An Introduction to Atomic Layer Deposition

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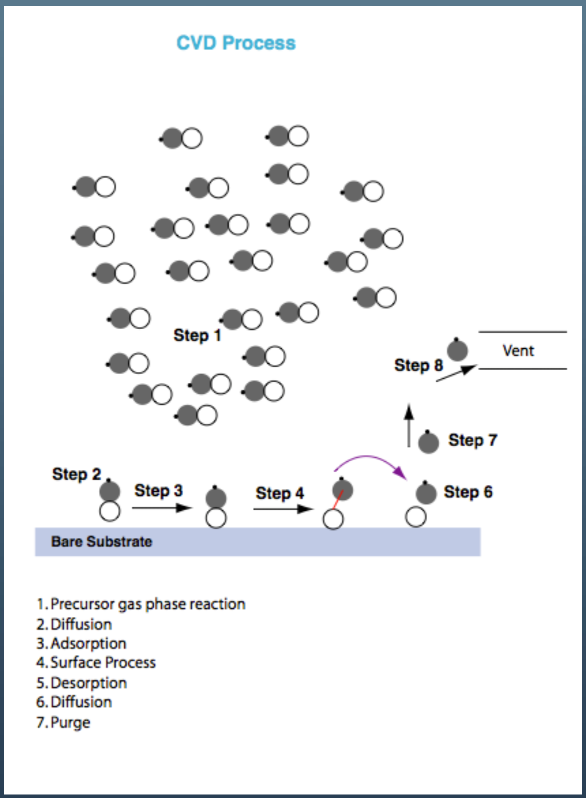
What is a Thin Film?

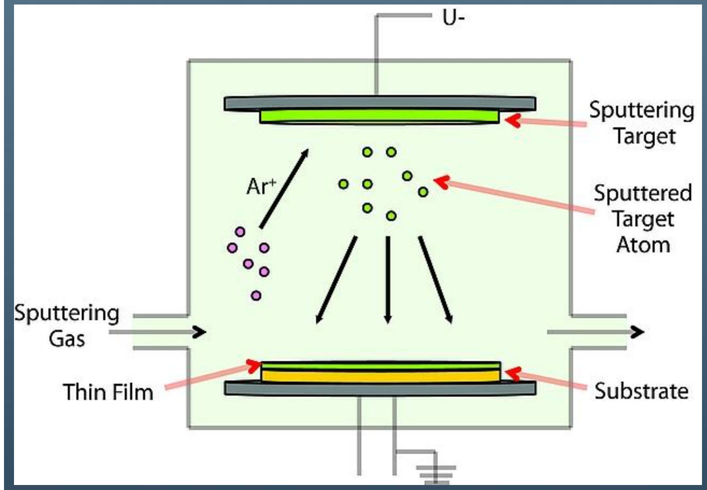
Thin film: thickness typically <1000nm.

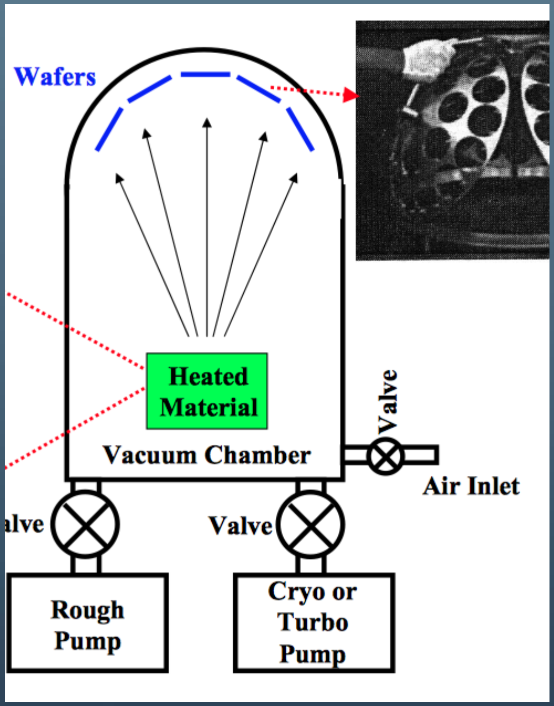
Special properties of thin films: different from bulk materials, it may be –

- Not fully dense
- Under stress
- Different defect structures from bulk
- Quasi - two dimensional (very thin films)
- Strongly influenced by surface and interface effects

Other Deposition Techniques



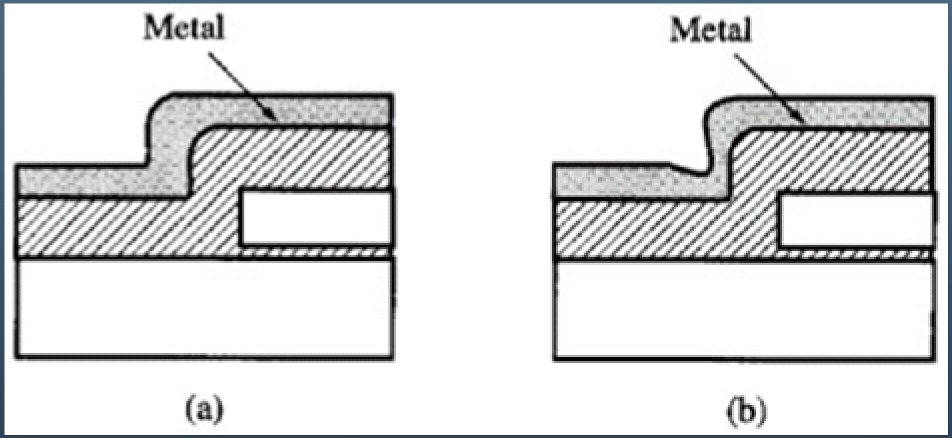


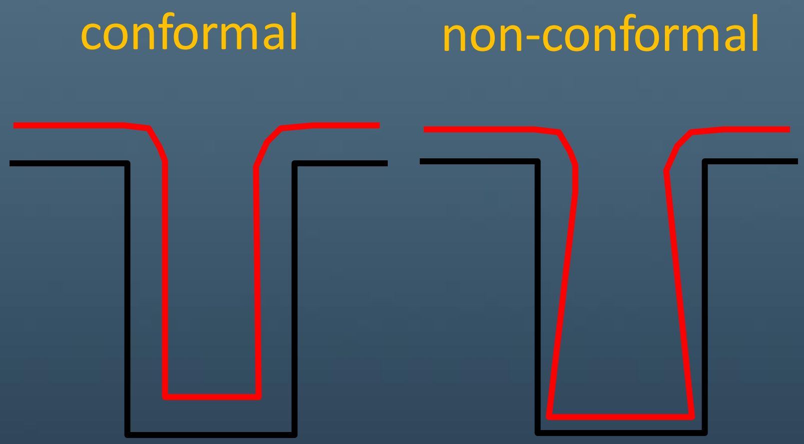


Common Denominator

- Deposition only occurs on substrates that "see" the target.
- Plasma process can damage the substrate
- Poor thickness control
- Poor Step Control
- High Pressure High Temperature Environment

Step Coverage Example





Step coverage of metal over non-planar topography.
(a) Conformal step coverage, with constant thickness on horizontal and vertical surfaces.
(b) Poor step coverage, here thinner for vertical surfaces.

Introduction

Atomic

Layer

Deposition

} A thin film "nanomanufacturing" tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control.

Based on:

- Paired gas surface reaction chemistries
- Benign non-destructive temperature and pressure environment
  - Room temperature -> 250 °C (even lower around 45 °C)
  - Vacuum

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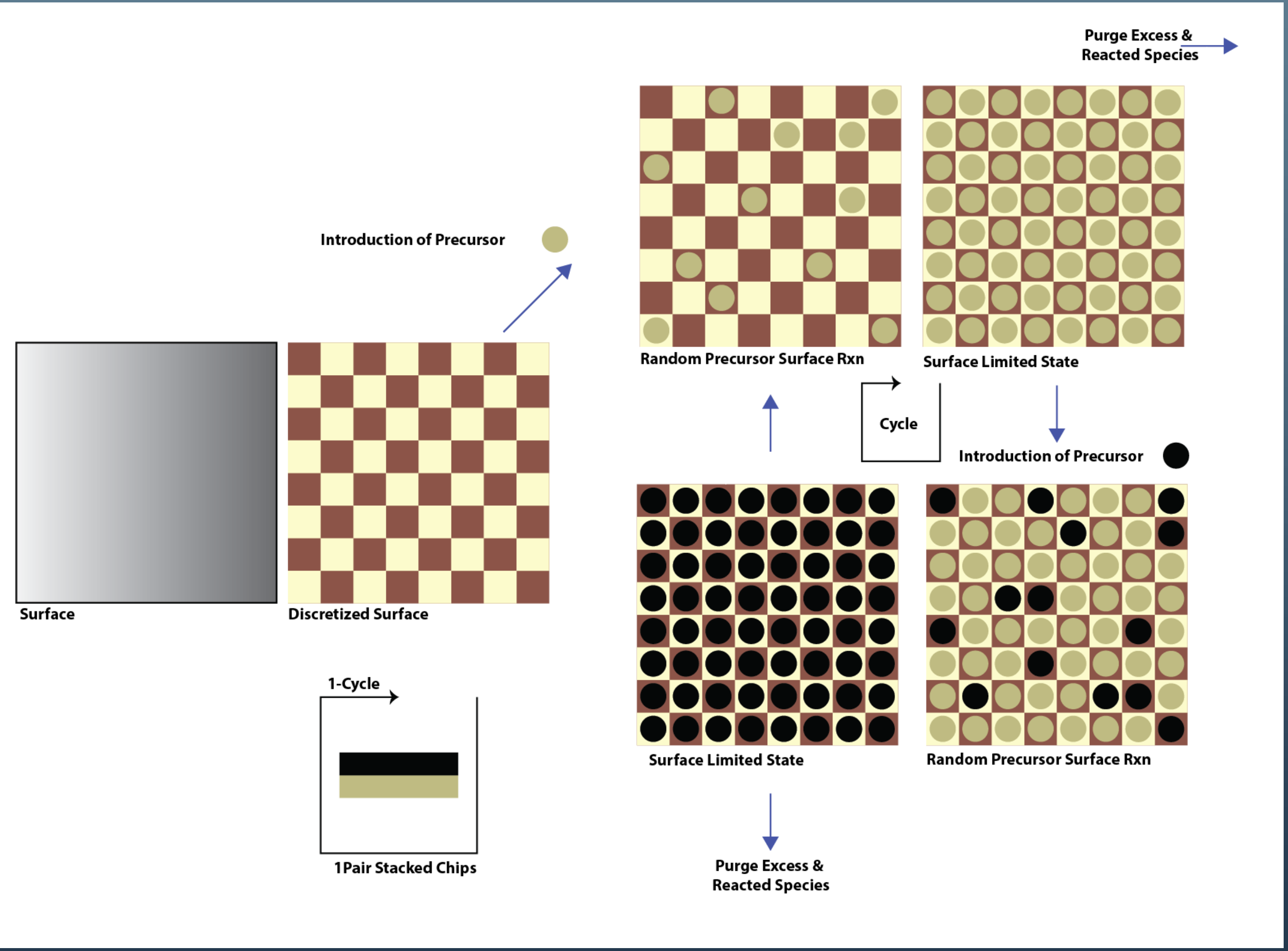
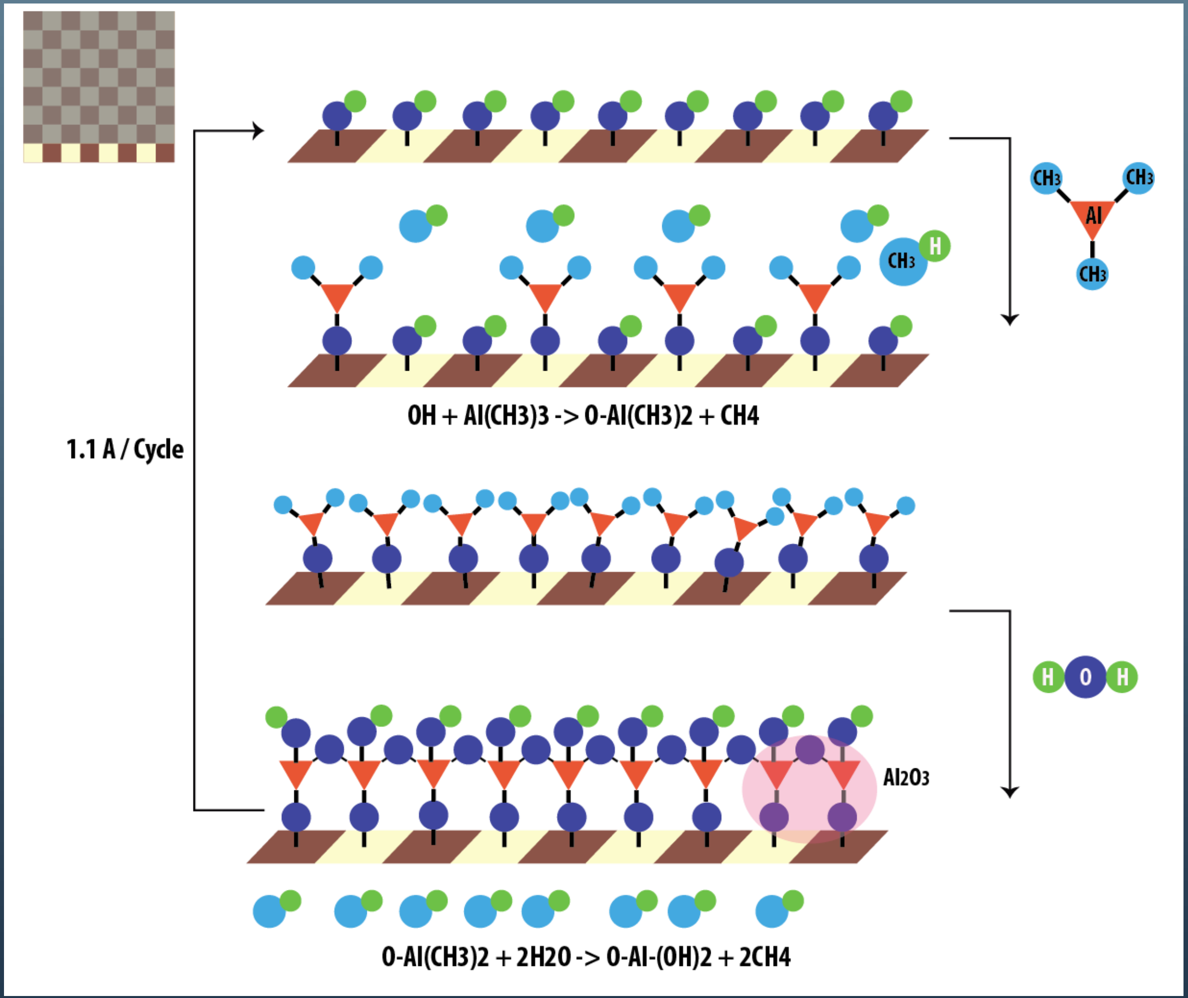
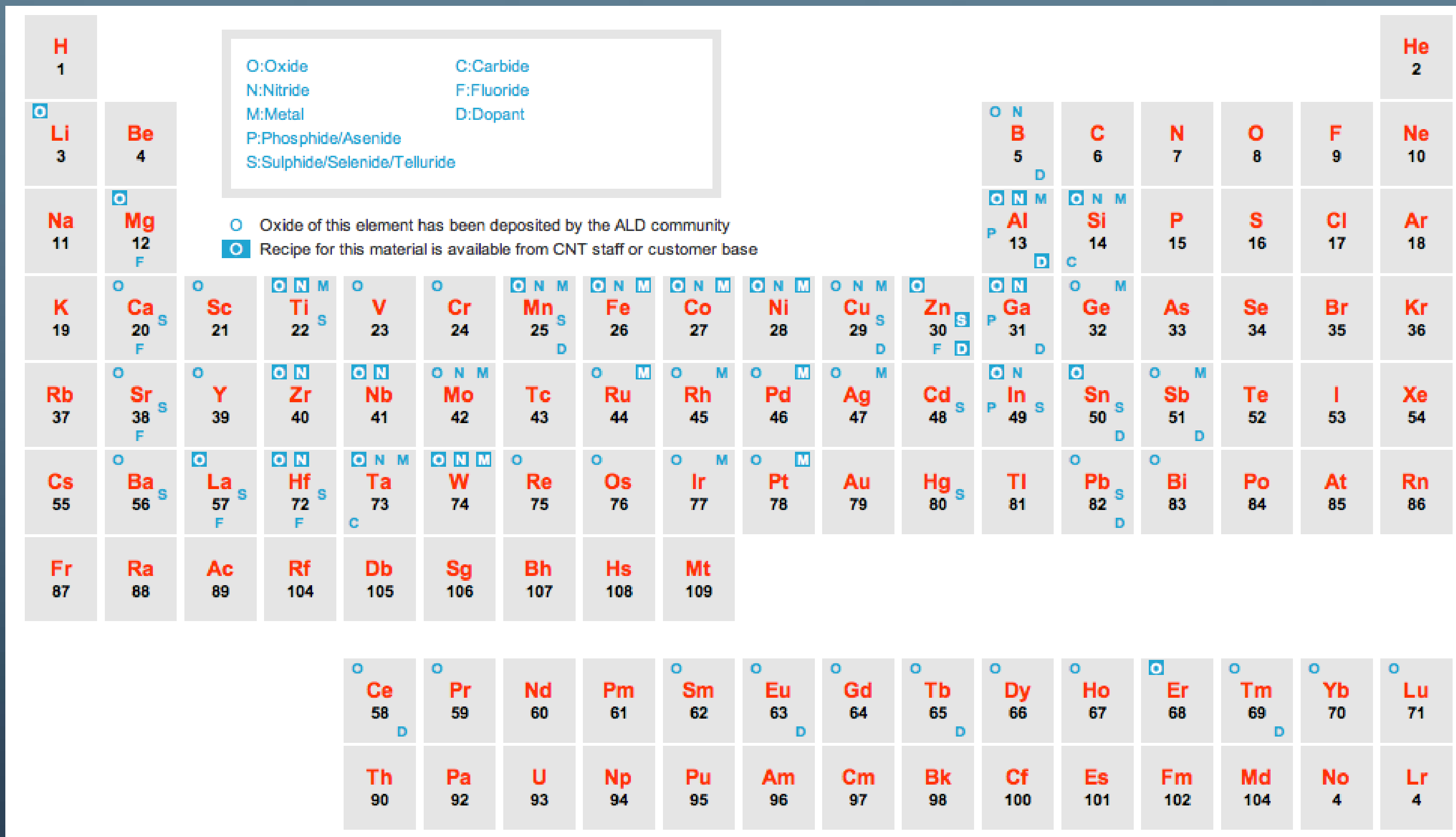
ALD Procedure



ALD Procedure



Periodic Table of ALD Films



Acknowledgements

- Gordon, Roy (2008). Atomic Layer Deposition (ALD): An Enable for Nanoscience and Nanotechnology. PowerPoint lecture presented at Harvard University, Cambridge, MA.
- Elam, Jeffrey (2007). ALD Thin Film Materials. Argonne National Laboratory

Advantageous Property

Precise Thickness Control

Thickness = $\mathscr{F}$(# monolayers)

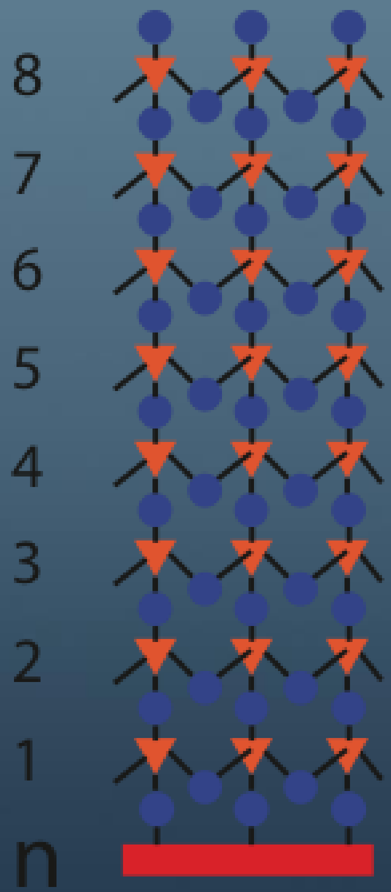
Example:

If 1 monolayer = 1 A

monolayers = 7

Thickness = 7 A

Reproducibility



Advantageous Property

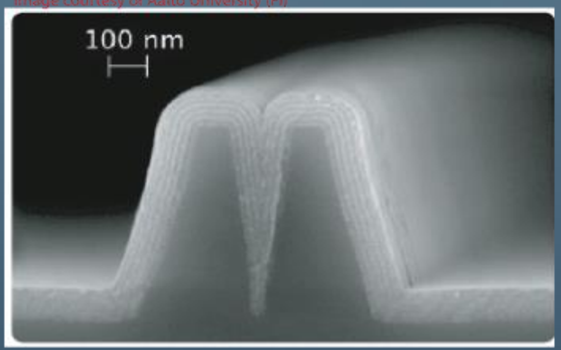
Substrate Independence

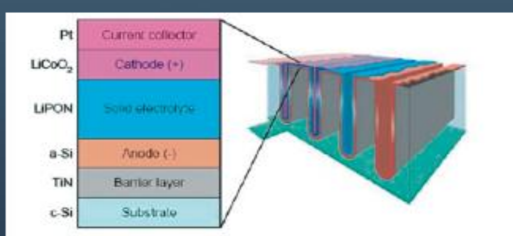
Advantageous Property

Epitaxial Growth

Artificial trench filled with an ALD nanolaminate

Image courtesy of Aalto University (FI)





Schematic of a 3D battery integrated in a Si- substrate. The cross-section shows the various functional layers in the battery stack as well as the candidate materials.

Knoops, H.C.M. et al., ECS Trans., 25 (2009) pp. 333-344

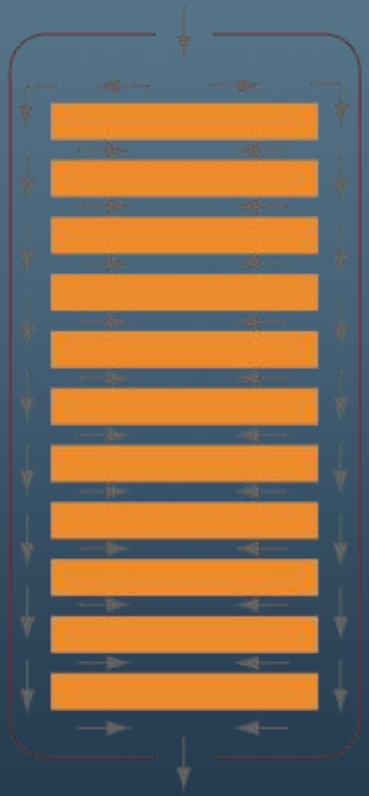
Multilayer consisting of:
Al2O3 - 25 nm
TiN - 20 nm
Al2O3 - 25 nm

Dr. Fred Roozeboom, NXP Semiconductors Research and Dr. Erwin Kessels, University of Technology, Eindhoventd

Batch Process

Coating Silver with Aluminum Oxide

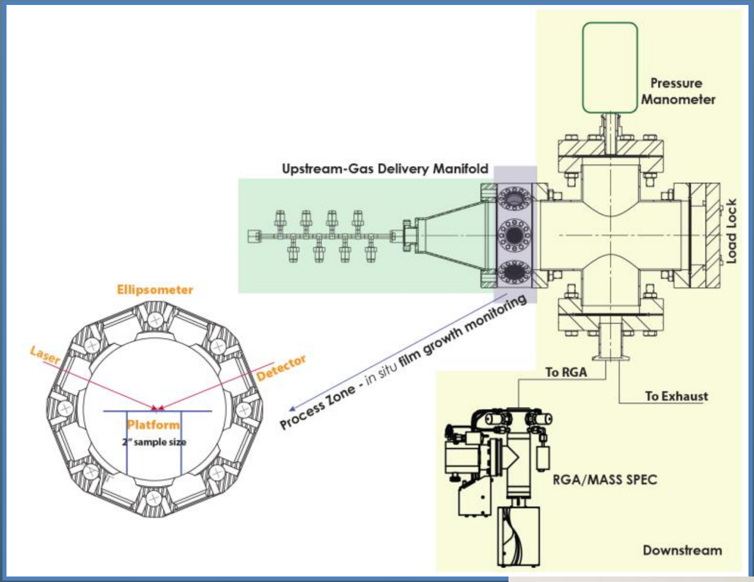
http://www.glassonweb.com/

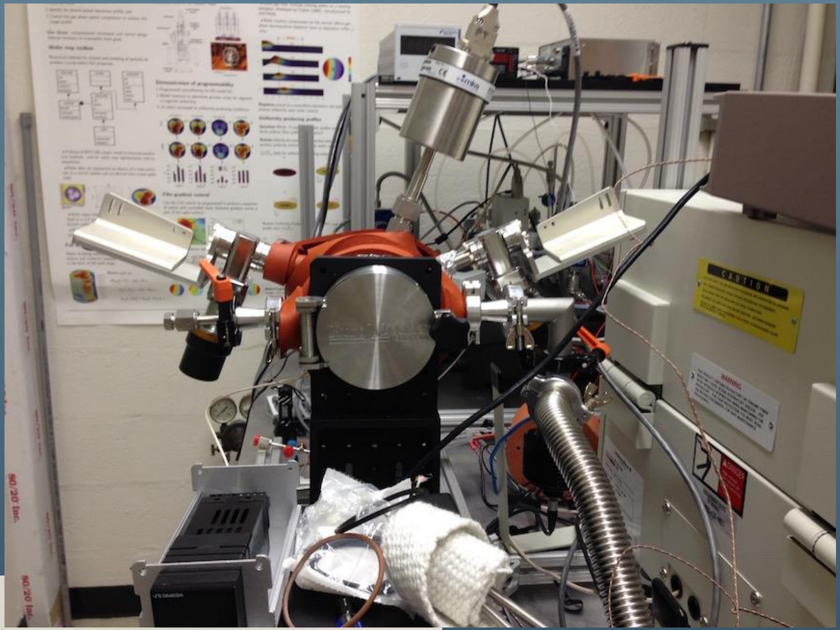


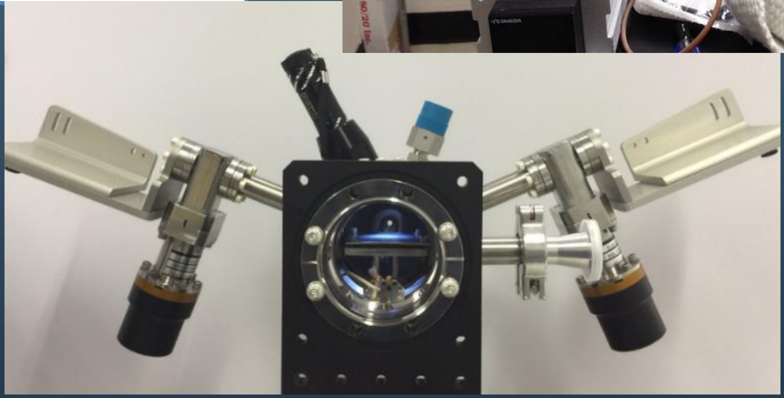
Building off a Commercial Reactor

Commercial Options

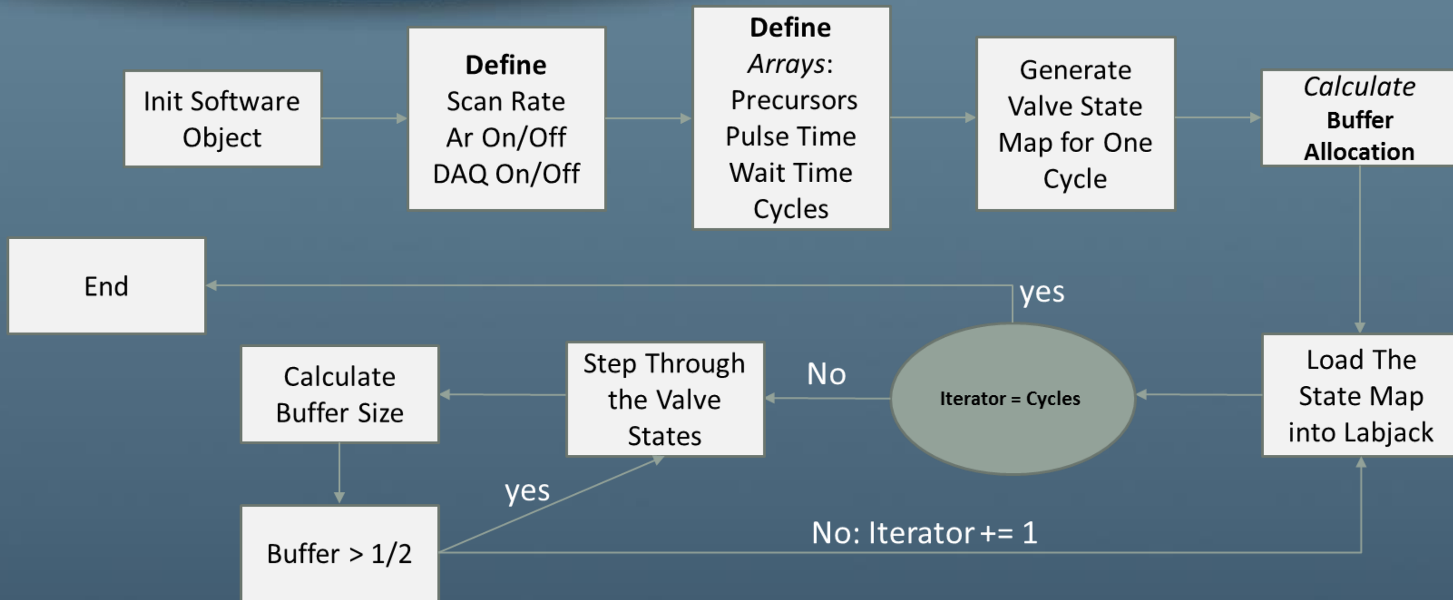
In-House Experimental ALD System

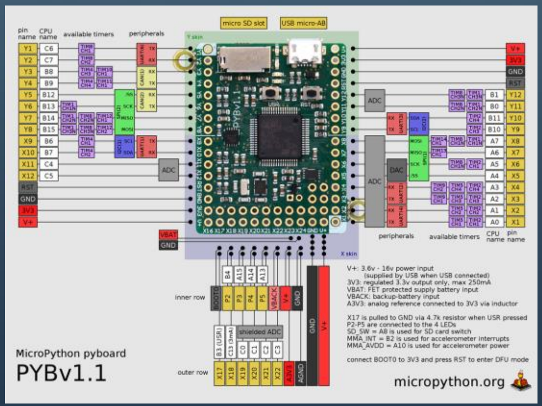


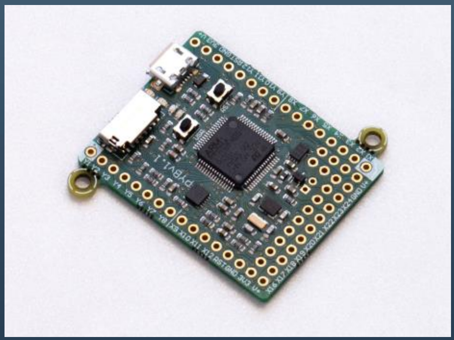




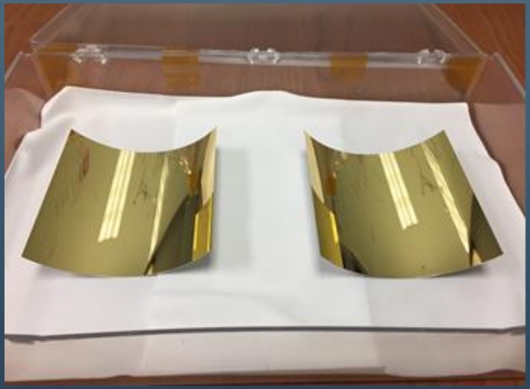
Open Source Solutions





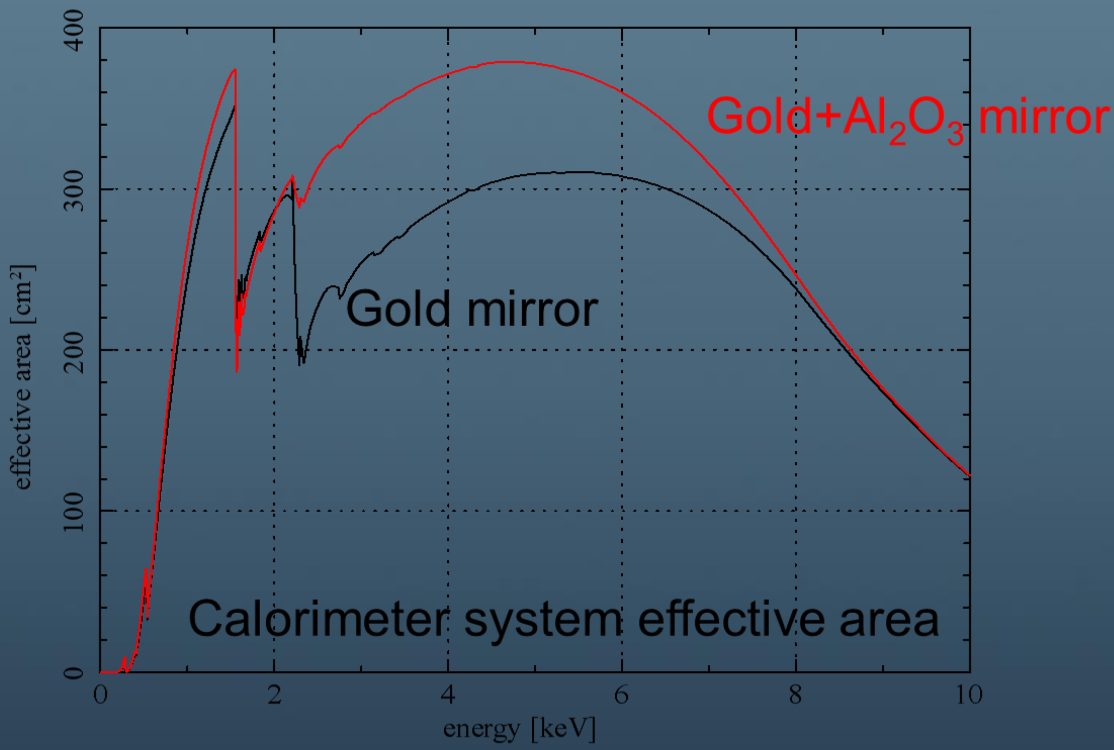


Applications and Results



~1600 Au Coated Mirrors
4x10" curved
50 cm/20"diameter cartridge

Effective area comparison



ZnO

$E = {}^{hc}/_{\lambda}$ where:

f = frequency in Hertz (Hz = $^{1}/_{sec}$)

λ = wavelength in meters (m)

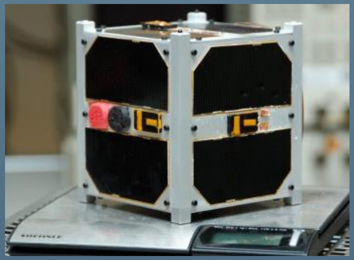
c = the speed of light (299792458 $^{m}/_{s}$)

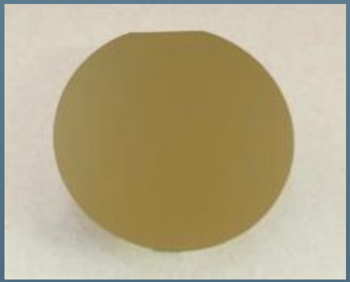
E = energy in electron Volts (eV)

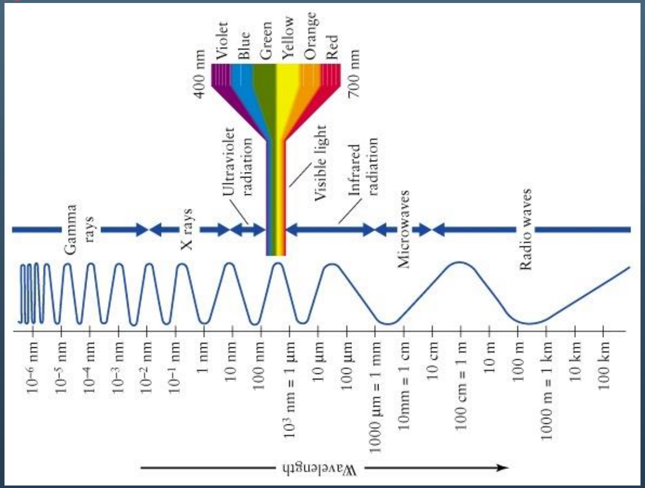
h = Plank's constant (6.626068×10^{-34} $^{m2kg}/_{s}$)

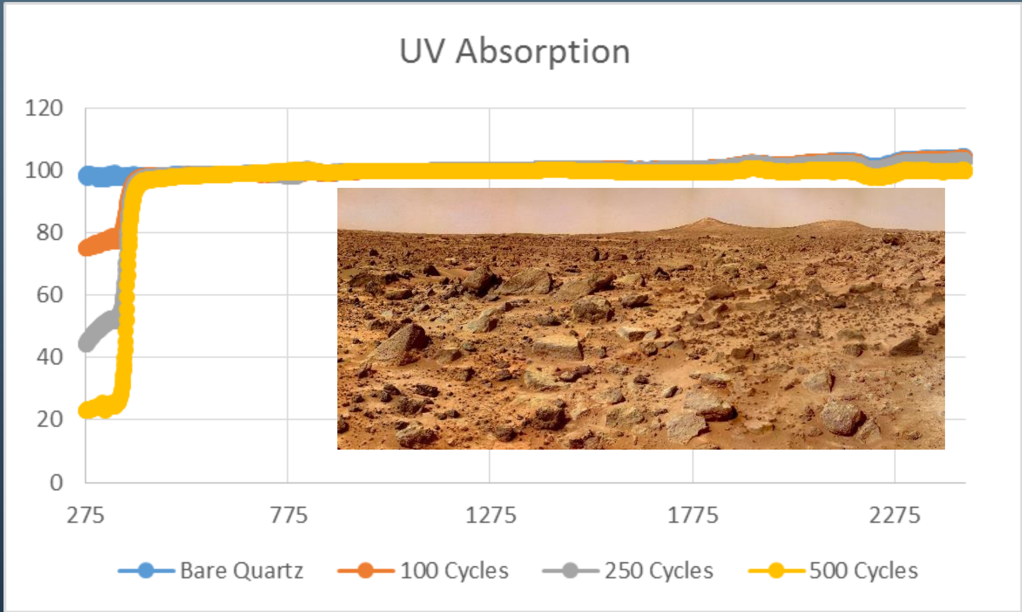
E_{ZnO}=3.3 eV

λ_{ZnO} ~ 375 nm

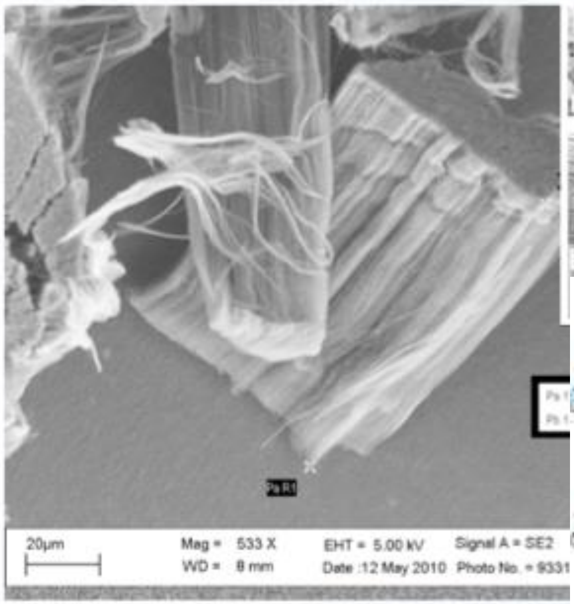


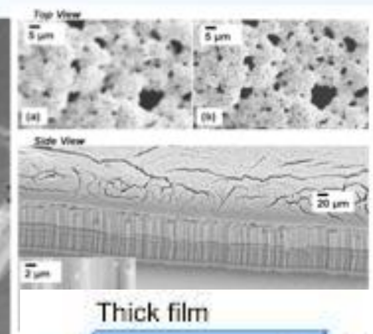


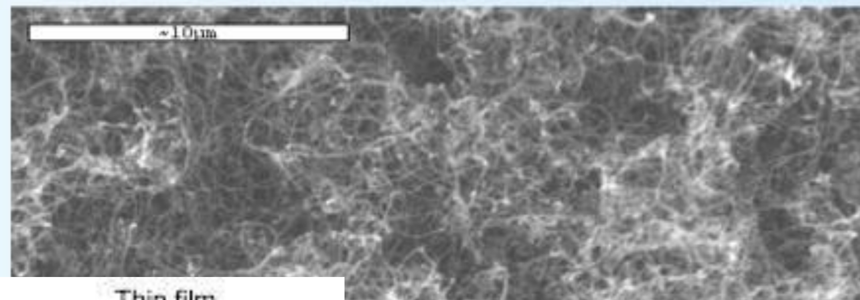


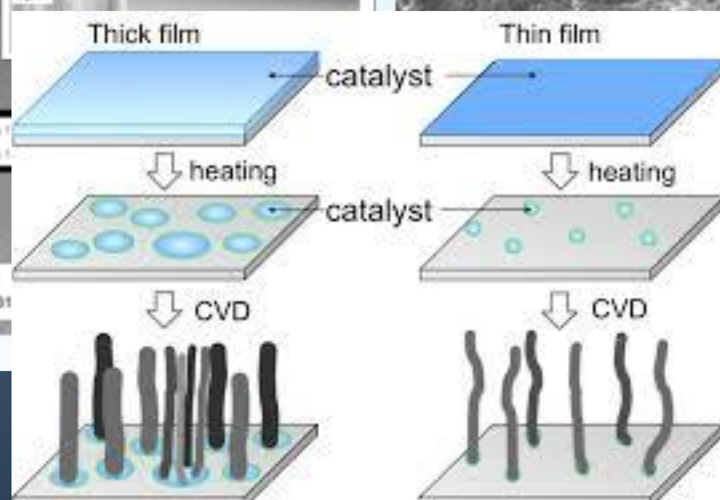


Blacker Than Black Carbon Nanotubes





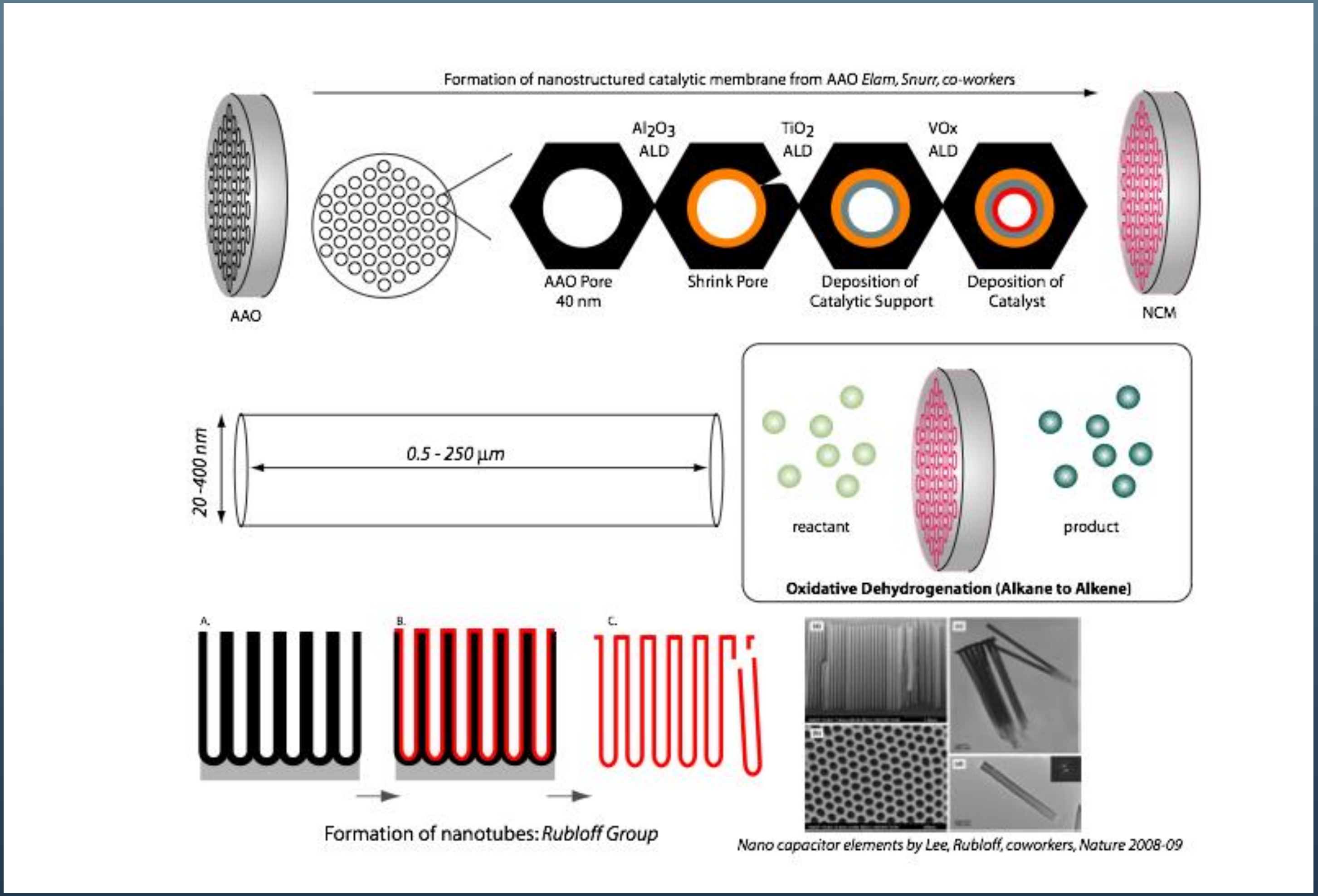




Substrate + Catalyst + Gas = CNNT
Si,Ti, flat, 3d + Iron + Ethylene

Blacker than NASA Z306 Paint 10X Darker

“Build” Nanotubes



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Atomic Oxygen Protection

100 nm on Kapton
1000 Cycles
155 °C
Al_2O_3

GPM Funded an experiment at Glenn to determine AO effects on materials.

99% mass retention after a simulated 5 year flux

Strategic Partnerships

Dr. Takashi Okajima (662)
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Dr. Brian Iverson (BYU)
Rydge Mulford (BYU)

Questions?

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