Atomic Layer Deposition at the Stanford Nanofabrication Facility

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NNIN ALD Workshop

ALD Equipment @ SNF all Cambridge Nanotech

Equipment	Online	Cleanliness	Comments
savannah	Fall 2009	MOS until summer 2012 now open	Metal oxides only currently. Previously a lot of metal nitride work
fiji1	Summer 2011	MOS clean	One half of a F202 system; metal oxides, metal nitrides, and BEOL MOS metals
fiji2	Summer 2012	Open to “all materials”	Heavy utilization (80% or more of 24/7); metal oxides, metal nitrides, metals
fiji3	Winter 2013	Open to “all materials”	Oxide only processing; also to meet capacity demand of fiji2
Savannah-mvd	Winter/Spring 2013	Open to “all materials”	- Incorporated into a glovebox - Plasma cleaner also in glovebox - Molecular Vapor Deposition

Films available @ SNF – Extensive Characterization

- **Al_2O_3**
  - Thermal (TMA + H_20)
  - Plasma (TMA + O_2 plasma)
- **HfO_2**
  - Thermal (TDMA-Hf + H_20)
  - Plasma (TDMA-Hf + O_2 plasma)
- **TiO_2**
  - Thermal (TDMA-Ti + H_20)
  - Plasma (TDMA-Ti + O_2 plasma)
- **ZrO_2**
  - Thermal (TDMA-Zr + H_20)
  - Plasma (TDMA-Zr + O_2 plasma)
- **SiO_2** (Plasma 3DMAS + O_2 plasma)
- **Pt**
  - Thermal (Me(CpMe)Pt + O_2)
  - Plasma (Me(CpMe)Pt + O_2 plasma (+ H_2 plasma))
- **TiN**
  - Thermal (TDMA-Ti + NH_3)
  - Plasma (TDMA-Ti + N_2 plasma)
  - Plasma (TDMA-Ti + NH_3 plasma – *early stages*)
- **ZnO**
  - Thermal (DEZ + H_20)
- **Ta_2O_5**
  - Thermal (TDEMATB-Ta + H_20)
  - Plasma (TDEMATB-Ta + O_2 plasma)

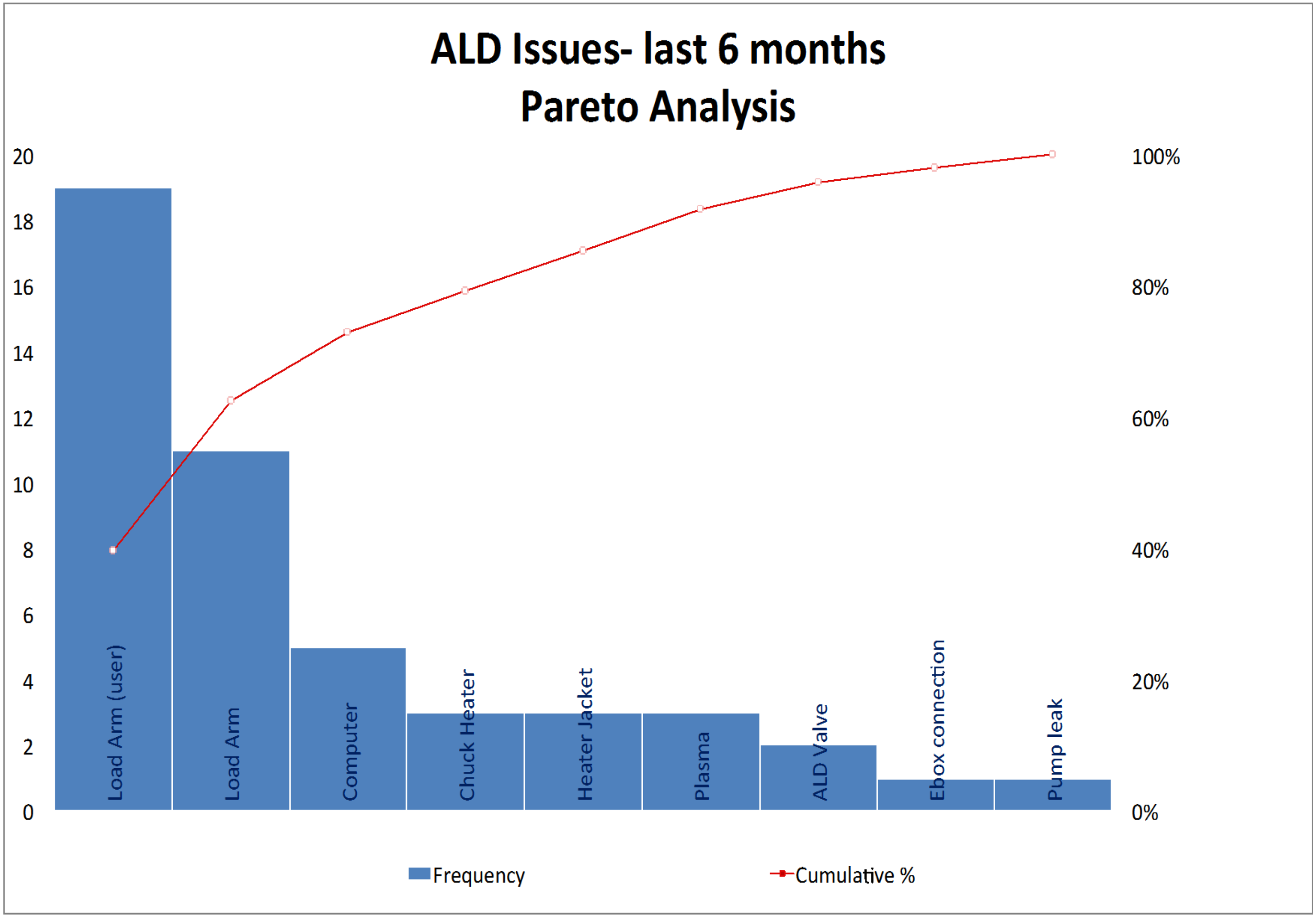
Films available @ SNF – Demonstrated Deposition

- **HfN (Hf_3N_4 really)**
  - Thermal (TDMA-Hf + NH_3)
  - Plasma (TDMA-Hf + N_2 plasma)
- **WO_x**
  - Thermal (BTDBMA-W + H_2O)
  - Plasma (BTDBMA-W + O_2 plasma)
- **WN**
  - Thermal (BTDBMA-W + NH_3)
  - Plasma (BTDBMA-W + N_2 plasma)
- **Ru**
  - Thermal ((CpEt)Ru + O_2)
- **SnO**
  - Thermal (TDMA-Sn + H2O2)
- **InO**
  - Thermal (CpIn + H_2O)
- **ITO** (see above)
- **Y2O3 (!)**
  - Thermal (Me(3MeCp)Y + H_2O or Me(2MeEtCp)Y + H_2O)
- **YSZ (yttria + zirconia)**
- **AZO (see above)**
- **NiO_x**
  - Thermal (nickelocene + H_2O)
  - **Ni** from H_2 plasma reduction
- **FeO_x**
  - Thermal (ferrocene + H_2O)
  - **Fe** from H_2 plasma reduction
- **AlN**
  - Plasma (TMA + N_2 plasma)
- **SrO**
  - Thermal (MeCpSr + H_2O)
- SiO_2
  - Thermal (tert-butoxy silanol + TMA)
  - YIKES!!! – discontinued.

Films @ SNF – Wish List

- TaN
- Ti
- Plasma Ru (better nucleation)
- W
- Y_2O_3
- Ideally want to support anything requested

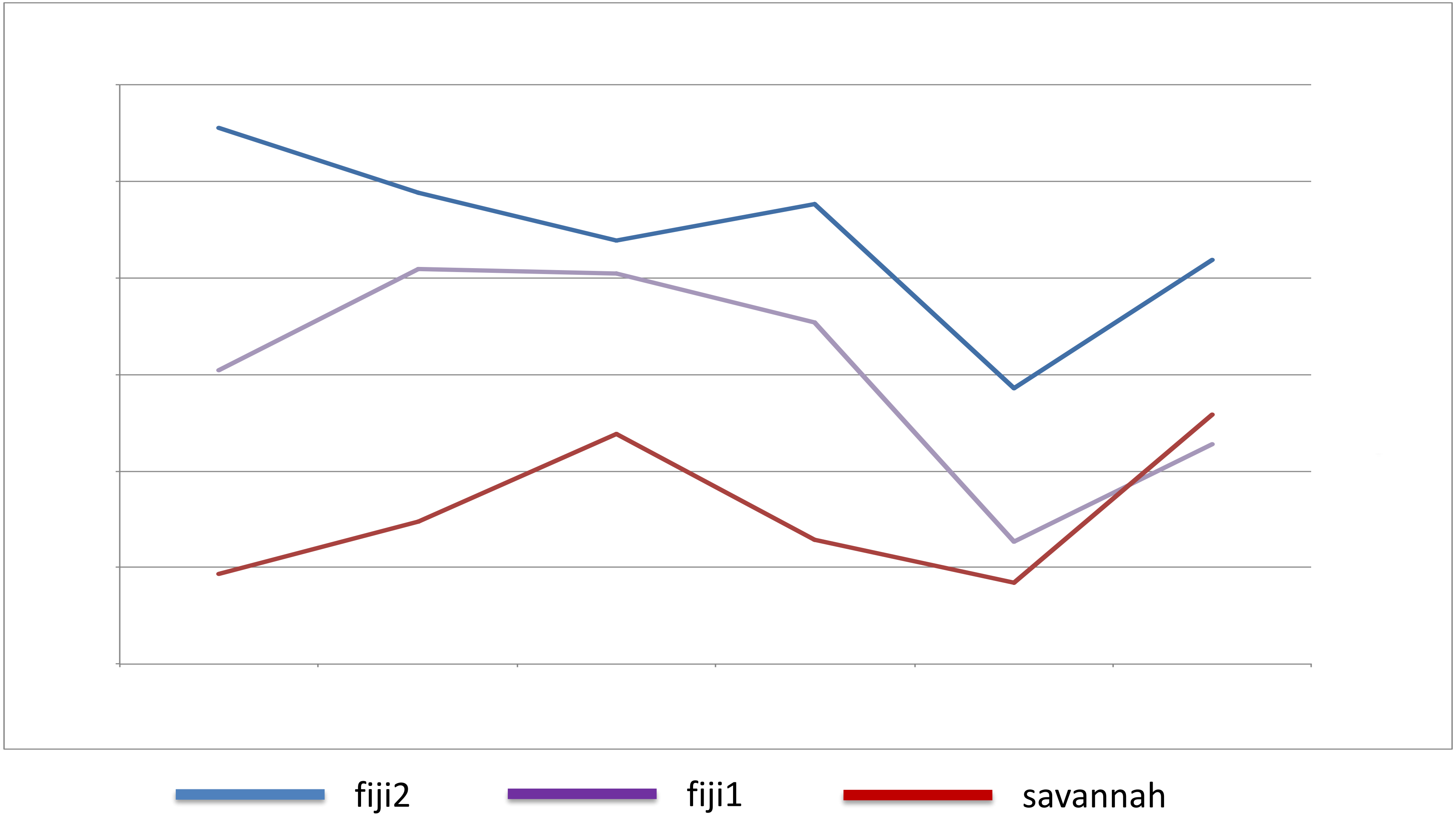
ALD Issues Pareto (last 6 months)



Primary Issues

- Primary issues related to Fiji load arms.
  - Most issues related to user error.
    - Fiji2 loading arm required refurbishment after being bent by user.
    - After summer break there was a large spike in errors. Once users re-familiarized themselves with loading process, error frequency dropped.
  - Setting screws to secure loading arm height also tend to drift and re-calibration of arm height is second most common error.
  - Fortunately these errors are relatively easy to recover from and result in minimal equipment downtime.

Tool Usage



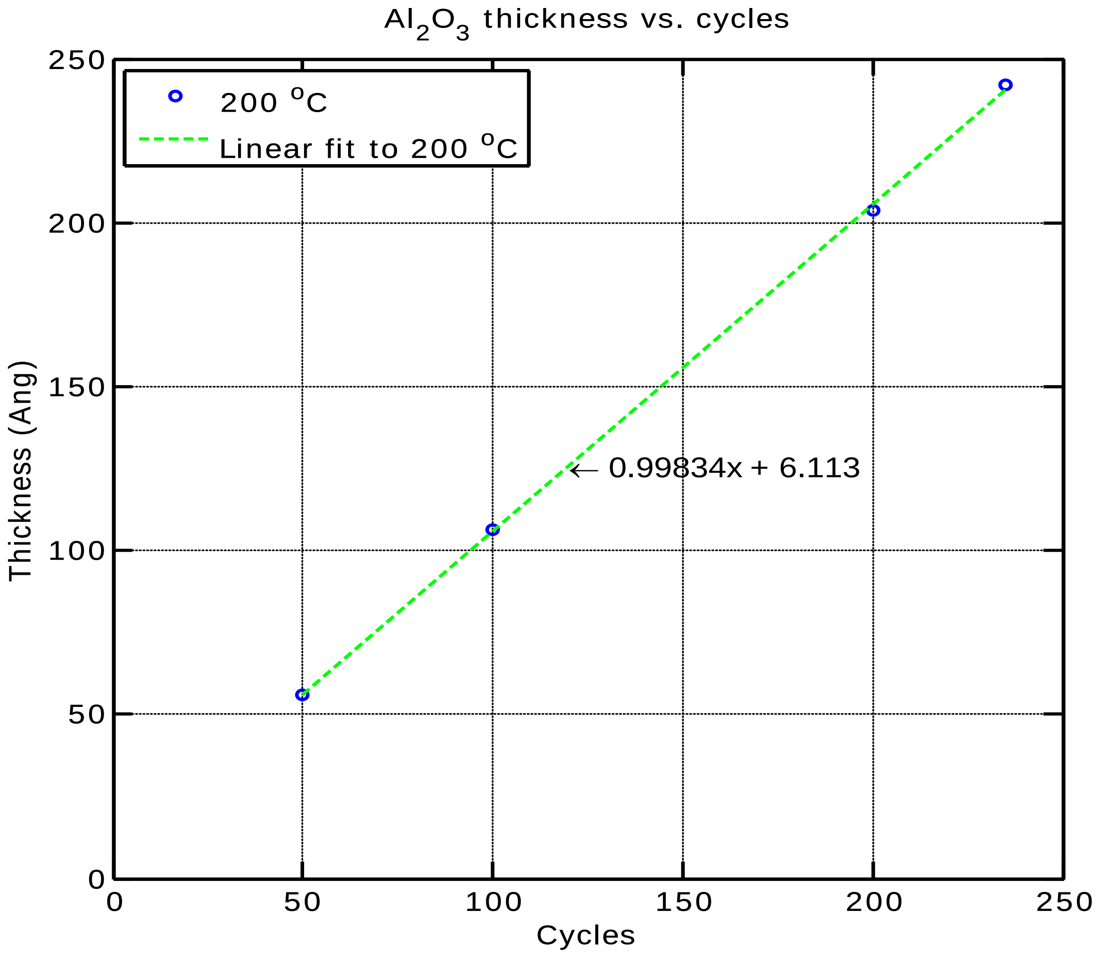
Maintenance Schedule

- Savannah
  - Reset pressure gauge (2x/yr)
  - Pump rebuild (1/yr); change oil (2x/yr)
  - Kalrez O-Ring (1/yr)
  - Chamber CO_2 clean: 1/yr (during shutdown)
  - Manifold clean: 4µm of film (coming soon)
- Fiji
  - Sample holder clean: As needed (~2X/year)
  - Load Arm refurbishment: Recommended 1/year
  - Chamber clean: haven't done yet
  - Manifold clean: 4µm of film

Additions to system

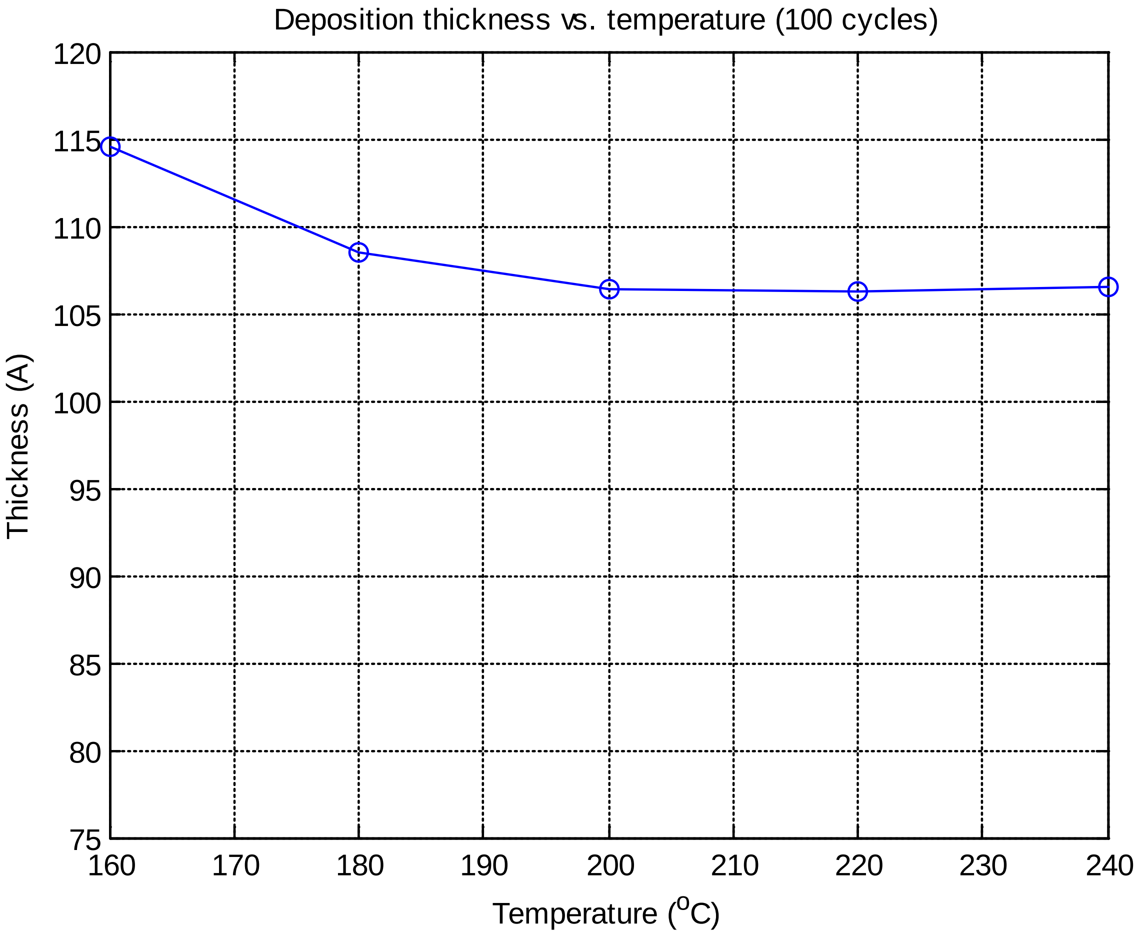
- We added a boost system in fall 2012 to aid with low volatility precursors
  - Similar to a bubbler
  - Very positive results (SrO and Y_2O_3)
  - Desire to add to more chambers
- Wish list
  - In situ film measurement
    - QCM
    - Ellipsometry (not really possible in several of our systems)
  - Ozone

Material Characterization: Al_2O_3



- Found deposition rate @ 200 ºC: ~0.99 A/cycle

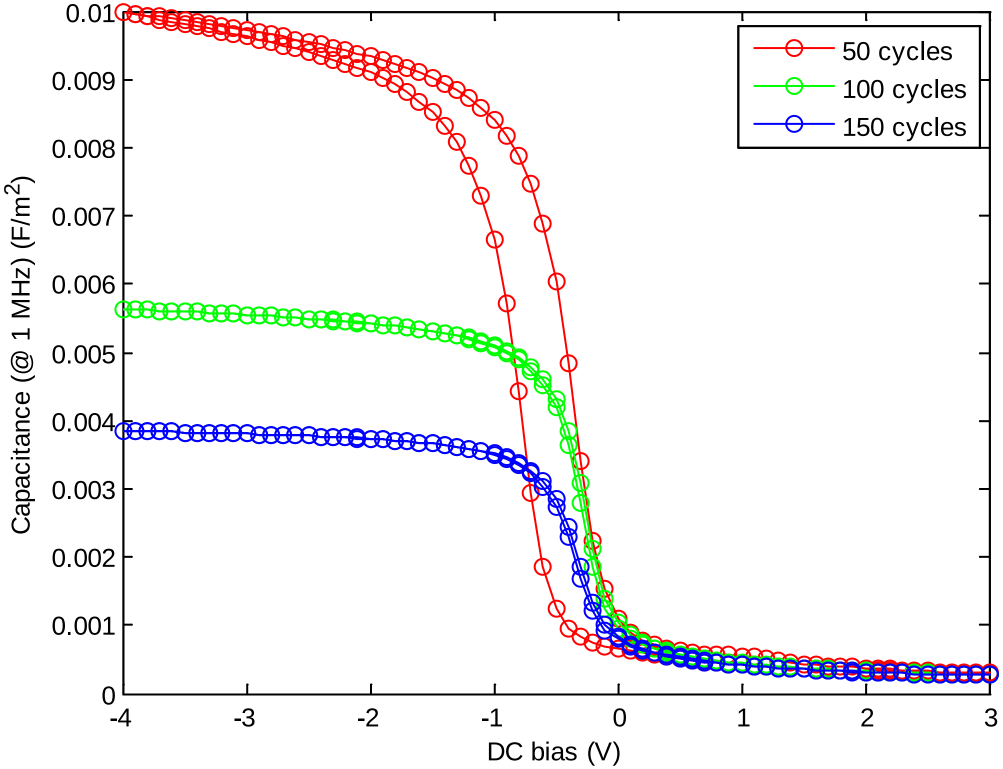
Material Characterization: Al_2O_3



- Deposition rate decreases with temperature increase

Material Characterization: Al_2O_3

- Dielectric constant is extracted from accumulation capacitance & measured dielectric thickness

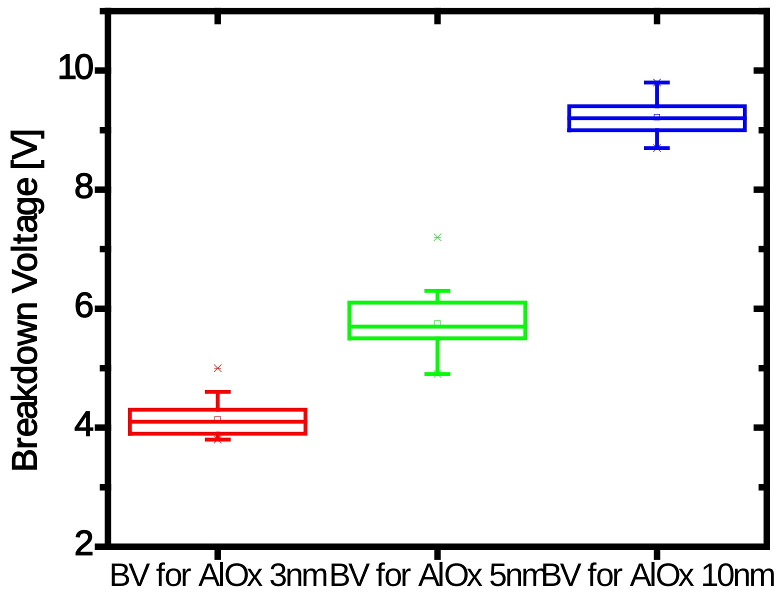


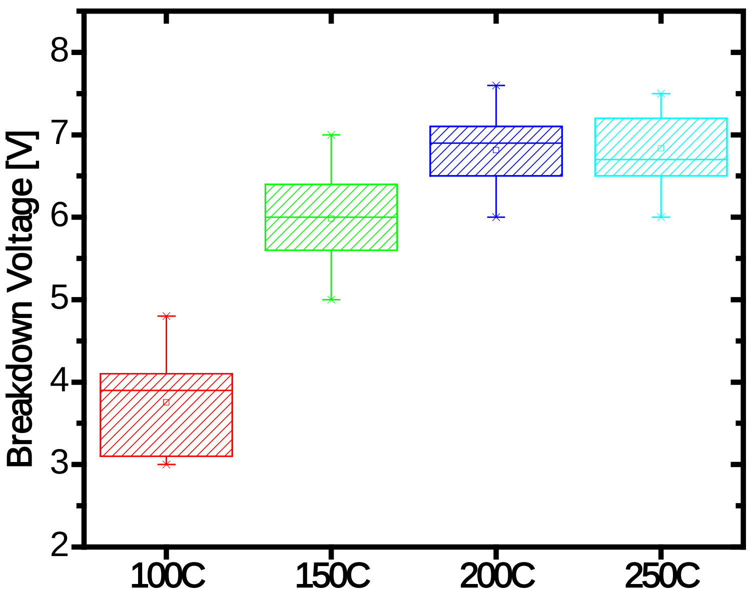
Cycles	Dielectric Constant (k)
50	6.30
100	6.77
150	6.74
200	6.76

·Deposition temperature: 200 ^{o}C

Extracted dielectric constant: ~6.75

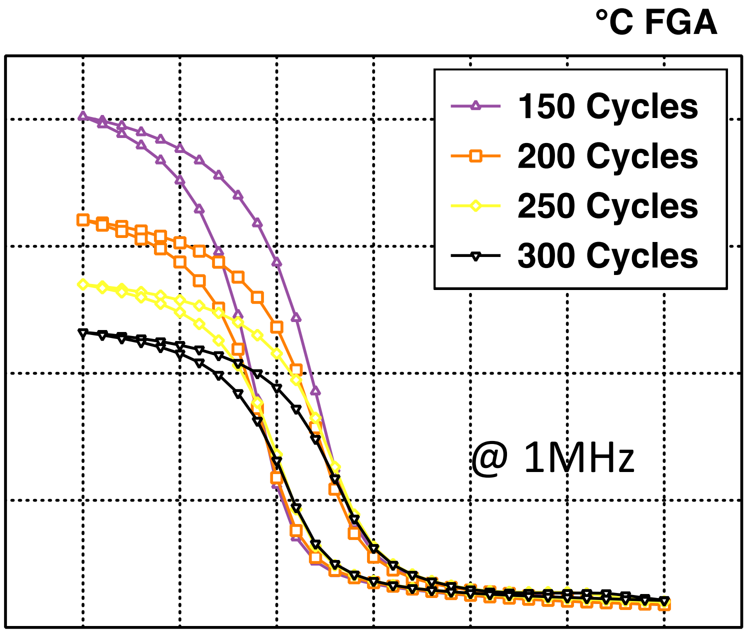
Material Characterization: Al_2O_3





Other well characterized metal oxides

- Similar data is available at the tool's website
  - Example HfO_2



Average Dielectric Constant : 15.27

Average Doping Concentration: 1.5 x 10^{16} /cm^3

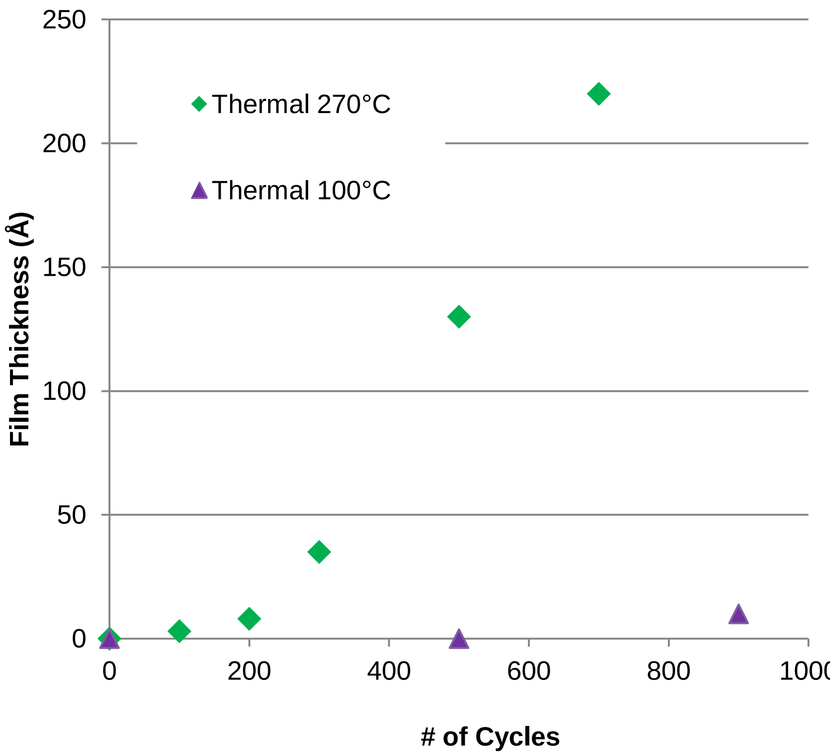
Hysteresis Range: 230mV-285mV

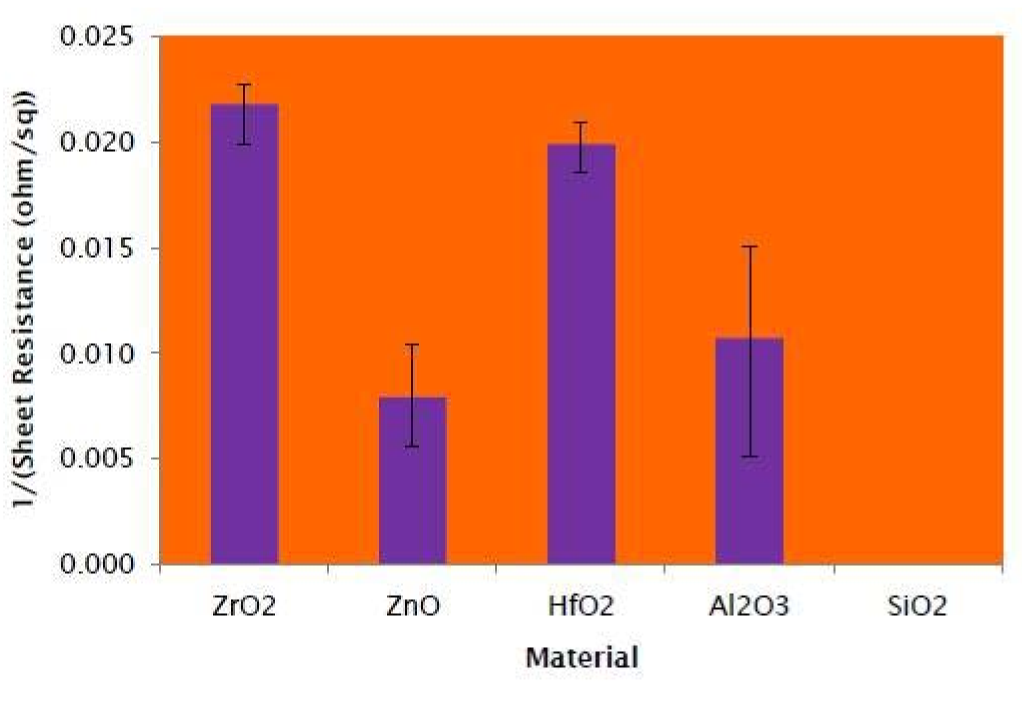
Mobile Charge Range: 8x10^{11} /1.4x10^{12} /cm^2

- Dielectric Constant (k), doping type and concentration were extracted at 1MHz.

Pt and Nucleation

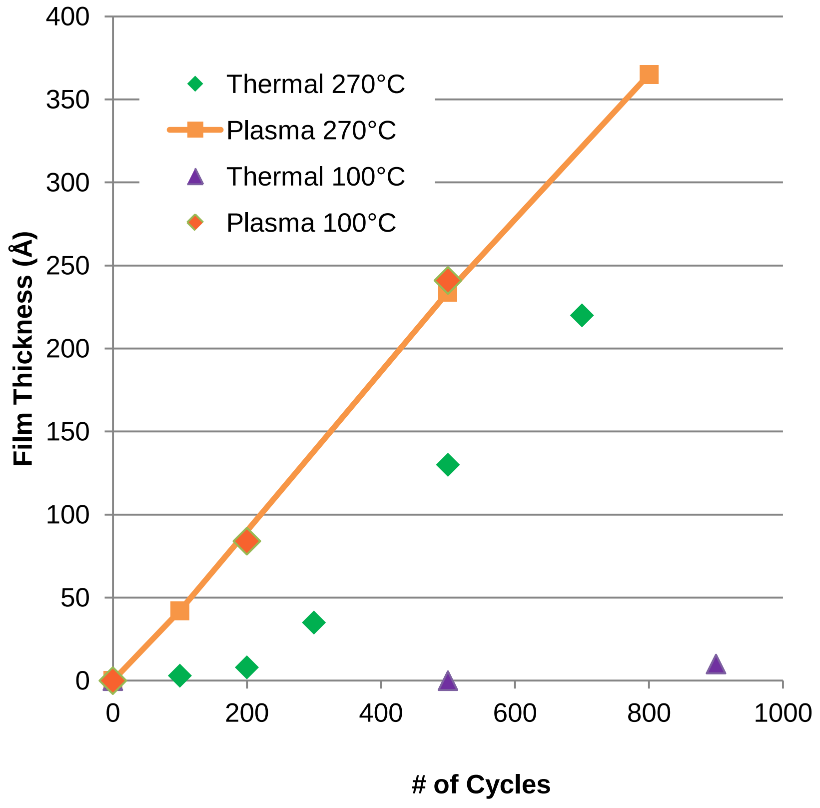
Thermal Pt from $MeCpPtMe_3$ and O_2





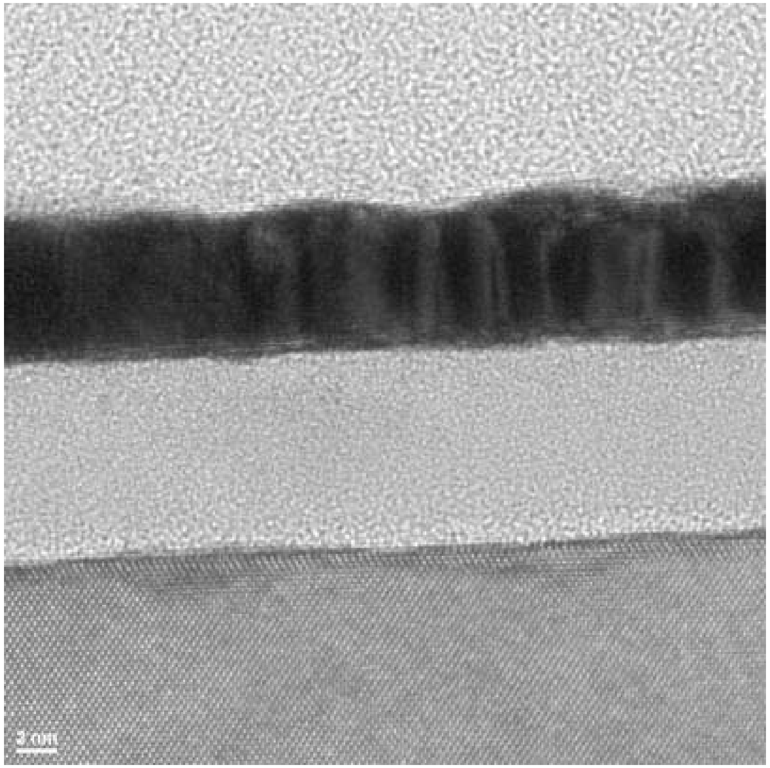
Pt and Nucleation

Plasma Pt from $MeCpPtMe_3$ and O_2

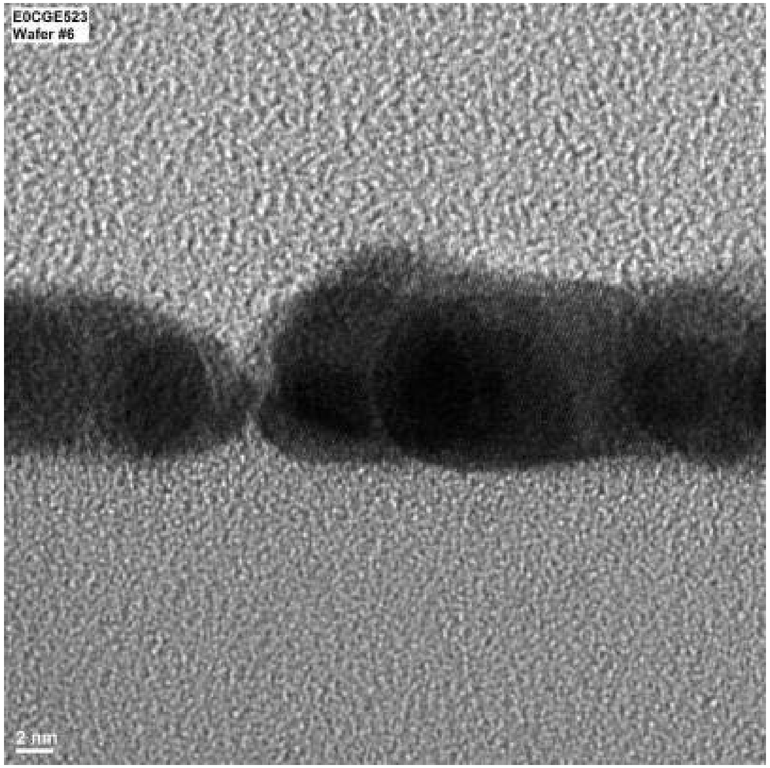


Pt and Nucleation

Plasma Pt from $MeCpPtMe_3$ and O_2



Plasma ALD Pt on Al_2O_3



Plasma ALD Pt on thermal SiO_2

TiN: Thermal vs Plasma

- Oxygen content kills conductivity of TiN
- With savannah we never saw less than 15% atomic weight in oxygen (mΩ-cm level resistivity)
- Switching to plasma in fiji 1% oxygen and best result is 10$\mu\Omega$-cm resistivity
- How well can the load locked, higher temp fiji do for thermal TiN?

Open questions of interest

- How to handle ZnO?
- General contamination concerns…
  - Sulfide ALD for instance
- Utilizing the tool for non-ALD projects
- Coating of powders and loose material
- Training and theory background for users
- Anyone with a fiji: load transfer arms

Thank you.
Any questions?