



An Introduction to Atomic Layer Deposition



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NASA GSFC Code 545



What is a Thin Film?

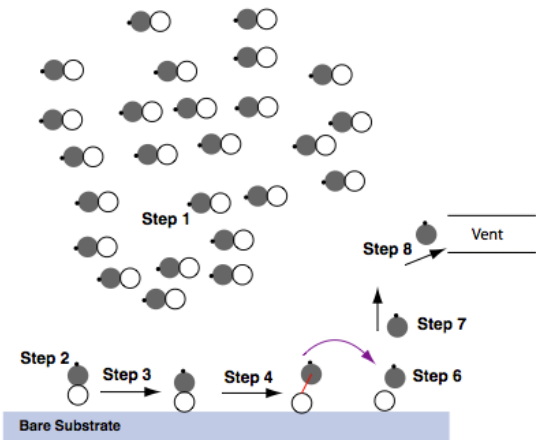
Thin film: **thickness typically $<1000\text{nm}$.**

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

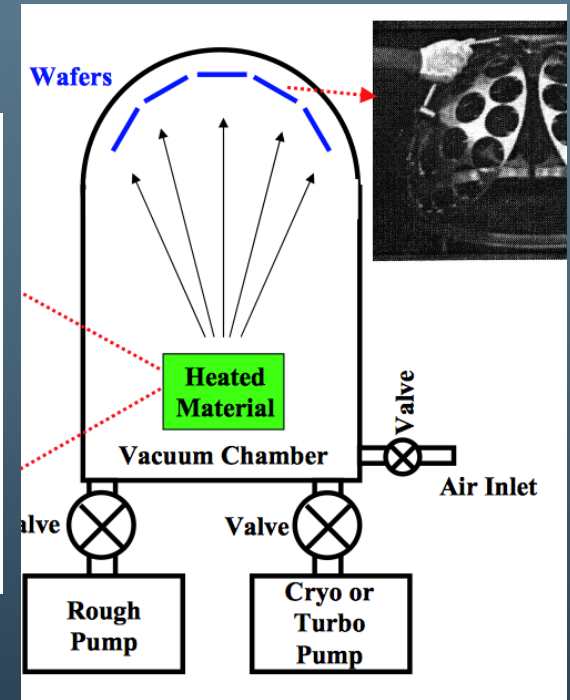
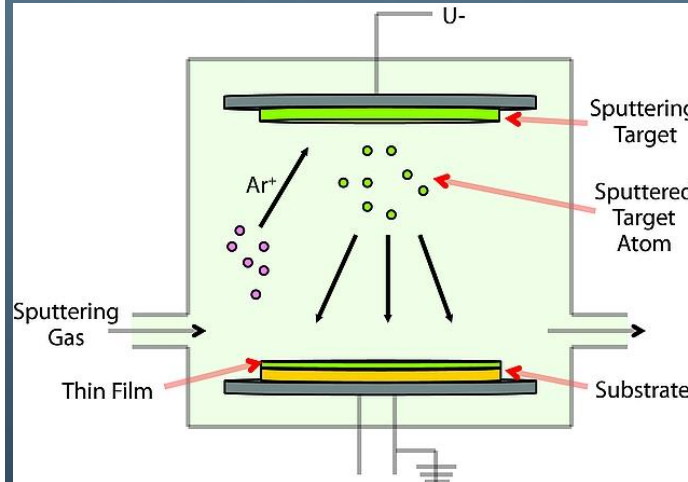
- Not fully dense
- Under stress
- Different defect structures from bulk
- Quasi - two dimensional (very thin films)
- Strongly influenced by surface and interface effects

Other Deposition Techniques

CVD Process



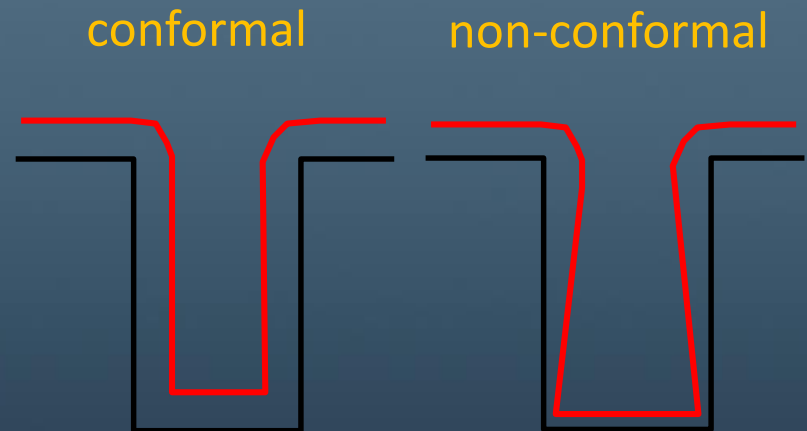
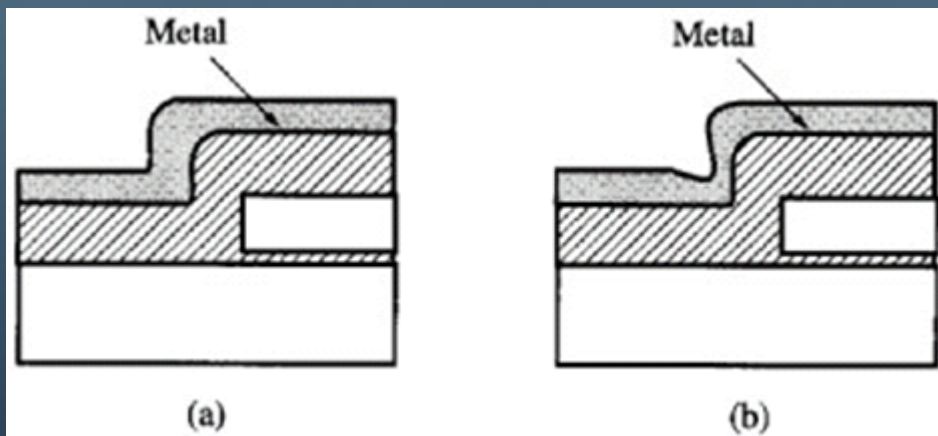
1. Precursor gas phase reaction
2. Diffusion
3. Adsorption
4. Surface Process
5. Desorption
6. Diffusion
7. Purge



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

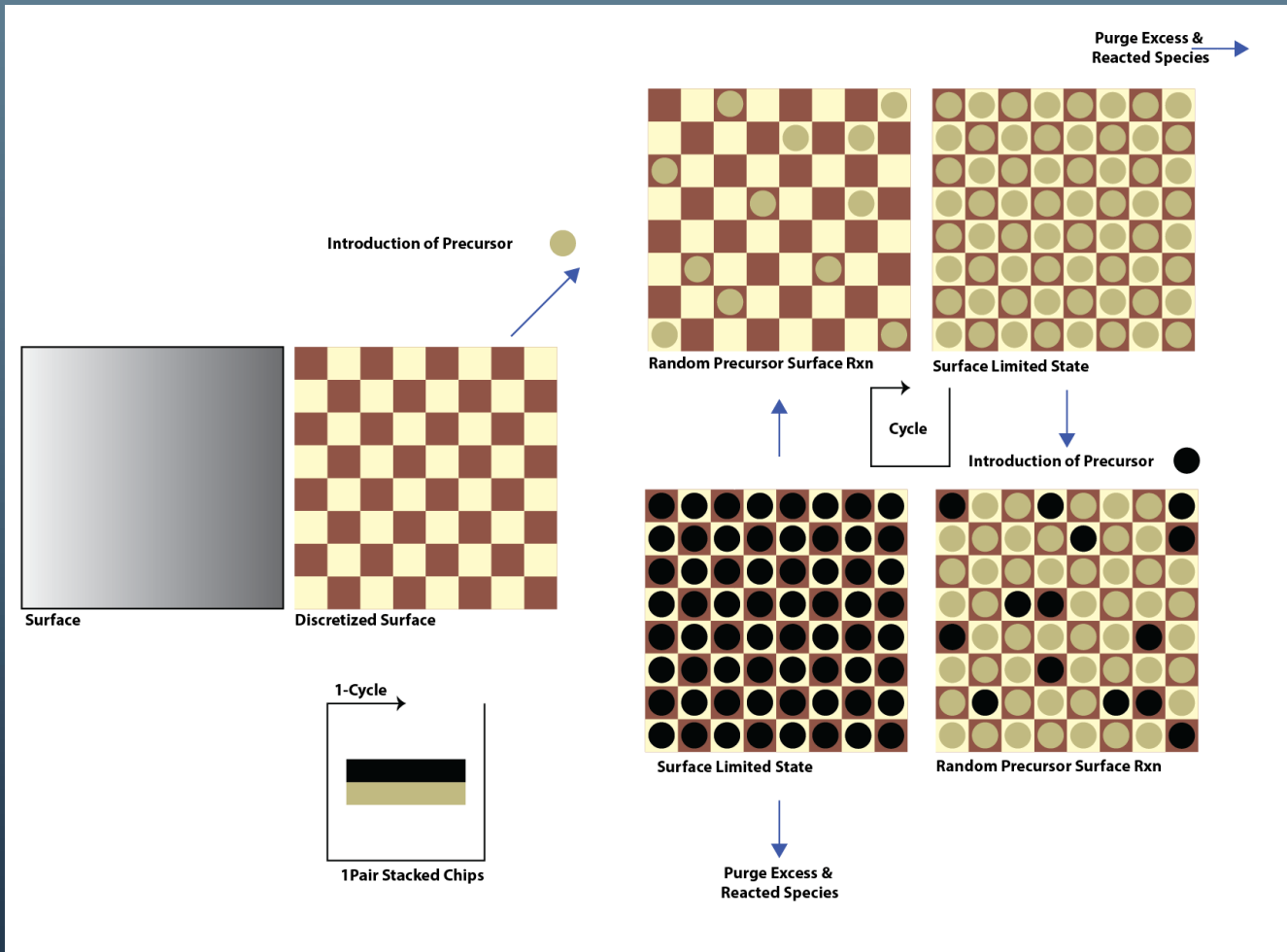


A thin film “nanomanufacturing” tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control.

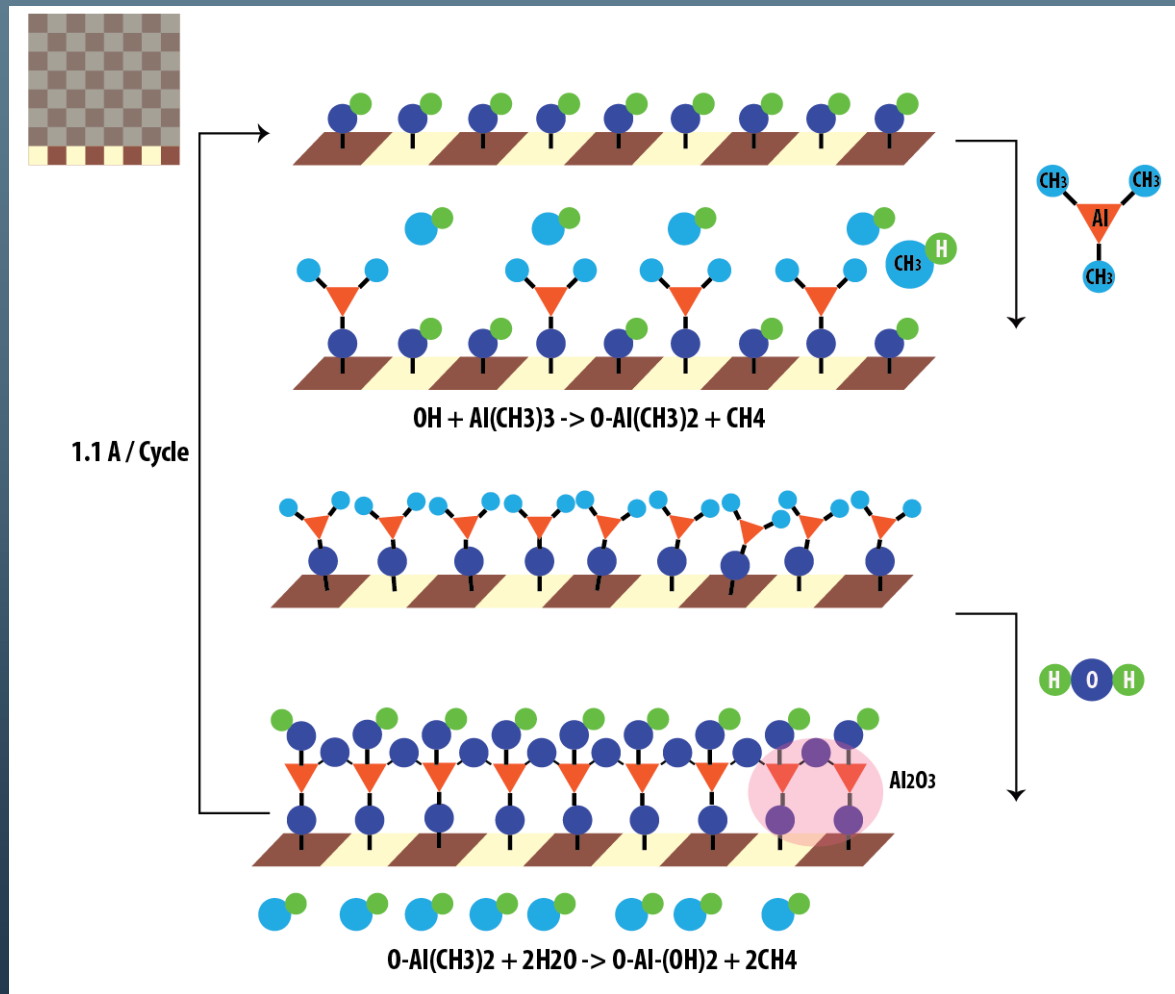
Based on:

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

ALD Procedure



ALD Procedure





Periodic Table of ALD Films

H 1																	He 2														
^O Li 3	Be 4																	^O B 5	C 6	N 7	O 8	F 9	Ne 10								
Na 11	^O Mg 12																	^O Al 13	^O Si 14	P 15	S 16	Cl 17	Ar 18								
K 19	^O Ca 20	^O Sc 21	^O Ti 22	^O V 23	^O Cr 24	^O Mn 25	^O Fe 26	^O Co 27	^O Ni 28	^O Cu 29	^O Zn 30	^O Ga 31	^O Ge 32	As 33	Se 34	Br 35	Kr 36														
Rb 37	^O Sr 38	^O Y 39	^O Zr 40	^O Nb 41	^O Mo 42	^O Tc 43	^O Ru 44	^O Rh 45	^O Pd 46	^O Ag 47	^O Cd 48	^O In 49	^O Sn 50	^O Sb 51	Te 52	I 53	Xe 54														
Cs 55	^O Ba 56	^O La 57	^O Hf 72	^O Ta 73	^O W 74	^O Re 75	^O Os 76	^O Ir 77	^O Pt 78	^O Au 79	^O Hg 80	^O Tl 81	^O Pb 82	^O Bi 83	Po 84	At 85	Rn 86														
Fr 87	Ra 88	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109																							
																		^O Ce 58	^O Pr 59	^O Nd 60	^O Pm 61	^O Sm 62	^O Eu 63	^O Gd 64	^O Tb 65	^O Dy 66	^O Ho 67	^O Er 68	^O Tm 69	^O Yb 70	^O Lu 71
																		Th 90	Pa 92	U 93	Np 94	Pu 95	Am 96	Cm 97	Bk 98	Cf 100	Es 101	Fm 102	Md 104	No 104	Lr 104

^O:Oxide
^N:Nitride
^M:Metal
^P:Phosphide/Asenide
^S:Sulphide/Selenide/Telluride
^C:Carbide
^F:Fluoride
^D:Dopant

^O Oxide of this element has been deposited by the ALD community
^O Recipe for this material is available from CNT staff or customer base

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 = \mathcal{F} (# monolayers)

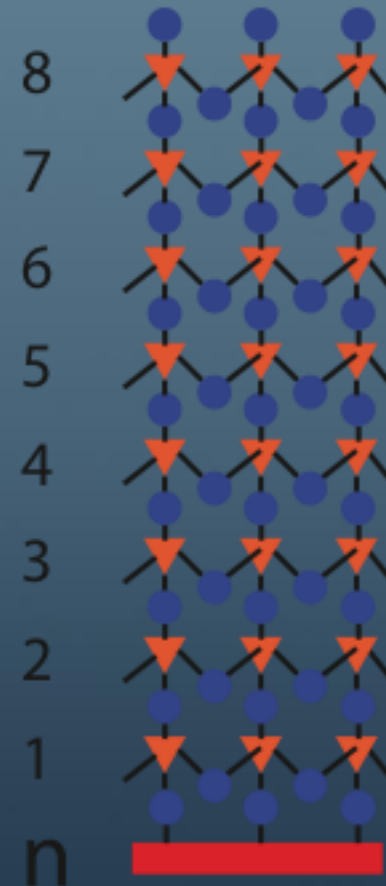
Example:

If 1 monolayer = 1 Å

monolayers = 7

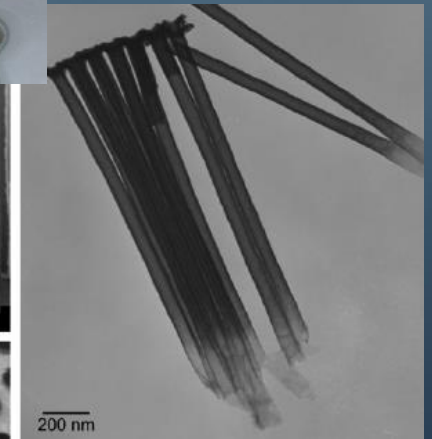
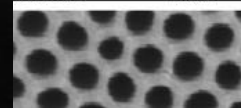
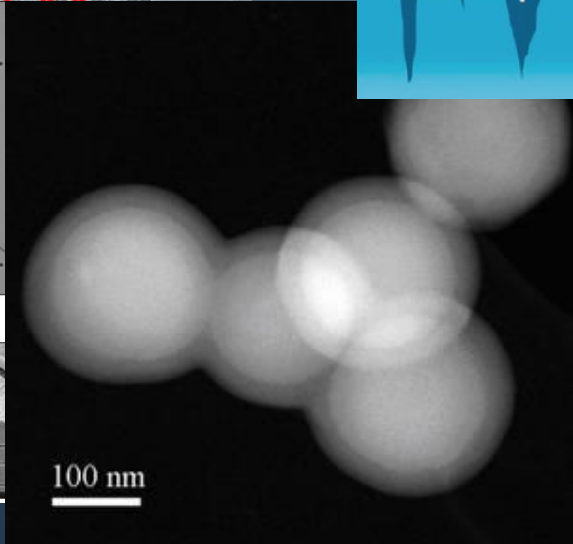
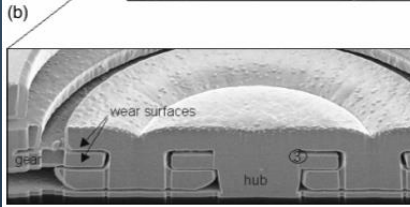
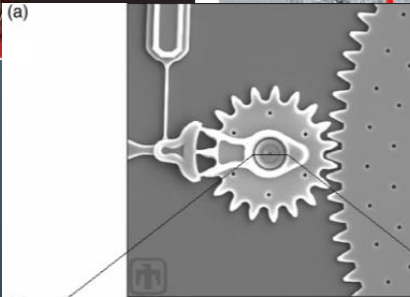
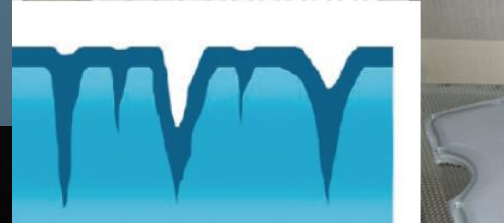
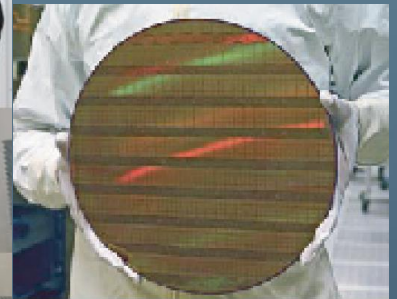
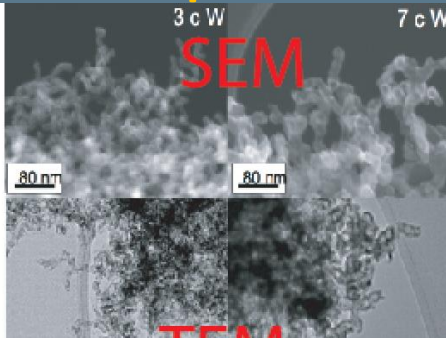
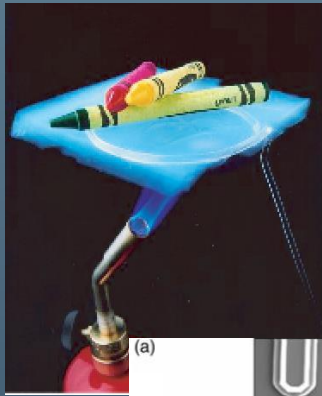
Thickness = 7 Å

Reproducibility



Advantageous Property

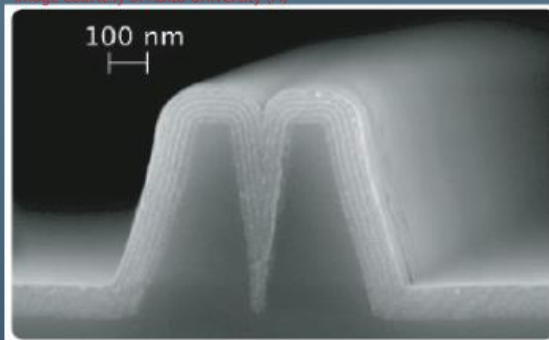
Substrate Independence



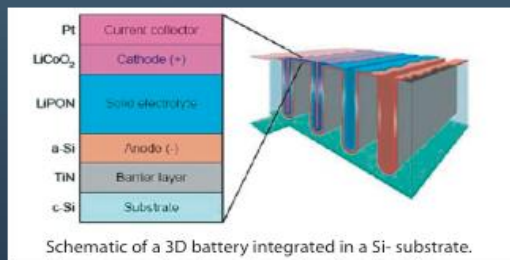
Advantageous Property

Epitaxial Growth

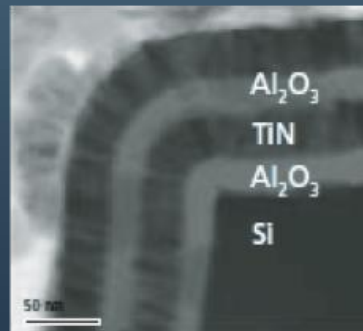
Artificial trench filled with an ALD nanolaminate
Image courtesy of Aalto University (FI)



Multilayer consisting of:
Al₂O₃ - 25 nm
TiN - 20 nm
Al₂O₃ - 25 nm
Dr. Fred Roseboom, NXP Semiconductor Research and
Dr. Erwin Kozicki, University of Technology, Eindhoven



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



Batch Process



Coating Silver with Aluminum Oxide
<http://www.glassonweb.com/>



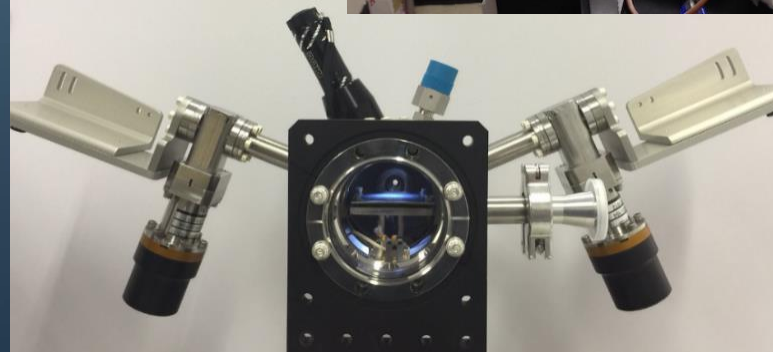
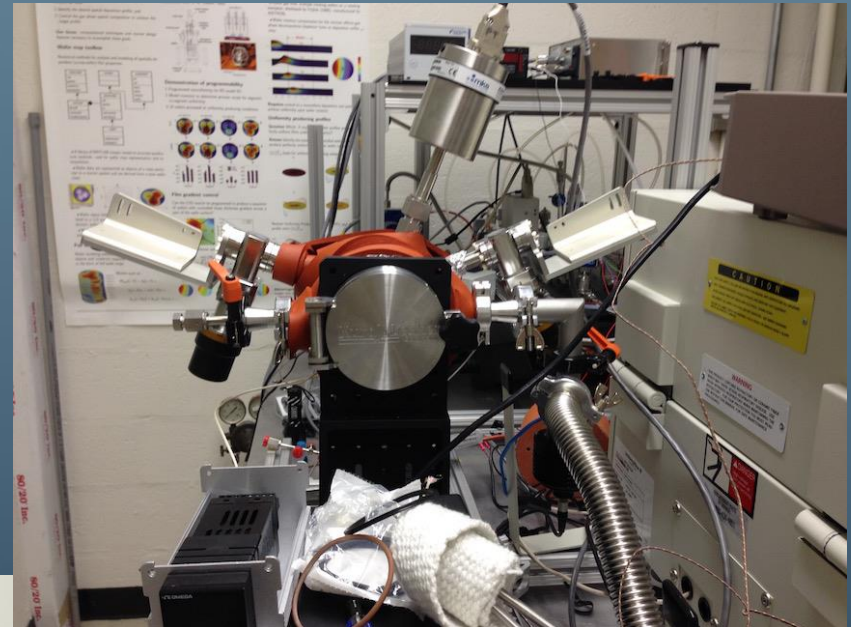
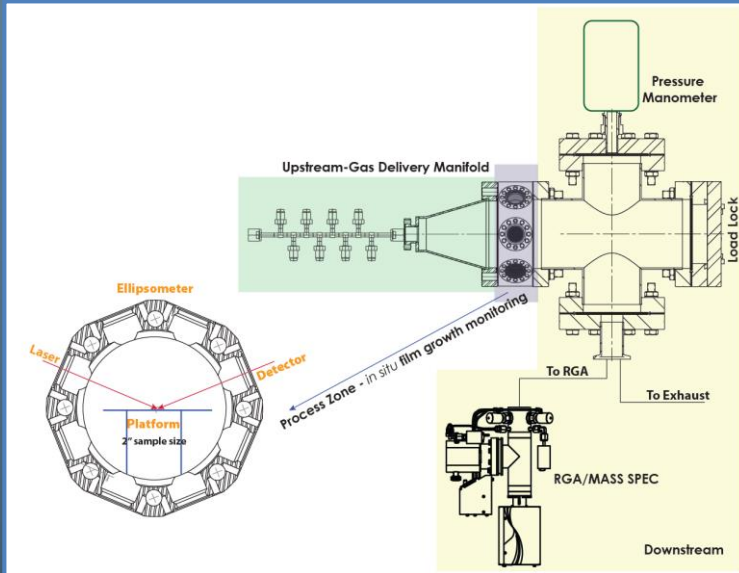
Building off a Commercial Reactor



Commercial Options

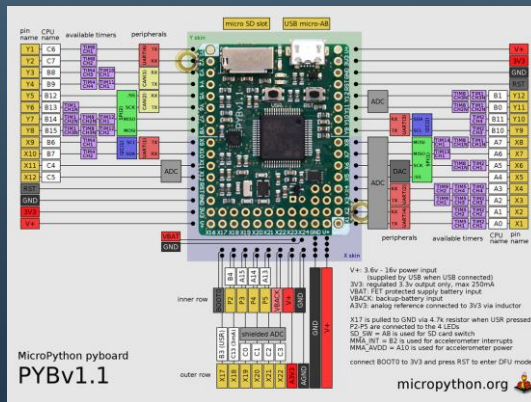
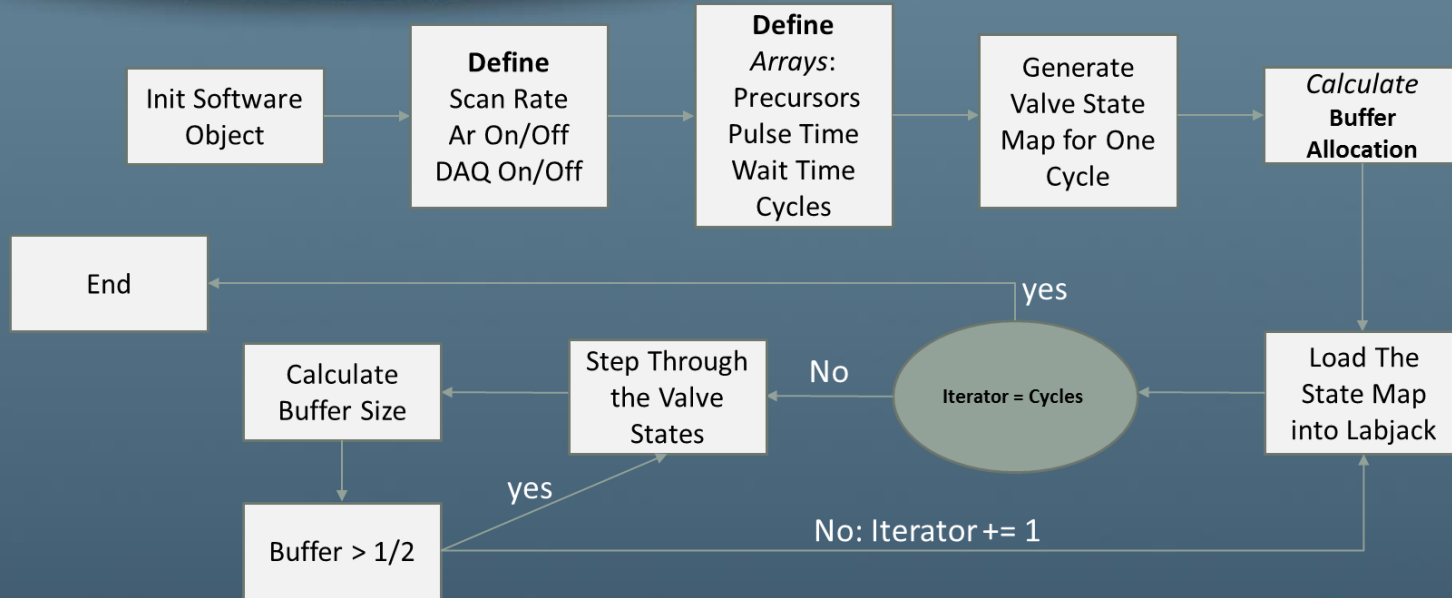


In-House Experimental ALD System

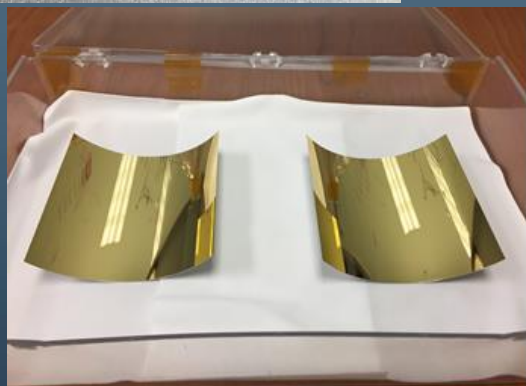




Open Source Solutions

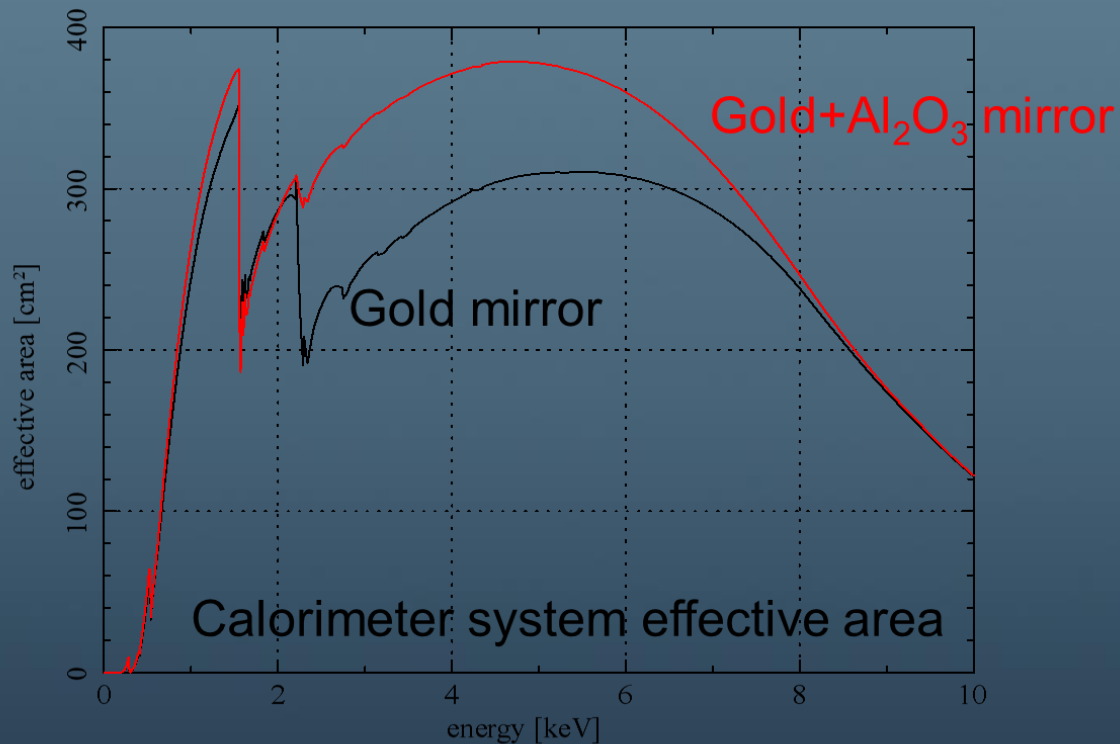


Applications and Results



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

Effective area comparison



ZnO

$E = hc/\lambda$ where:

$f =$ frequency in Hertz ($\text{Hz} = 1/\text{sec}$)

$\lambda =$ wavelength in meters (m)

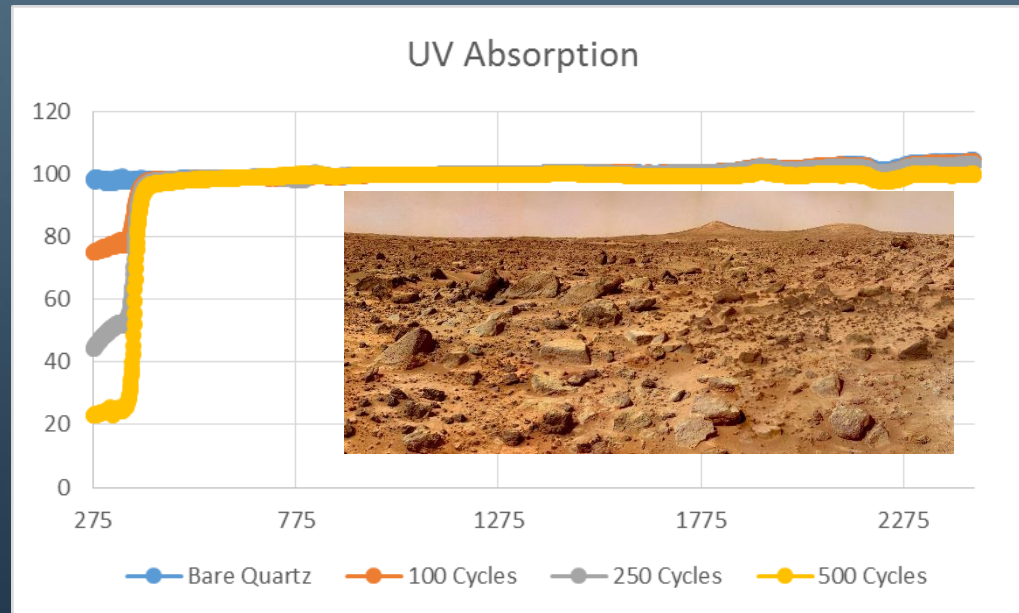
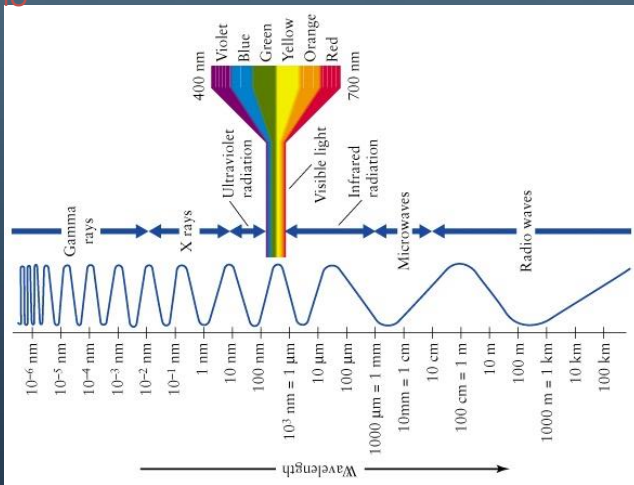
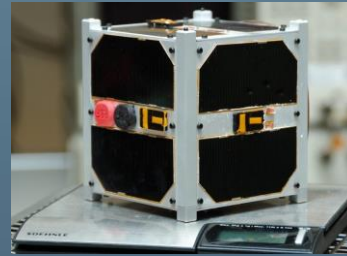
$c =$ the speed of light (299792458 m/s)

$E =$ energy in electron Volts (eV)

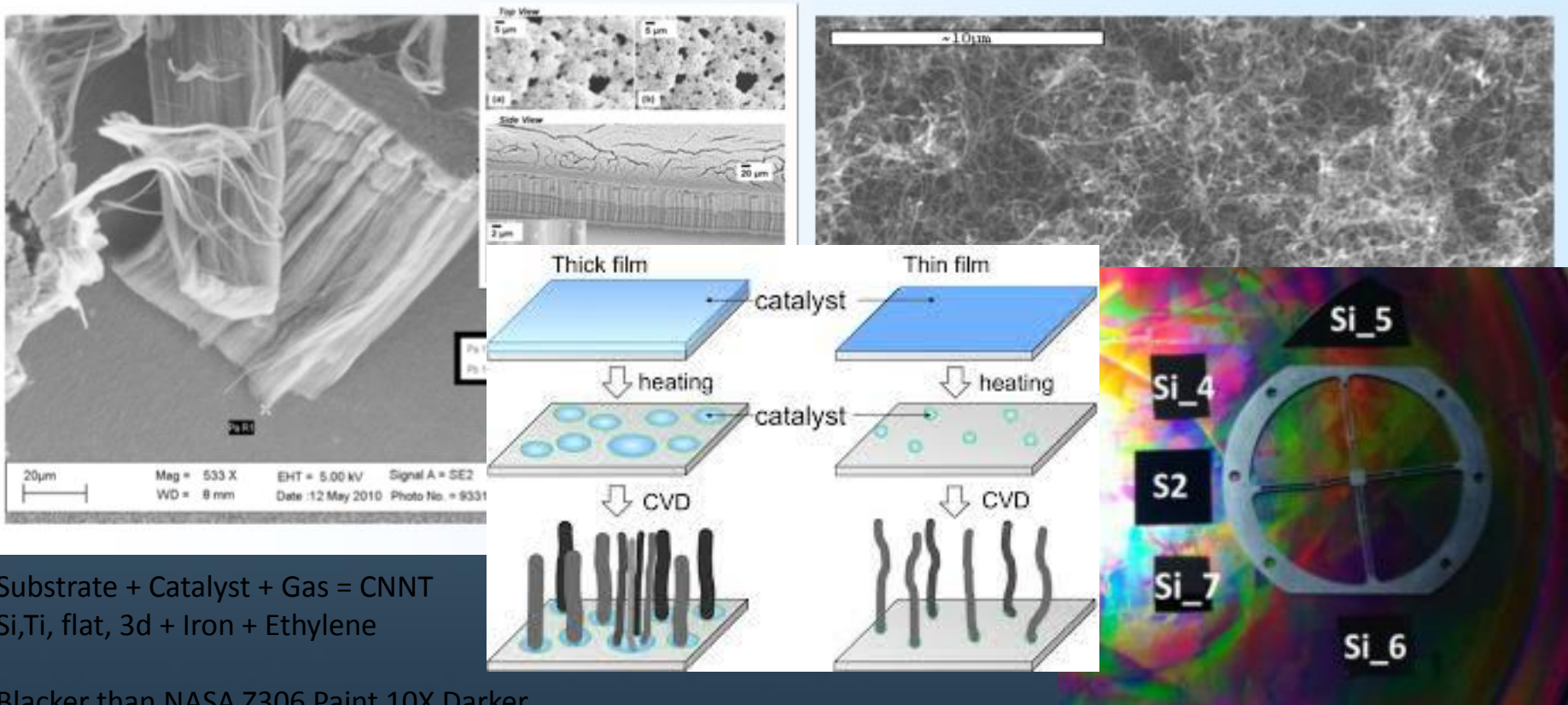
$h =$ Planck's constant ($6.626068 \times 10^{-34} \text{ m}^2\text{kg/s}$)

$E_{\text{ZnO}} = 3.3 \text{ eV}$

$\lambda_{\text{ZnO}} \sim 375 \text{ nm}$



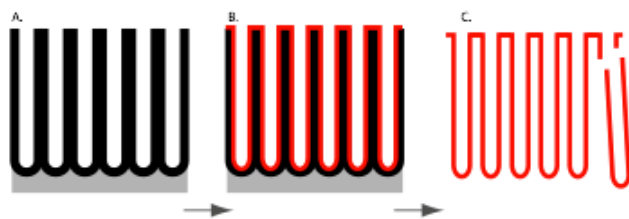
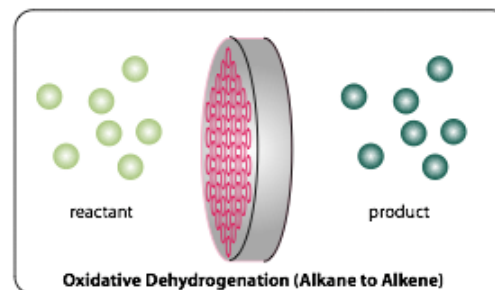
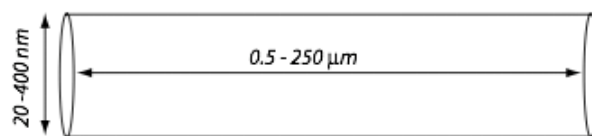
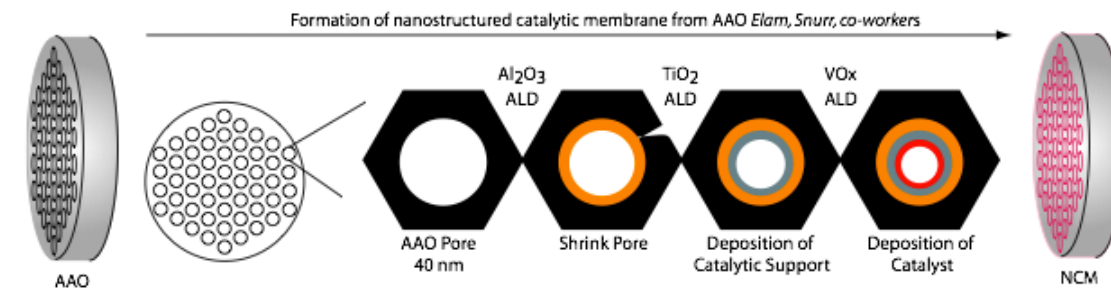
Blacker Than Black Carbon Nanotubes



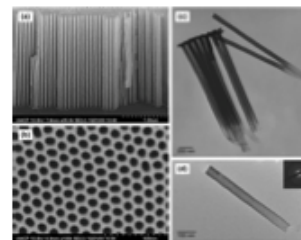
Substrate + Catalyst + Gas = CNNT
Si,Ti, flat, 3d + Iron + Ethylene

Blacker than NASA Z306 Paint 10X Darker

“Build” Nanotubes



Formation of nanotubes: Rubloff Group



Nano capacitor elements by Lee, Rubloff, coworkers, Nature 2008-09

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

INSTRUMENT SYSTEMS & TECHNOLOGY DIVISION

OPTICS BRANCH

CODE 551



- Dr. Takashi Okajima (662)
- Mark Hasegawa (546)
- Dr. Manuel Quijada (551)
- Dr. Raymond Adomaitis (UMD)
- Dr. Brian Iverson (BYU)
- Rydge Mulford (BYU)



Questions?

