



An Introduction to Atomic Layer Deposition



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NASA GSFC Code 545



What is a Thin Film?

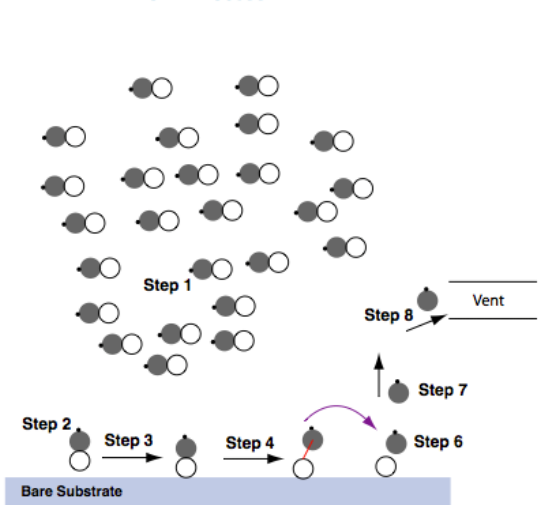
Thin film: **thickness typically $<1000\text{nm}$.**

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

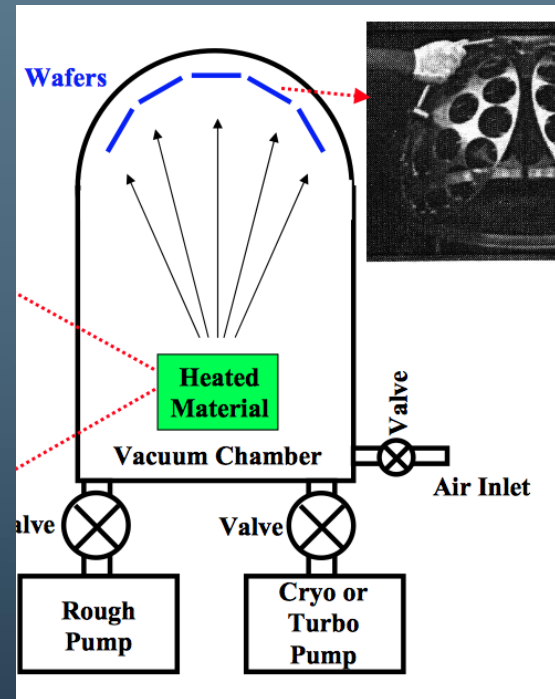
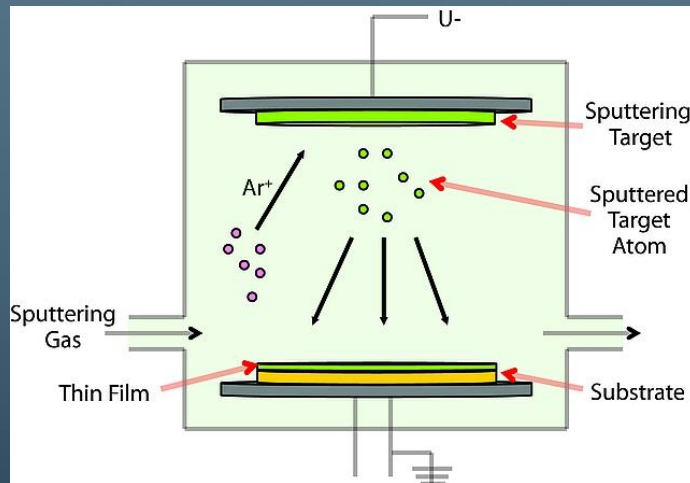
- **Not fully dense**
- **Under stress**
- **Different defect structures from bulk**
- **Quasi - two dimensional (very thin films)**
- **Strongly influenced by surface and interface effects**

Other Deposition Techniques

CVD Process



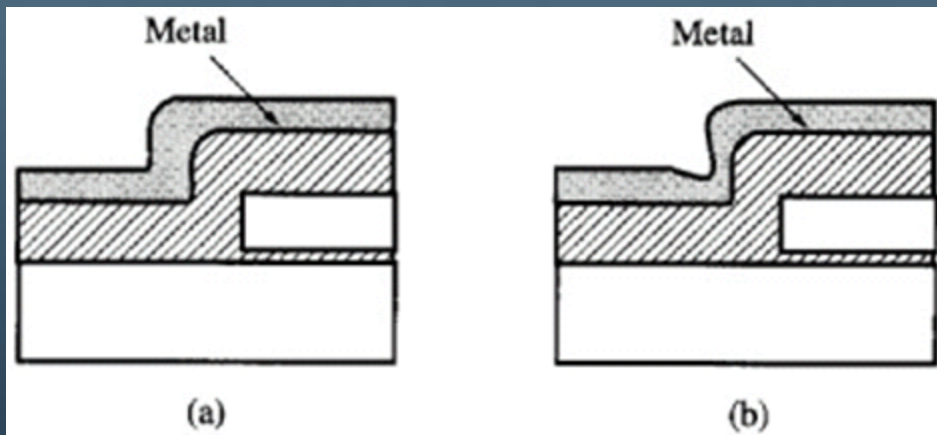
1. Precursor gas phase reaction
2. Diffusion
3. Adsorption
4. Surface Process
5. Desorption
6. Diffusion
7. Purge



Common Denominator

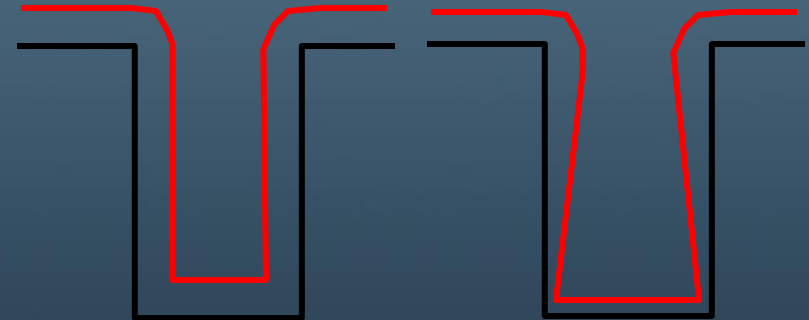
- Deposition only occurs on substrates that “see” the target.
- Plasma process can damage the substrate
- Poor thickness control
- Poor Step Control
- High Pressure High Temperature Environment

Step Coverage Example



conformal

non-conformal



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

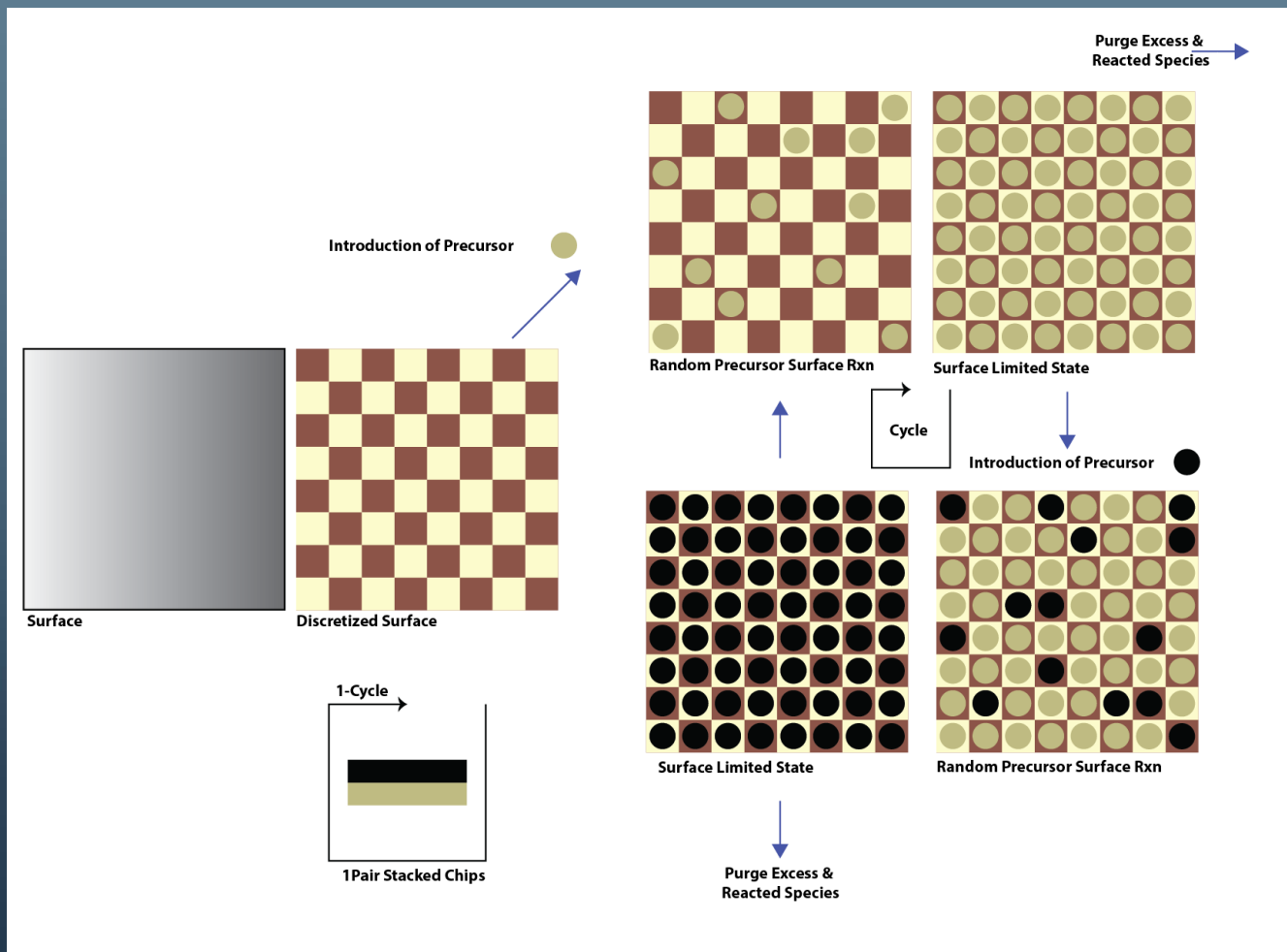


A thin film “nanomanufacturing” tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control.

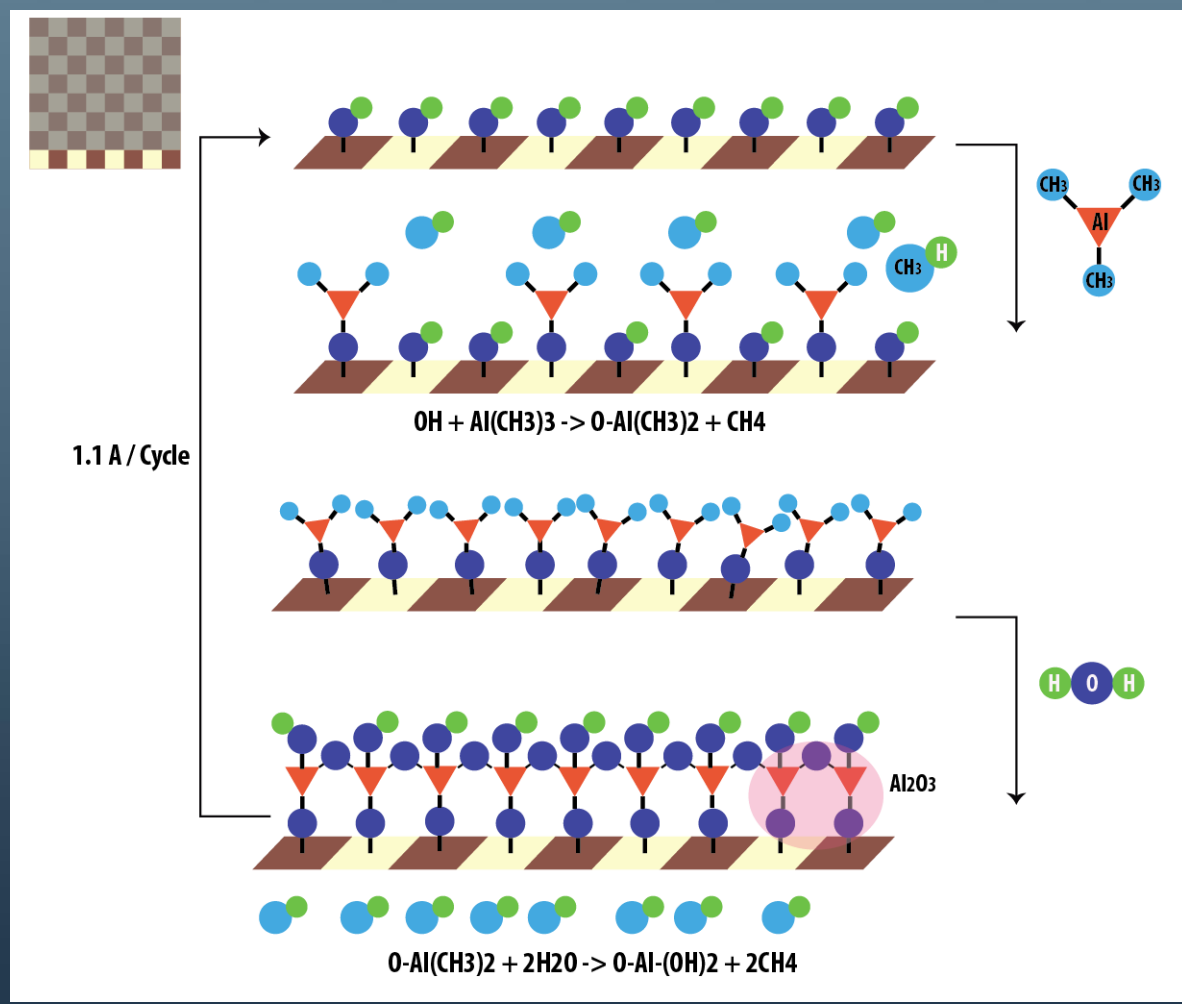
Based on:

- 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 N} B 5	C 6	N 7	O 8	F 9	Ne 10											
Na 11	^O Mg 12 F																	^{O N M} Al 13 P	^{O N M} Si 14 D C	P 15	S 16	Cl 17	Ar 18											
K 19	^O Ca 20 F S	^O Sc 21	^{O N M} Ti 22 S	^O V 23	^O Cr 24	^{O N M} Mn 25 S D	^{O N M} Fe 26	^{O N M} Co 27	^{O N M} Ni 28	^{O N M} Cu 29 S D	^O Zn 30 S F D	^{O N M} Ga 31 P D	^{O N M} Ge 32	As 33	Se 34	Br 35	Kr 36																	
Rb 37	^O Sr 38 F S	^O Y 39	^{O N} Zr 40	^{O N} Nb 41	^{O N M} Mo 42	Tc 43	^{O M} Ru 44	^{O M} Rh 45	^{O M} Pd 46	^{O M} Ag 47	^O Cd 48 S	^{O N} In 49 S P	^O Sn 50 S D	^{O M} Sb 51 D	Te 52	I 53	Xe 54																	
Cs 55	^O Ba 56 S F	^O La 57 F S	^{O N} Hf 72 F S C	^{O N M} Ta 73	^{O N M} W 74	^O Re 75	^O Os 76	^{O M} Ir 77	^{O M} Pt 78	Au 79	^O Hg 80 S	^O Tl 81 D	^O Pb 82 S D	^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 D	^O Pr 59	Nd 60	Pm 61	^O Sm 62	^O Eu 63 D	^O Gd 64	^O Tb 65 D	^O Dy 66	^O Ho 67	^O Er 68	^O Tm 69 D	^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 C:Carbide
 N:Nitride F:Fluoride
 M:Metal D:Dopant
 P:Phosphide/Asenide
 S:Sulphide/Selenide/Telluride

^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)

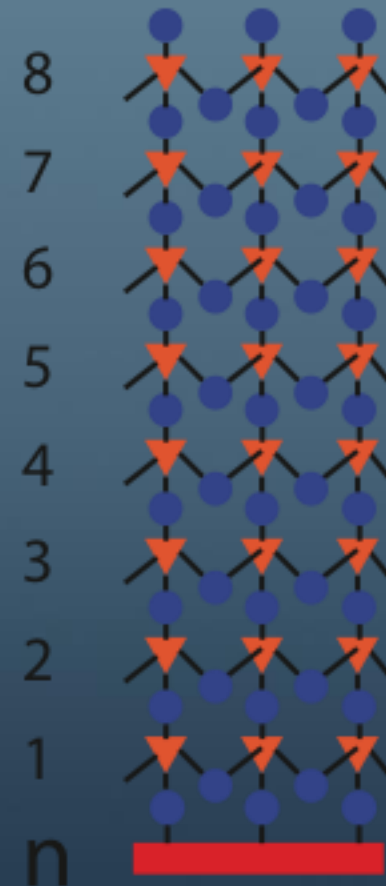
Example:

If 1 monolayer = 1 Å

monolayers = 7

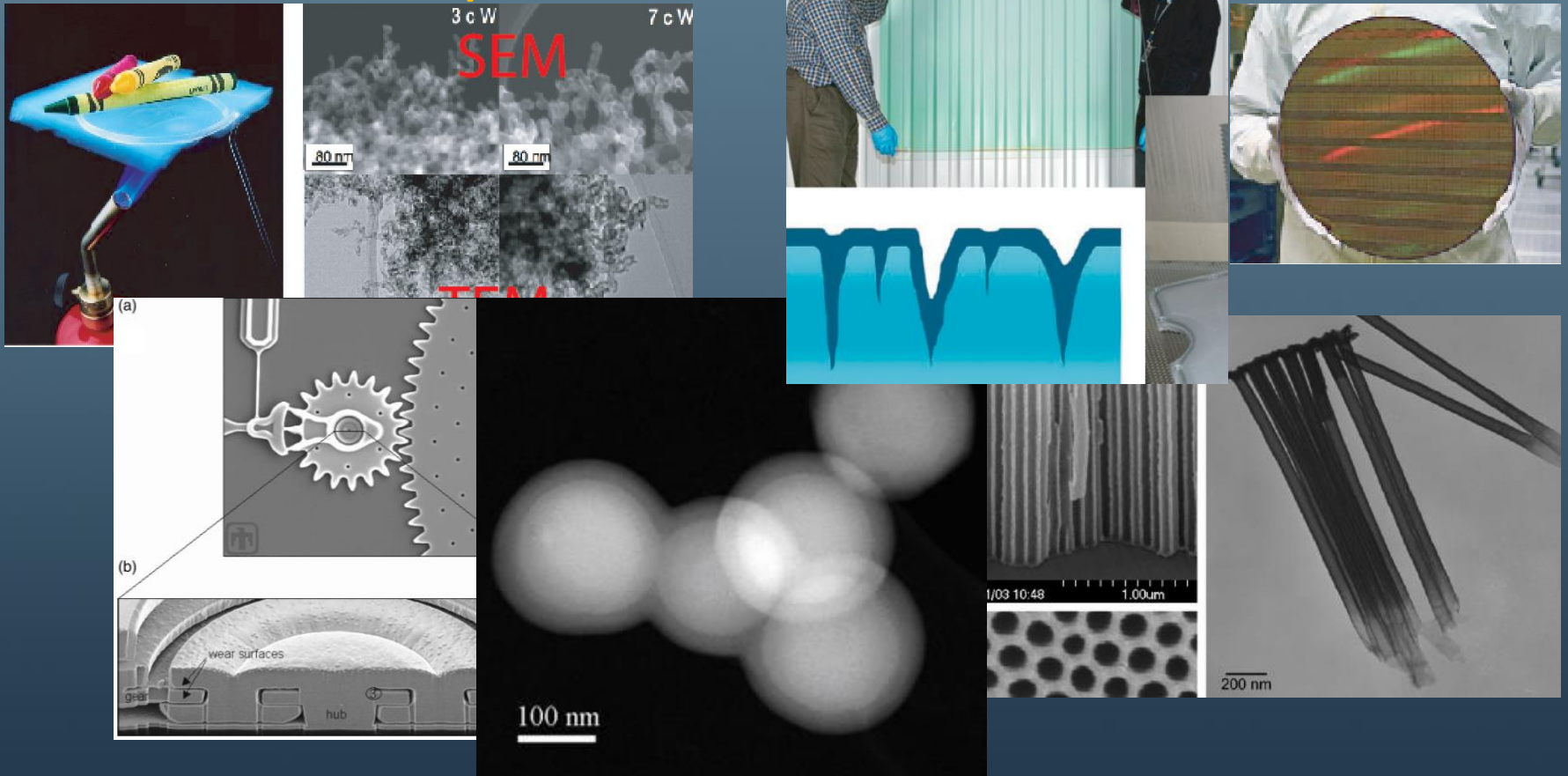
Thickness = 7 Å

Reproducibility



Advantageous Property

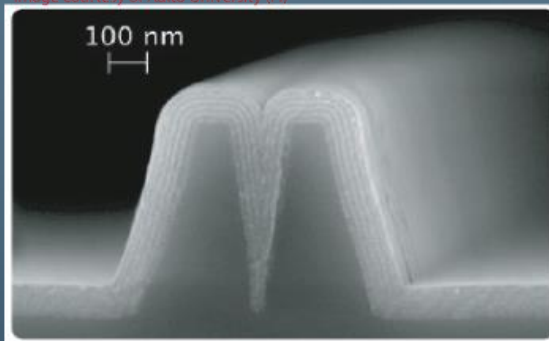
Substrate Independence



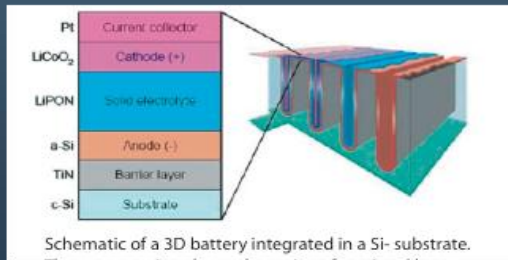
Advantageous Property

Epitaxial Growth

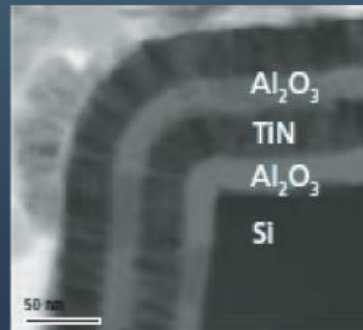
Artificial trench filled with an ALD nanolaminate
Image courtesy of Aalto University (FI)



Multilayer consisting of:
 Al_2O_3 - 25 nm
 TiN - 20 nm
 Al_2O_3 - 25 nm
 Dr. Fred Rosselboom, NXP Semiconductors Research and
 Dr. Erwin Kessels, 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.glassanweb.com/>



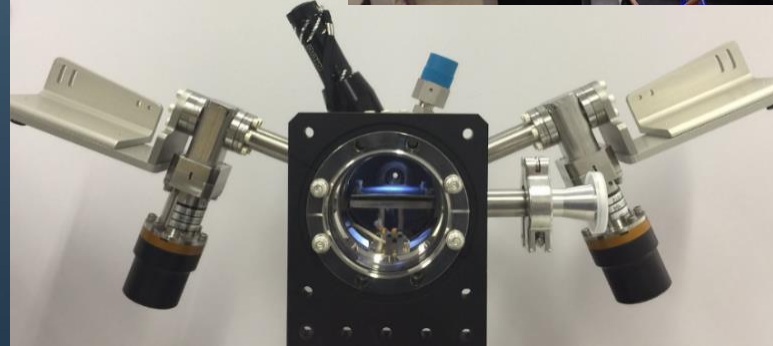
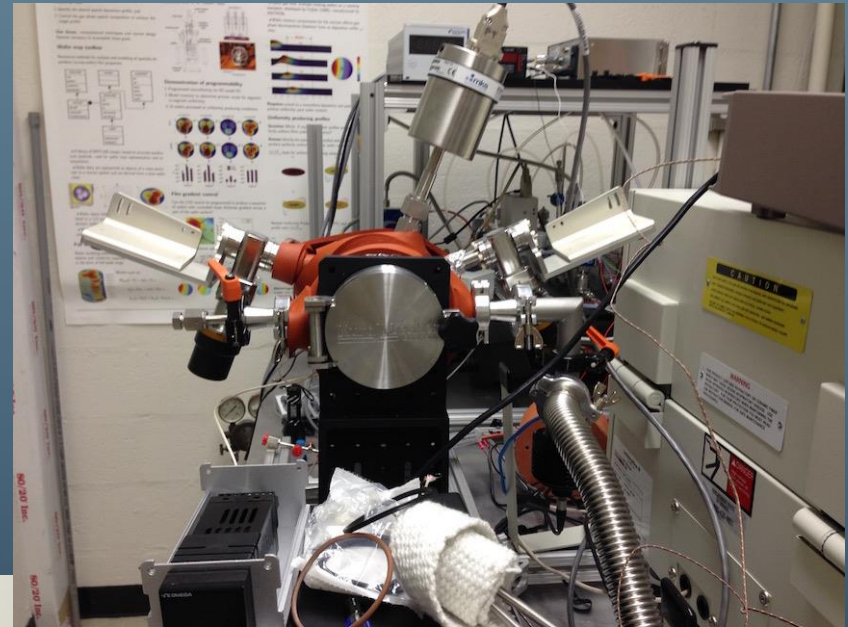
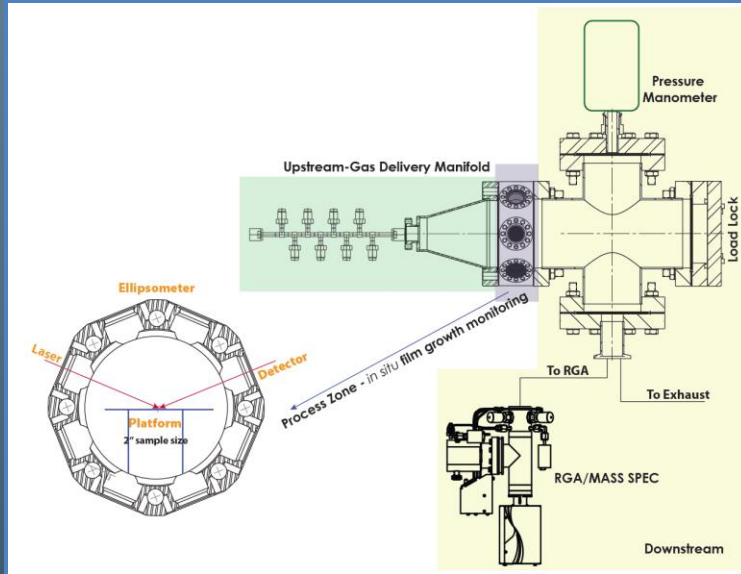


Building off a Commercial Reactor

Commercial Options

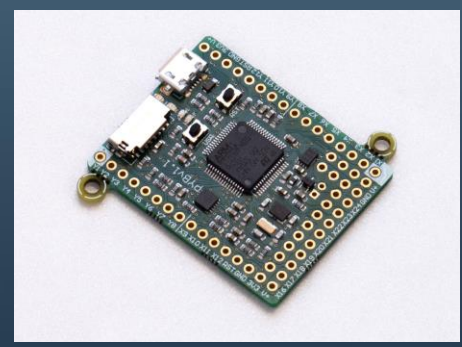
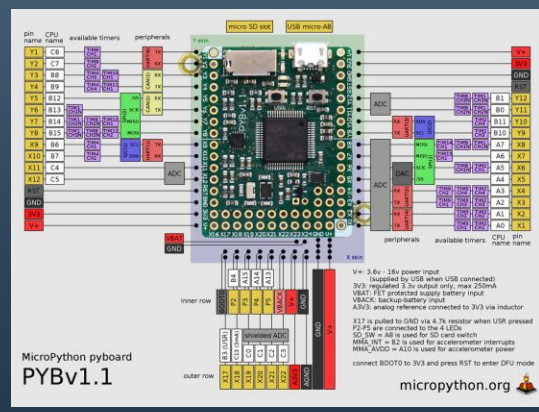
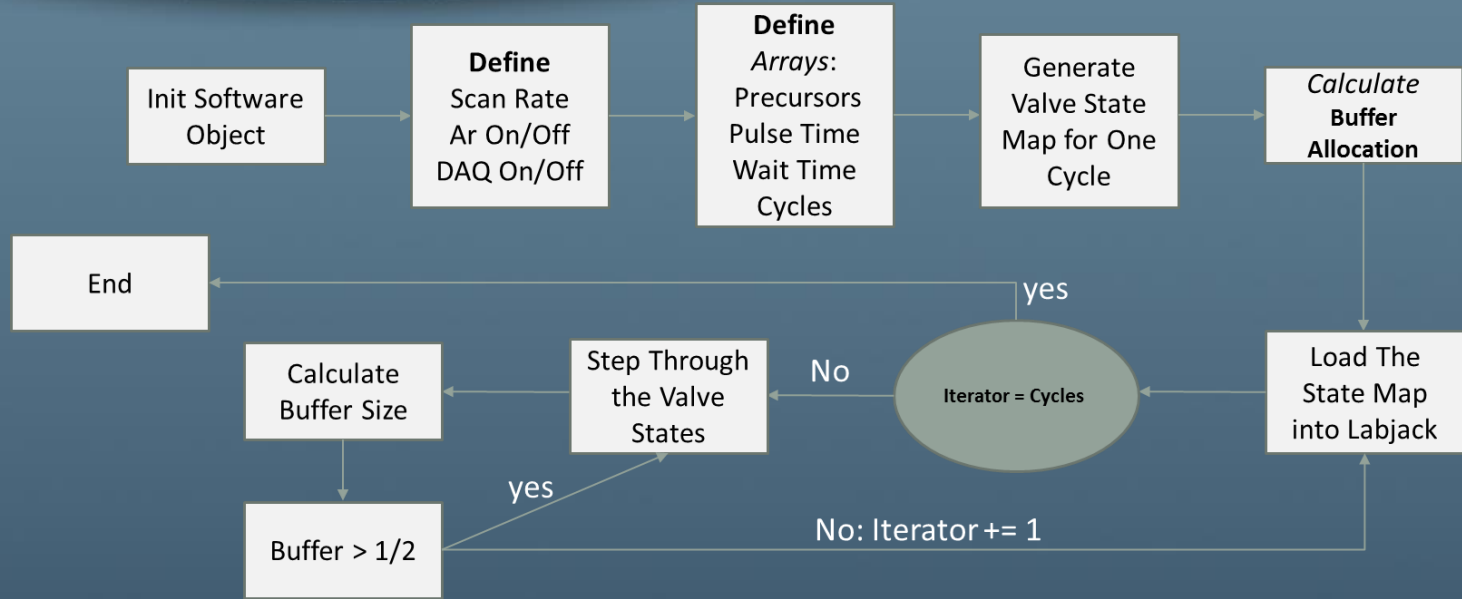


In-House Experimental ALD System

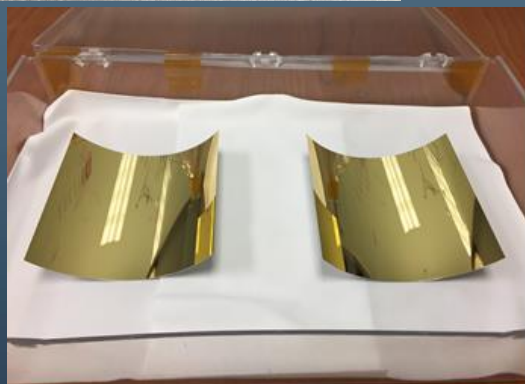




Open Source Solutions

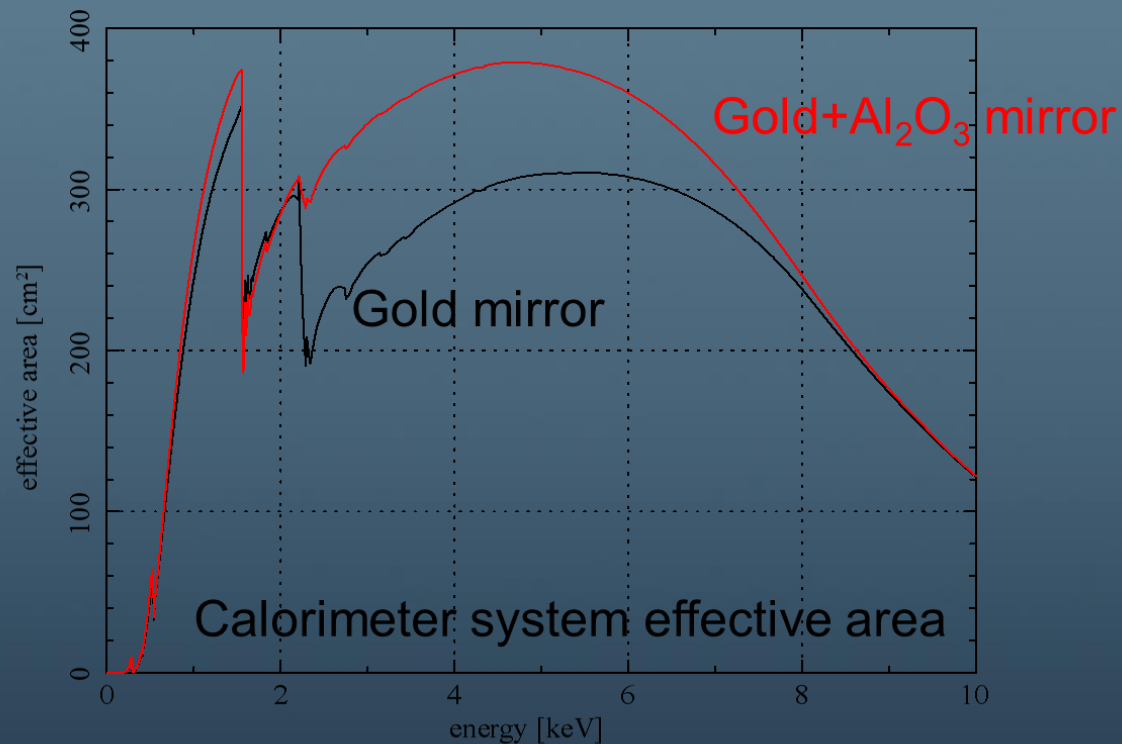


Applications and Results



~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)

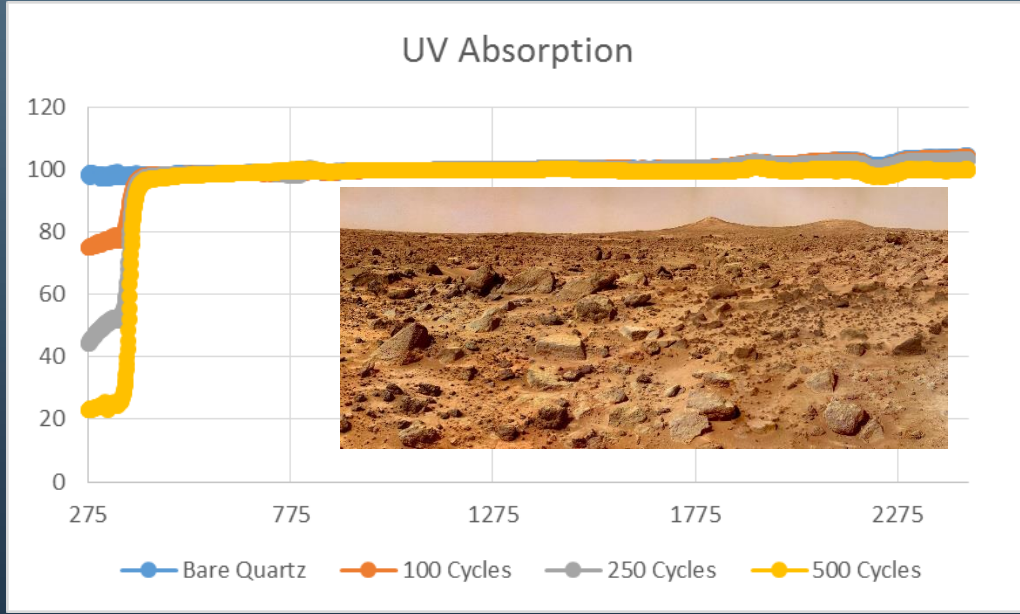
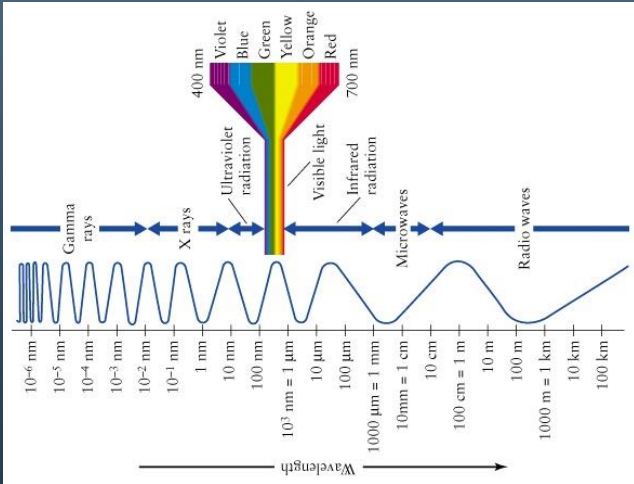
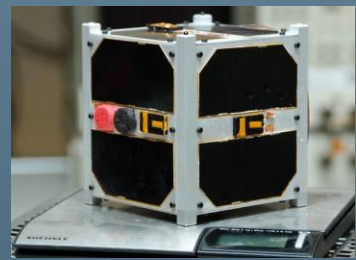
c = the speed of light (299792458 m/s)

E = energy in electron Volts (eV)

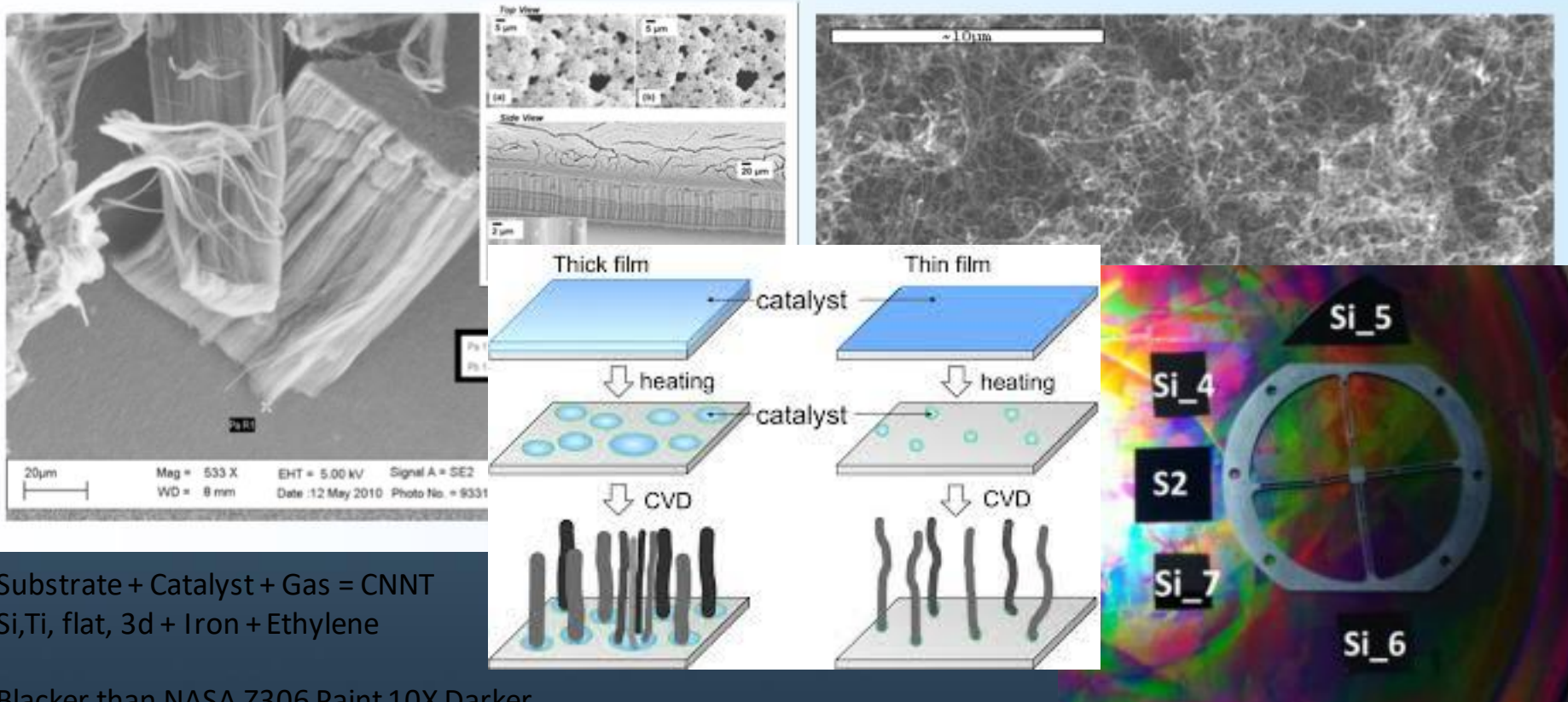
h = Plank's constant (6.626068×10^{-34} m²kg/s)

$E_{ZnO} = 3.3$ eV

$\lambda_{ZnO} \sim 375$ nm



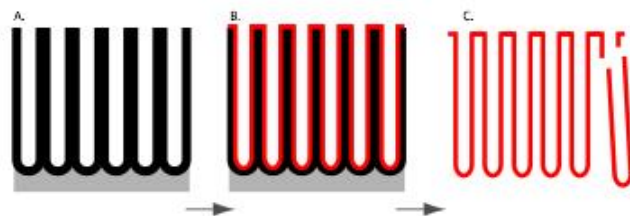
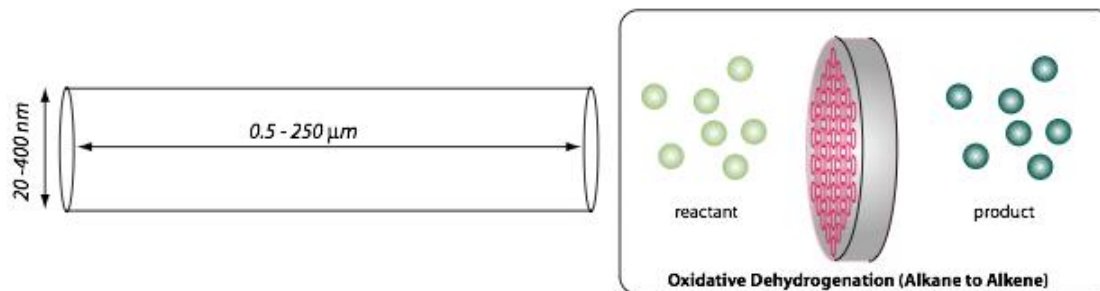
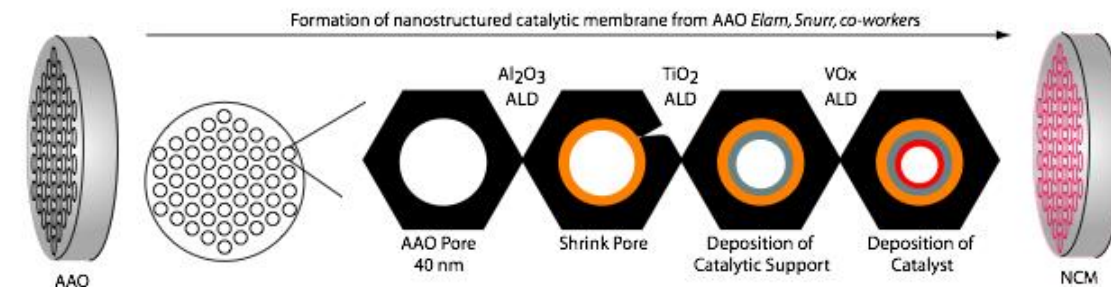
Blacker Than Black Carbon Nanotubes



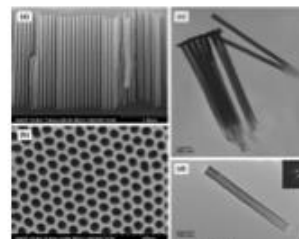
Substrate + Catalyst + Gas = CNNT
Si,Ti, flat, 3d + Iron + Ethylene

Blacker than NASA Z306 Paint 10X Darker

“Build” Nanotubes



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



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Dr. Raymond Adomaitis (UMD)

Dr. Brian Iverson (BYU)

Rydge Mulford (BYU)



Questions?

