An Introduction to Atomic Layer Deposition

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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

Wafers

Vacuum Chamber

Heated Material

Rough Pump

Cryo or Turbo Pump

Valve

Air Inlet

Valve

Sputtering Gas

Thin Film

Substrate

Sputtering Target

Sputtered Target Atom

U+
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.
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

1.1 Å/Cycle

OH + Al(CH3)3 → O-Al(CH3)2 + CH4

0-Al(CH3)2 + 2H2O → 0-Al-(OH)2 + 2CH4
Acknowledgements
- Elam, Jeffrey (2007). ALD Thin Film Materials. Argonne National Laboratory
Precise Thickness Control

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

Example:

If 1 monolayer = 1 Å

# monolayers = 7

Thickness = 7 Å

Reproducibility
Advantageous Property

Substrate Independence
Advantageous Property

Epitaxial Growth

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. 

Kaneppi, K.C. et al., ECS Trans., 23 (2009), pp. 233-244

Batch Process

Multi-layer consisting of:
- Al2O3 - 25 nm
- TiN - 10 nm
- Al2O3 - 25 nm

Fabrication Process: NASA Glenn Research Center and SLAC National Accelerator Laboratory. 

Casting Silver with Aluminum Oxide
http://www.glassonweb.com/
Building off a Commercial Reactor

Commercial Options
In-House Experimental ALD System
Open Source Solutions

- Init Software Object
- Define Scan Rate
  - Ar On/Off
  - DAQ On/Off
- Define Arrays:
  - Precursors
  - Pulse Time
  - Wait Time
  - Cycles
- Generate Valve State Map for One Cycle
- Calculate Buffer Allocation
- Calculate Buffer Size
- Step Through the Valve States
- Buffer > 1/2
- Yes: Load The State Map into Labjack
- No: Iterate = Cycles
- No: Iterator += 1
- End

[Images of circuit board and microcontroller]
Applications and Results

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

Effective area comparison

Gold+Al₂O₃ mirror

Gold mirror

Calorimeter system effective area
ZnO

\[ E = \frac{hc}{\lambda} \] where:

- \( f \) = frequency in Hertz (Hz = \( \frac{1}{\text{sec}} \))
- \( \lambda \) = wavelength in meters (m)
- \( c \) = the speed of light (299,792,458 m/s)
- \( E \) = energy in electron Volts (eV)
- \( h \) = Plank's constant (6.626068 \( \times \) 10\(^{-34} \) m\(^2\)kg/s)

\( E_{\text{ZnO}} = 3.3 \) eV

\( \lambda_{\text{ZnO}} \sim 375 \) 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 nanostructured catalytic membrane from AAO. Elsm, Snurr, co-workers

AAO

Formation of nanotubes: Rubloff Group

Oxidative Dehydrogenation (Alkane to Alkene)

reactant

product

Nano capacitor elements by Lee, Rubloff coworkers. Nature 2008-09
Atomic Oxygen Protection

100 nm on Kapton
1000 Cycles
155 °C
Al₂O₃

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

99% mass retention after a simulated 5 year flux
Strategic Partnerships

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Questions?

Any Questions?