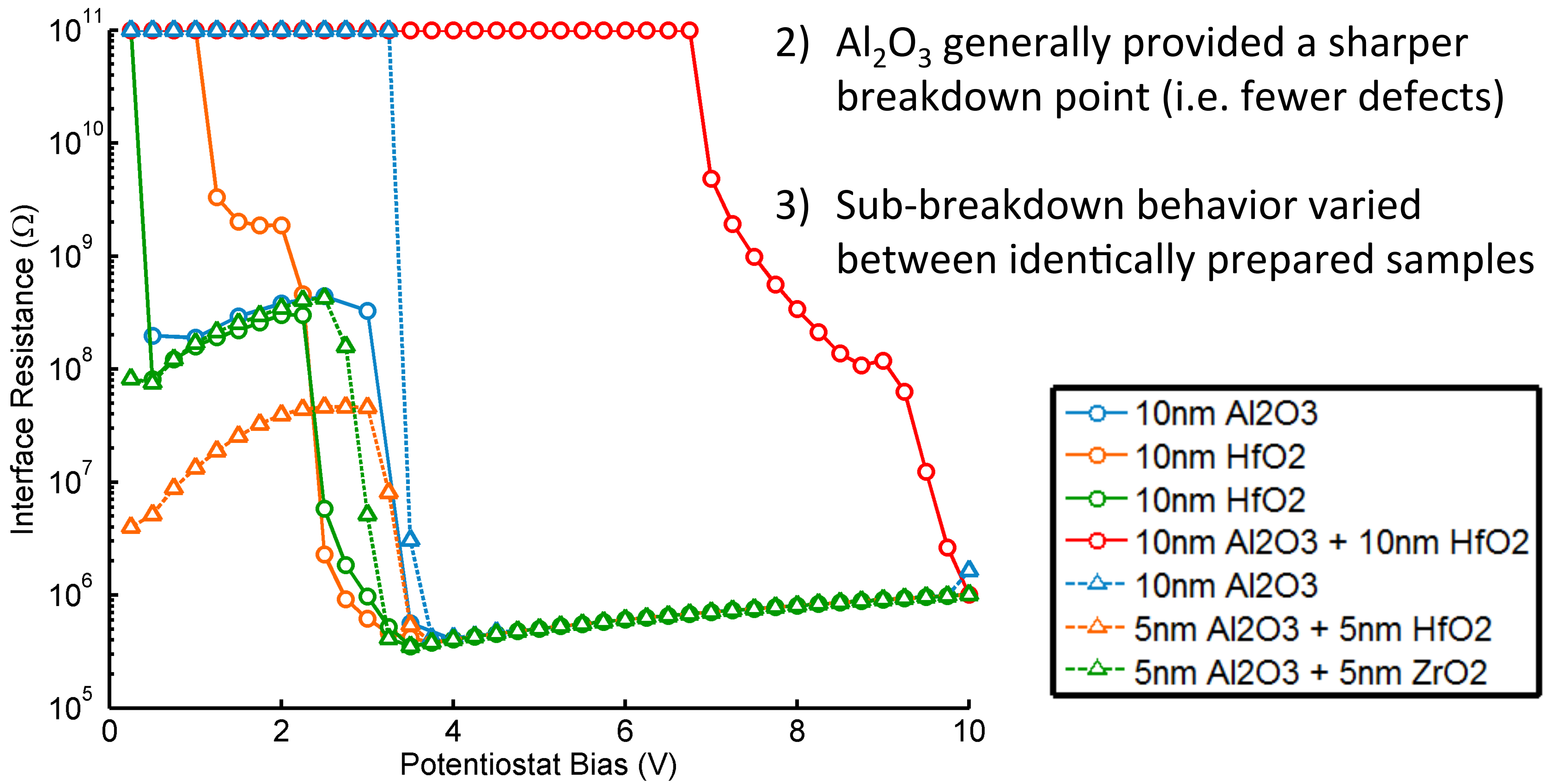
Failure occurs at on spot first and expands quickly.

Breakdown comparison

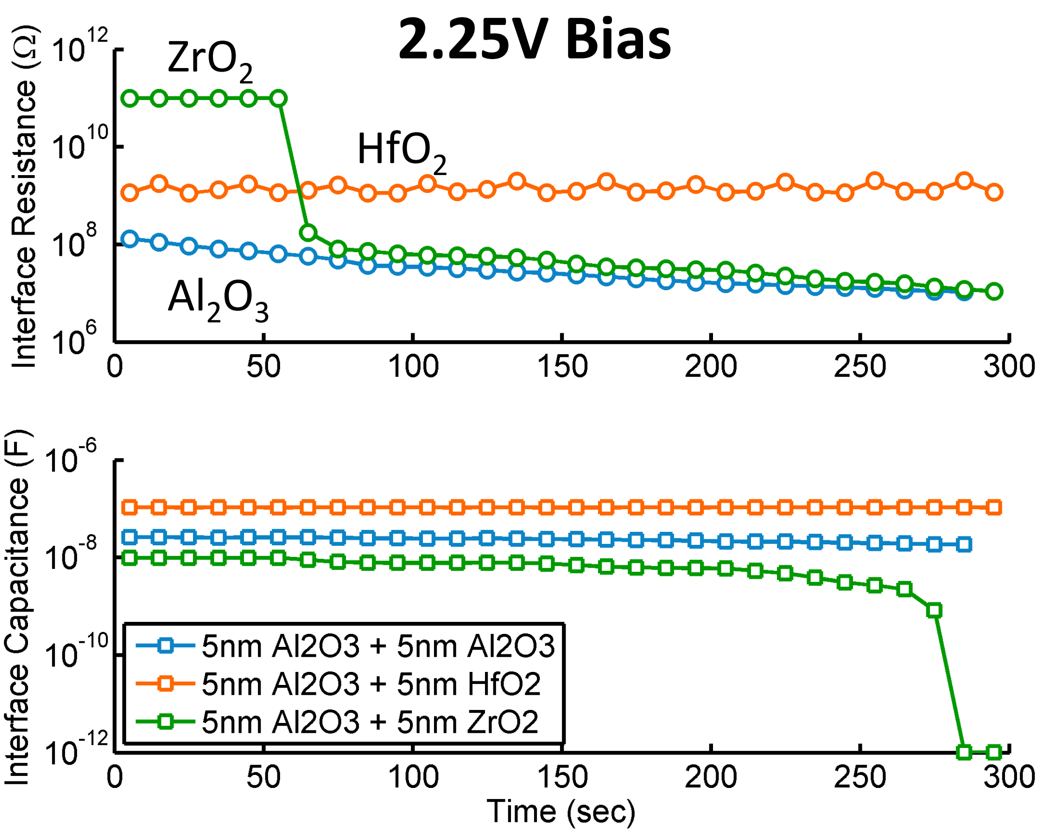
1) All films broke down @ 0.25-0.35 V/nm (vs. 0.8-1.5 V/nm in EE412 Fall 2010)

2) Al_2O_3 generally provided a sharper breakdown point (i.e. fewer defects)

3) Sub-breakdown behavior varied between identically prepared samples



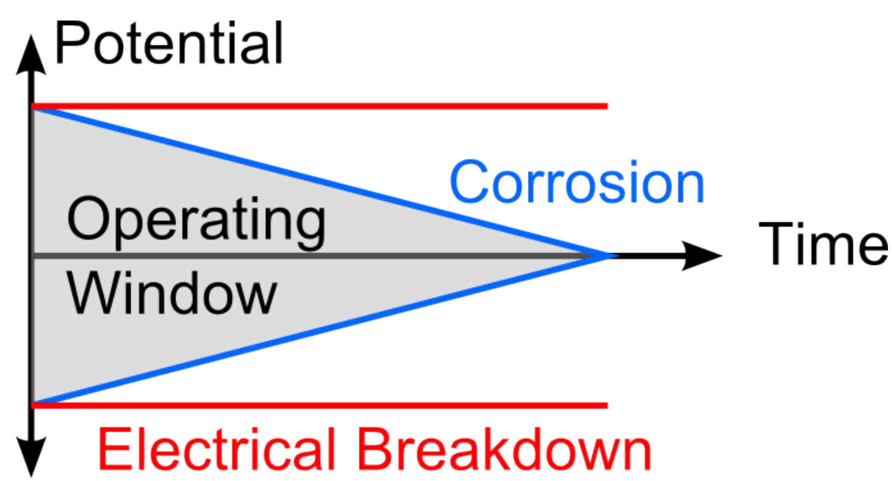
Time comparison



1) HfO_2 may provide better long term stability than Al_2O_3 or ZrO_2 (but need more data)
2) 10nm Al2O3 stable @ 1V for 15 hours (not shown)
3) Coatings are generally stable for minutes to hours at <50% breakdown voltage

Conclusions

- Failure occurs at weak points in the coating
  - Sample cleaning and roughness are critical
- Our recommendations…
  - Start by assuming 0.2 V/nm
  - Start with an Al_2O_3 or Al_2O_3/HfO_2 bilayer structure
  - Results will vary depending on your particular device layout/fabrication



Thank you EE412 class,
staff, mentors and J.

Questions?