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

CVD Process

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

Wafers

Heated Material

Vacuum Chamber

Rough Pump

Cryo or Turbo Pump
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

Introduction of Precursor → Surface

Discretized Surface

Random Precursor Surface Rxn → Surface Limited State

Cycle

Introduction of Precursor

Surface Limited State

Random Precursor Surface Rxn

Purge Excess & Reacted Species

1-Cycle

1Pair Stacked Chips

Purge Excess & Reacted Species
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
Periodic Table of ALD Films

Acknowledgements
• Elam, Jeffrey (2007). ALD Thin Film Materials. Argonne National Laboratory
Precise Thickness Control

\[ \text{Thickness} = F \left( \# \text{ monolayers} \right) \]

Example:
If 1 monolayer = 1 A
\[ \# \text{ monolayers} = 7 \]
 Thickness = 7 A

Reproducibility
Advantageous Property

Substrate Independence
Advantageous Property

Epitaxial Growth

Artificial trench filled with an ALD nanolaminate
Image courtesy of Victor S. Volskiy

Batch Process

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

Multilayer consisting of:
N2O3 - 25 nm
TIN - 10 nm
Al2O3 - 25 nm

Mod. J. C.У.В., 2008. Advanced Materials Research, vol. 11, Space Science Laboratory of Technology, California

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

Commercial Options

[Image of commercial reactor options]
In-House Experimental ALD System
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

energy [keV]
$E = \frac{hc}{\lambda}$ where:
- $f$ = frequency in Hertz (Hz = $\frac{1}{\text{sec}}$)
- $\lambda$ = wavelength in meters (m)
- $c$ = the speed of light ($299792458 \text{ m/s}$)
- $E$ = energy in electron Volts (eV)
- $h$ = Plank's constant ($6.626068 \times 10^{-34} \text{ m}^2\text{kg/s}$)

$E_{\text{ZnO}} = 3.3 \text{ eV}$
$\lambda_{\text{ZnO}} \approx 375 \text{ nm}$
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 nanostructured catalytic membrane from AAO Elsm, Snurr, co-workers

AAO Pore 40 nm → Shrink Pore → Deposition of Catalytic Support → Deposition of Catalyst → NCM

20-400 nm → 0.5-250 μm

Oxidative Dehydrogenation (Alkane to Alkene)

A → B → C

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
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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Rydge Mulford (BYU)
Questions?

ANY QUESTIONS?