THERMAL & FLUIDS ANALYSIS WORKSHOP

GSFC · 2015

An Introduction to Atomic Layer Deposition with Thermal Applications

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NASA GSFC Code 545

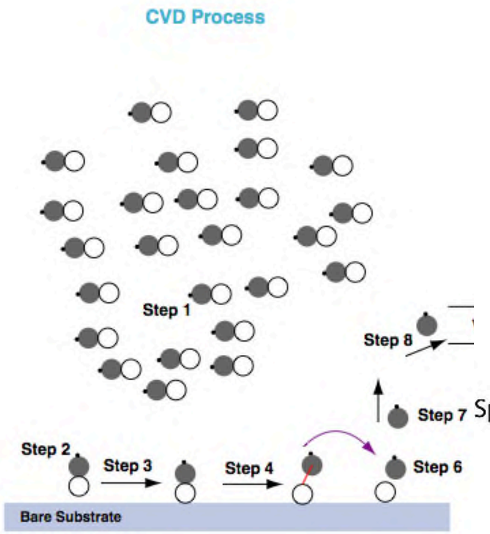
What is a Thin Film?

Thin film: thickness typically <1000nm.

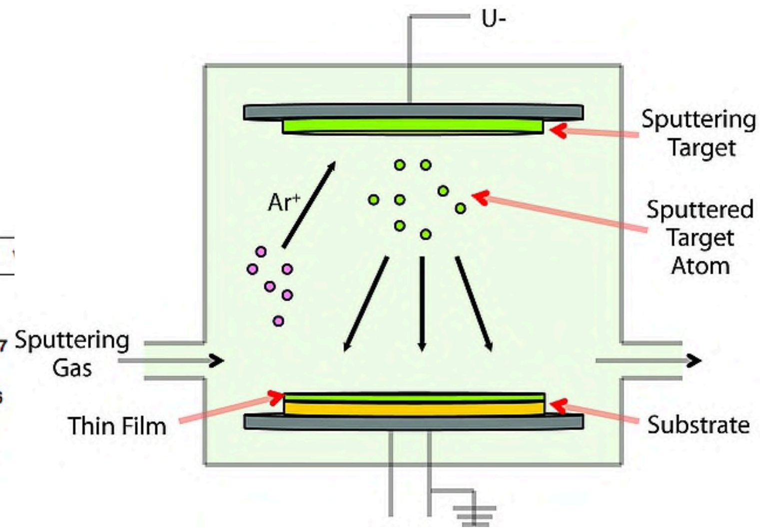
Special properties of thin films: different from bulk materials, it may be –

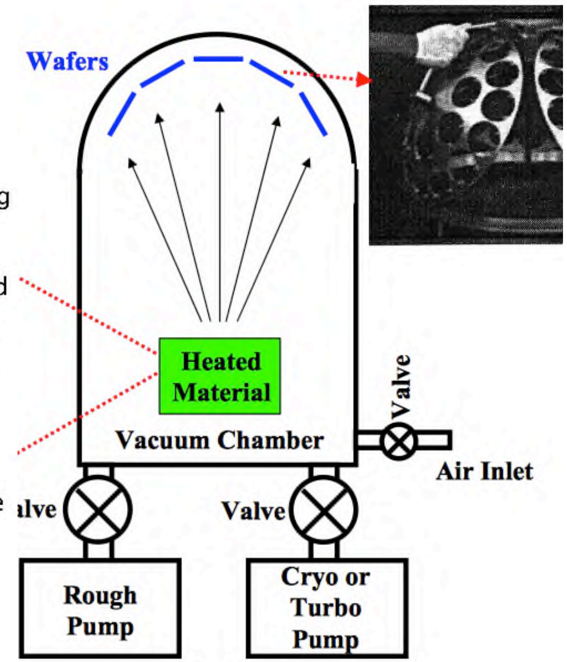
- Not fully dense
- Under stress
- Different defect structures from bulk
- Quasi - two dimensional (very thin films)
- Strongly influenced by surface and interface effects

Other Deposition Techniques



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

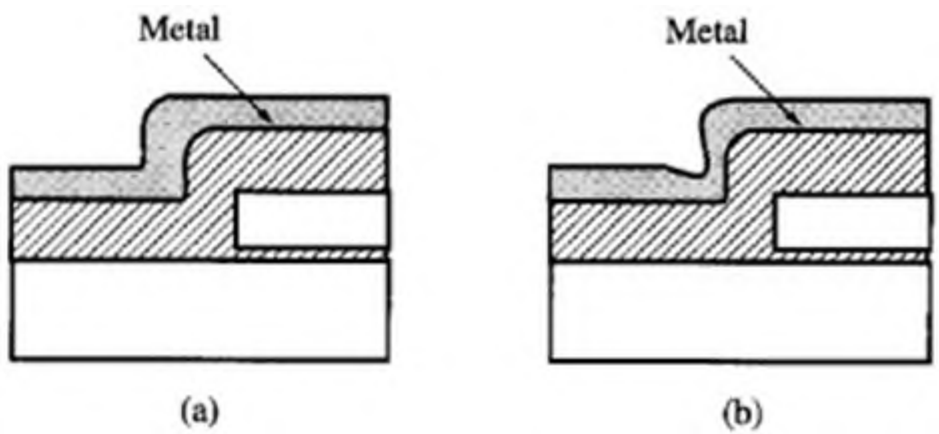




Common Denominator

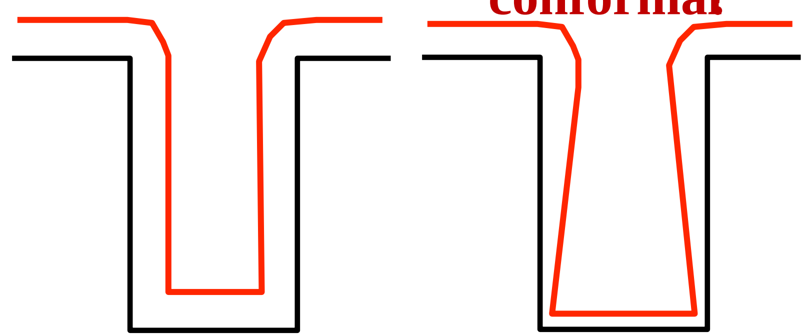
- Deposition only occurs on substrates that “see” the target.!
- Plasma process can damage the substrate!
- Poor thickness control!
- Poor Step Control!
- High Pressure High Temperature Environment!

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

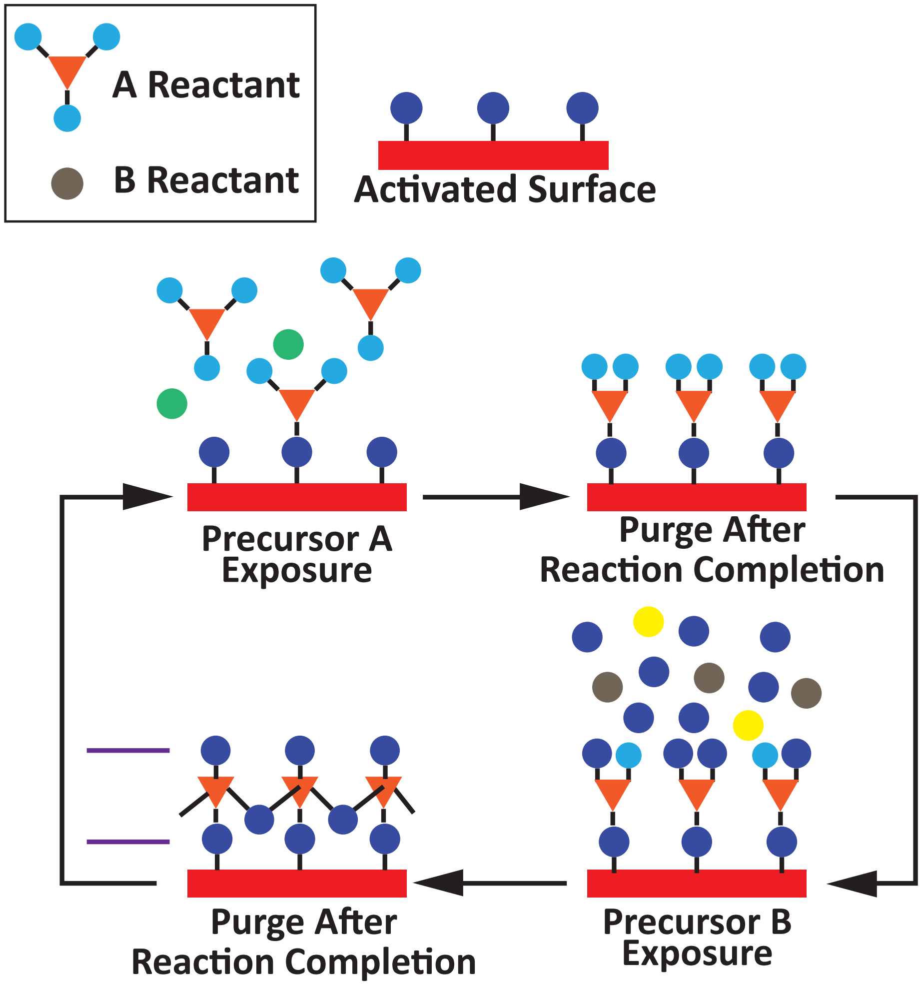
Atomic
Layer
Deposition

} **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



- **A or B exposure = Half Cycle!**
- **A+B = Full Cycle = 1 Monolayer!**
- **Digital Process: ABABABAB!**
- **Not Line of Sight, EVERYTHING GETS COATED!**
- **Substrate Independent**

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)

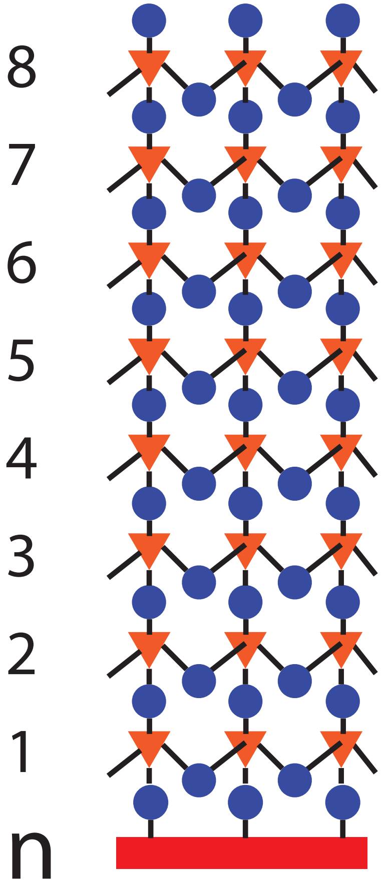
Example:

If 1 monolayer = 1 A

monolayers = 7

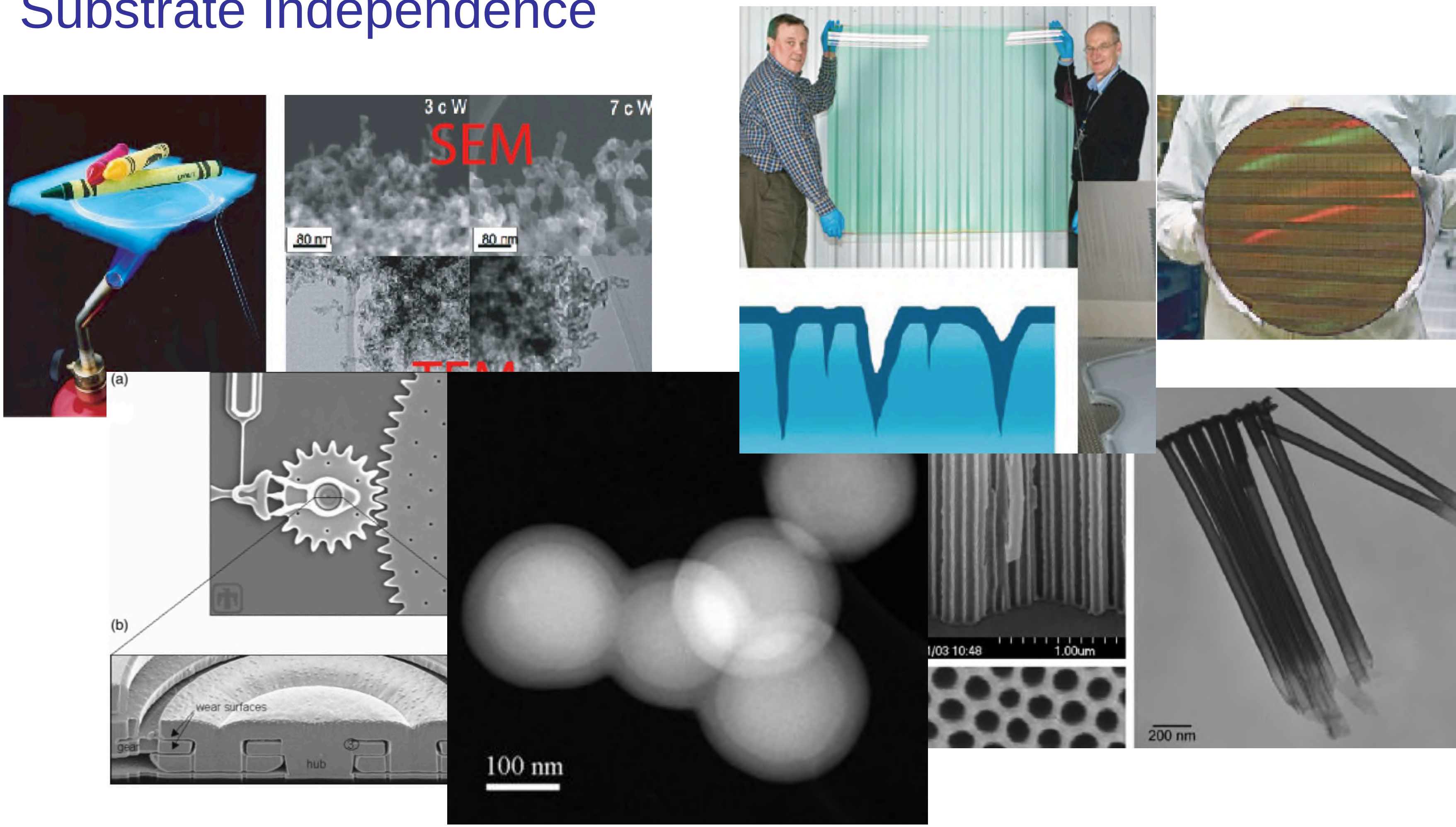
Thickness = 7 A

Reproducibility



Advantageous Property

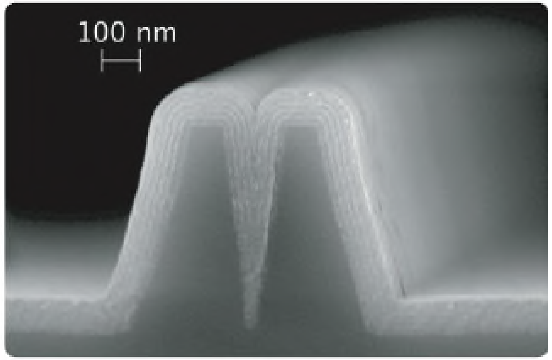
Substrate Independence



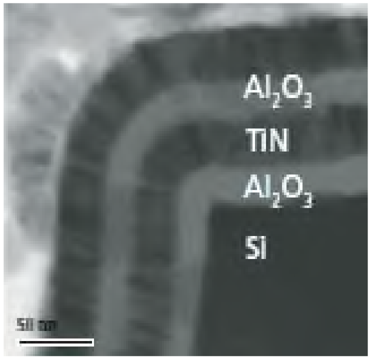
Advantageous Property

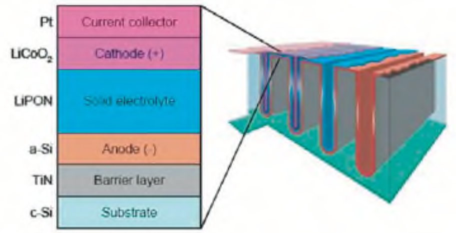
Epitaxial Growth

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



Multilayer consisting of:
Al_2O_3 - 25 nm
TiN - 20 nm
Al_2O_3 - 25 nm
Dr. Fred Roozeboom, NXP Semiconductors Research and
Dr. Erwin Kessels, University of Technology, Eindhovend

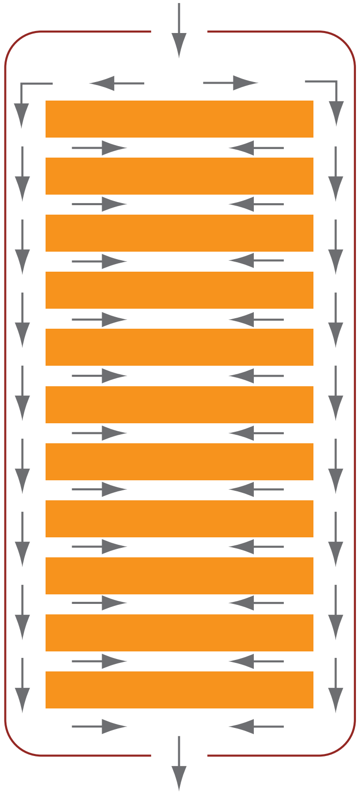




Schematic of a 3D battery integrated in a Si- substrate.
The cross-section shows the various functional layers
in the battery stack as well as the candidate materials.
Knoops, H.C.M. et al., ECS Trans., 25 (2009) pp. 333-344

Batch Process

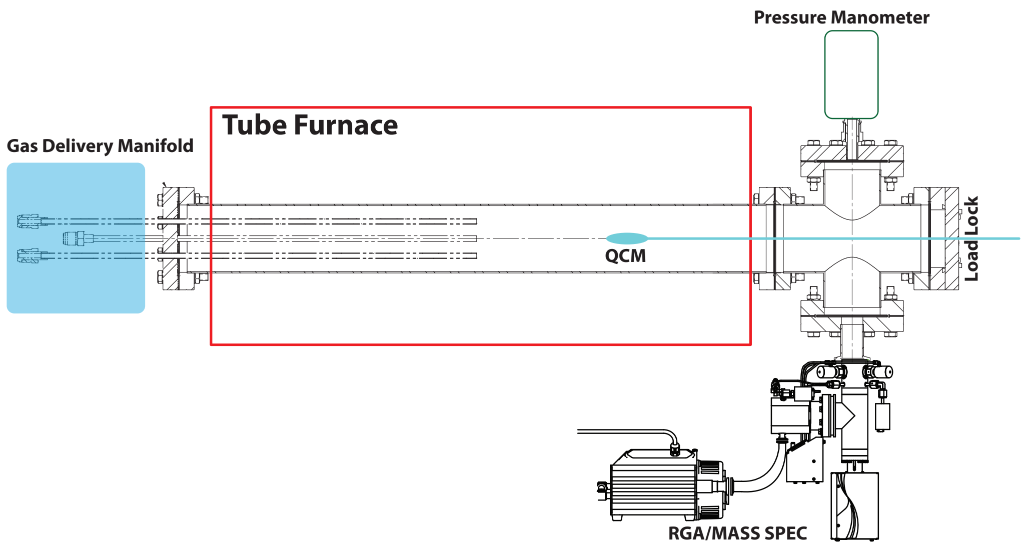
Coating Silver with Aluminum Oxide
http://www.glassonweb.com/

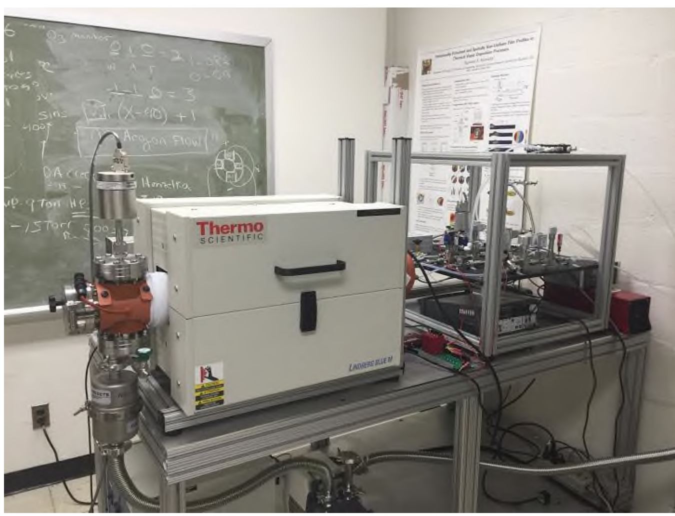


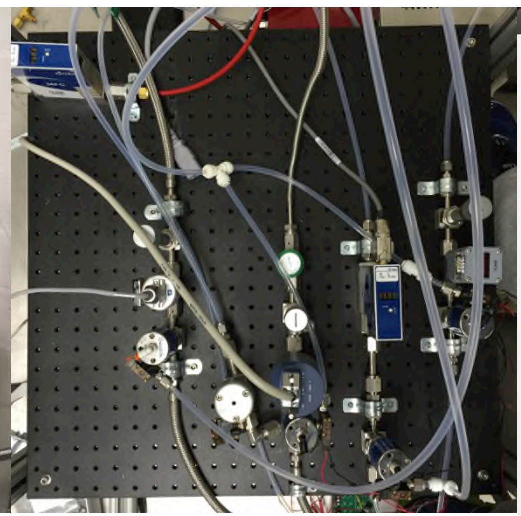
Building off a Commercial Reactor

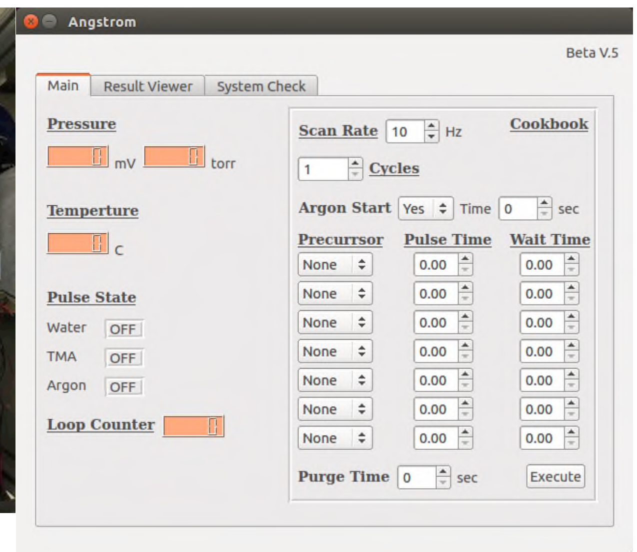
Commercial Options

In-House Experimental ALD System

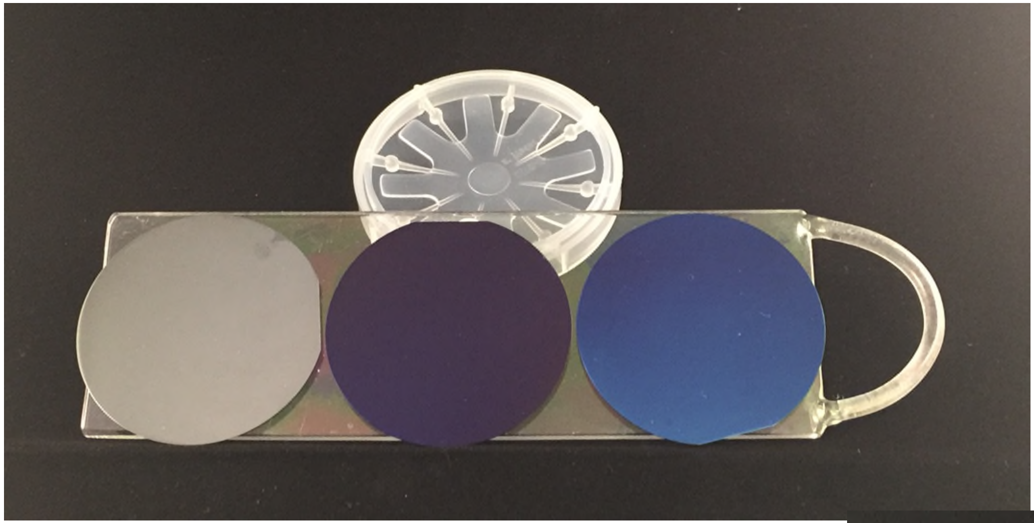


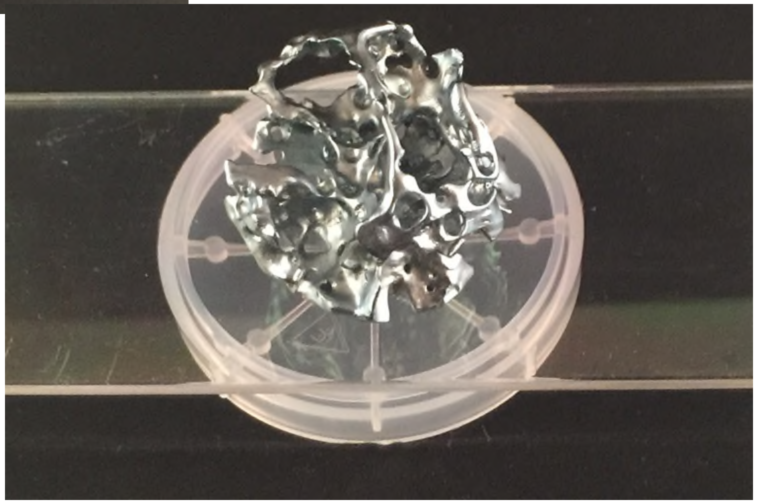




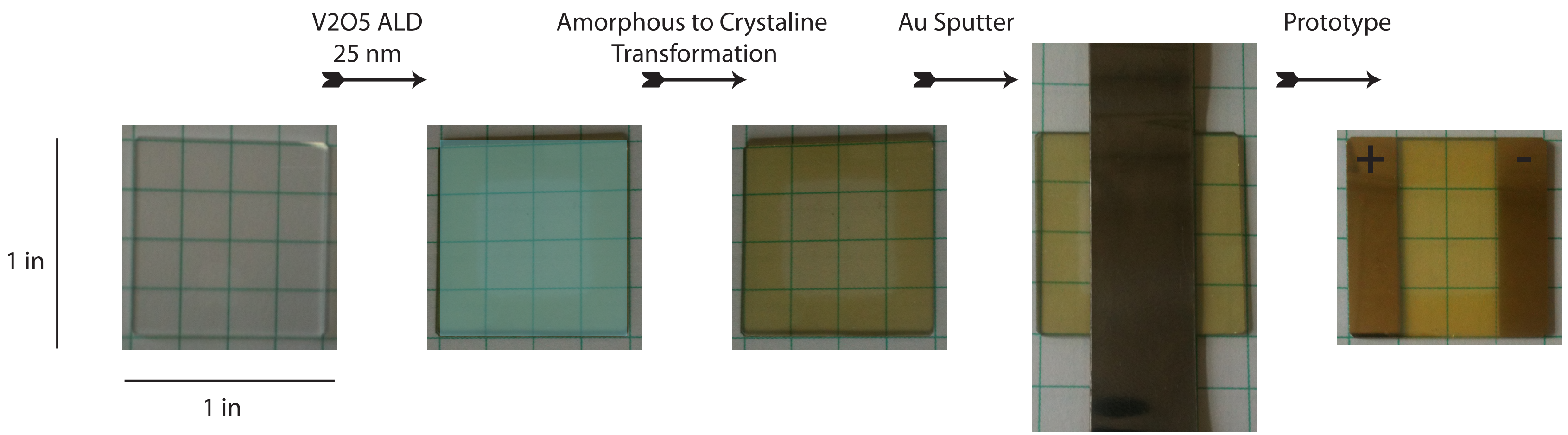


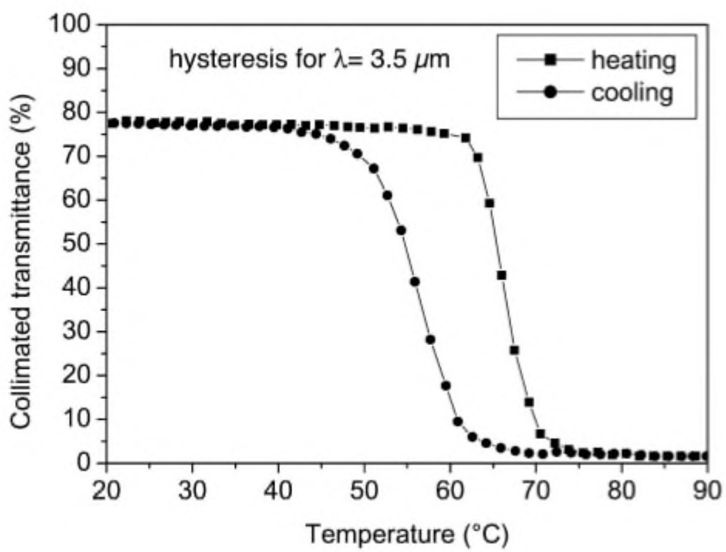
Thermal Applications and Results

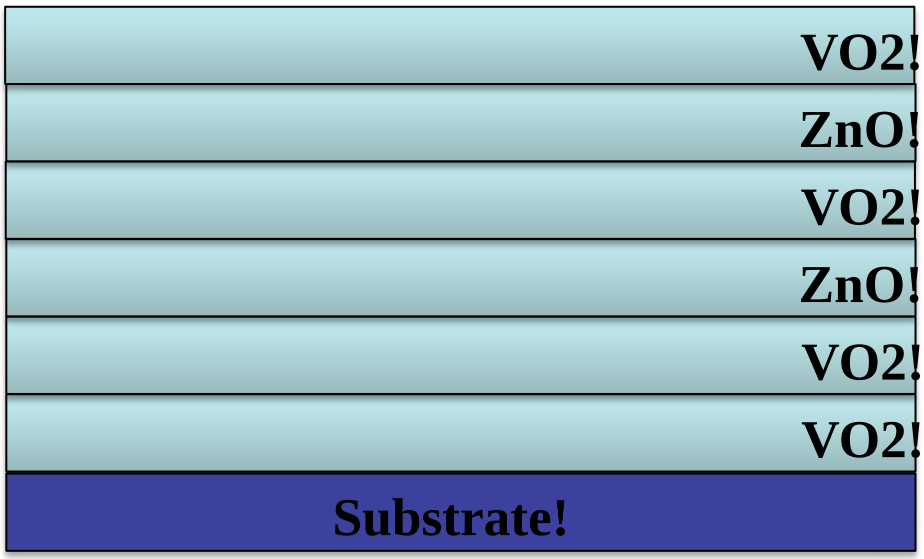




Passive Thermal Films

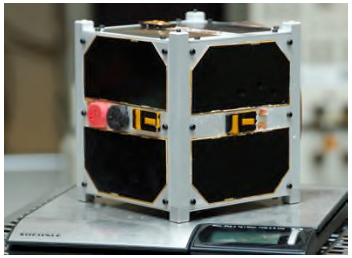


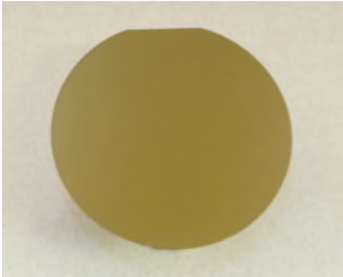


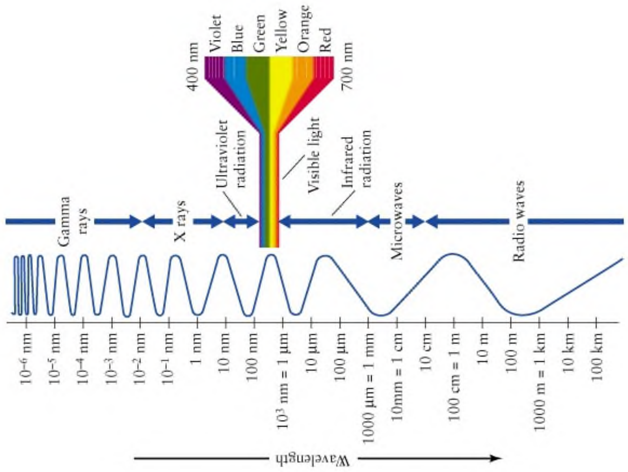


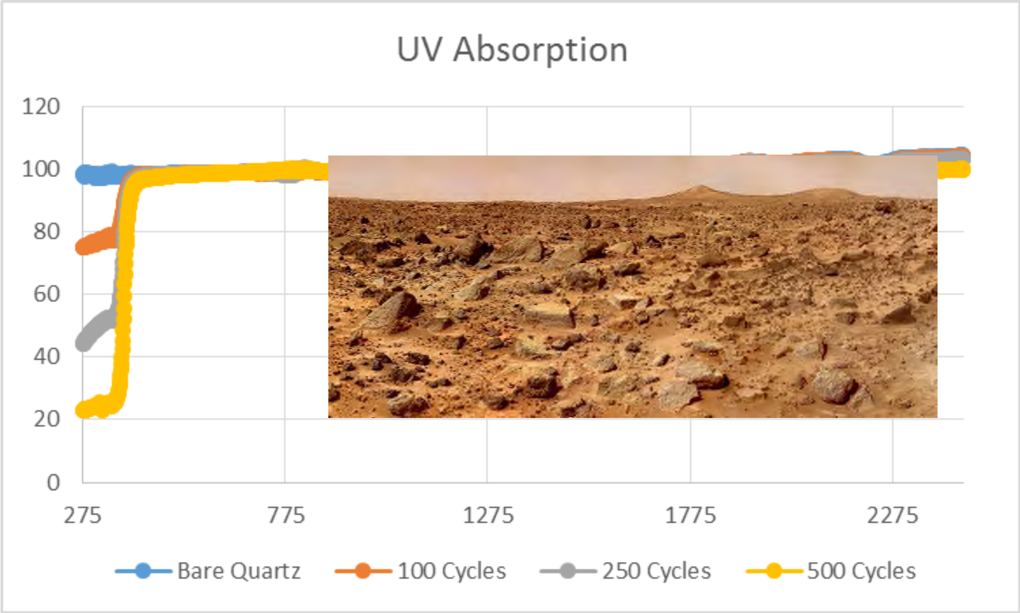
ZnO

E = $^{hc}/_{„}$where: !
f = frequency in Hertz (Hz = $^{1}/_{sec}$) !
" = 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!
$"_{ZnO}$ ~ 375 nm!
!
!
!
!



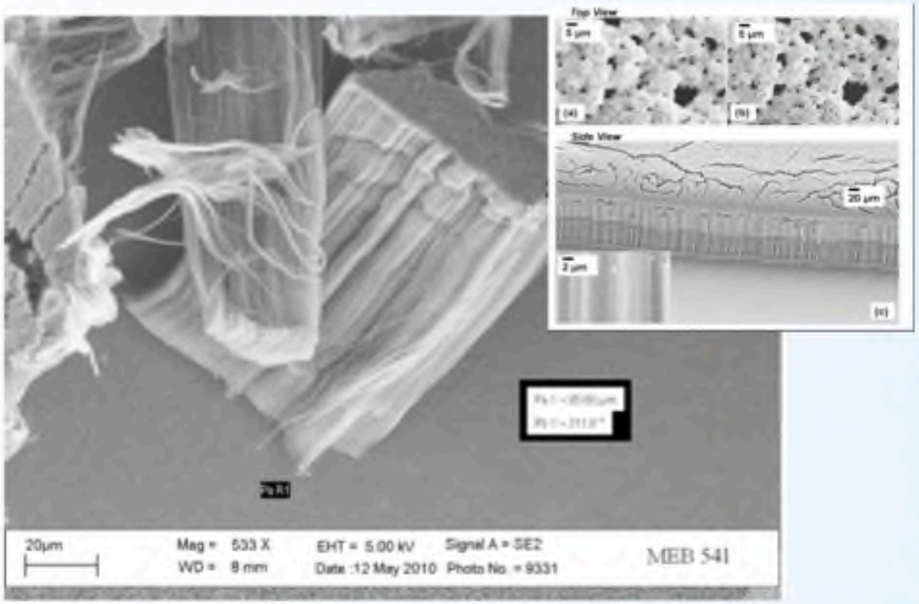


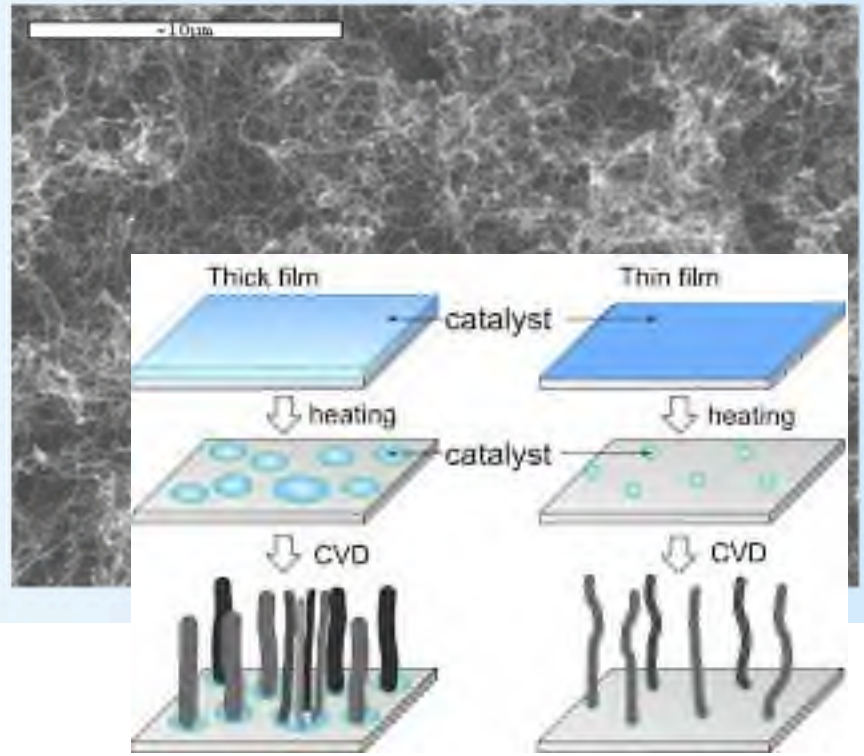




Blacker Than Black Carbon Nanotubes

Fe ALD on Complex Geometries for Carbon Nanotube Growth





Substrate + Catalyst + Gas = CNNT!
Si,Ti, flat, 3d + Iron + Ethylene!
!
Blacker than NASA Z306 Paint 10X Darker!

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!

Questions?