An Introduction to Atomic Layer Deposition with Thermal Applications

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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
• 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.
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
• 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

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<th>Periodic Table of ALD Films</th>
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Acknowledgements!

- Elam, Jeffrey (2007). ALD Thin Film Materials. Argonne National Laboratory!
Precise Thickness Control
Thickness = \( T \) (# monolayers)
Example:
If 1 monolayer = 1 Å
# monolayers = 7
Thickness = 7 Å
Reproducibility
Advantageous Property

Substrate Independence
Epitaxial Growth

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

Multilayer consisting of:
Al2O3 - 25 nm
TaN - 20 nm
Al2O3 - 25 nm
Dr. Fred Roozeboom, 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.

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

Batch Process
Building off a Commercial Reactor

Commercial Options
In-House Experimental ALD System

Tube Furnace
Pressure Manometer
Load Lock
Gas Delivery Manifold
QCM
RGA/MASS SPEC

TFAWS 2015 – August 3-7, 2015 – Silver Spring, MD
Passive Thermal Films

V2O5 ALD 25 nm
Amorphous to Crystalline Transformation
Au Sputter
Prototype

VO2
ZnO
VO2
ZnO
VO2
Substrate!
E = \frac{hc}{\lambda} \text{ where: !}

f = \text{frequency in Hertz (Hz = } \frac{1}{\text{sec}}\text{)}!

\lambda = \text{wavelength in meters (m)}!

c = \text{the speed of light (} 299792458 \text{ m/s)}!

E = \text{energy in electron Volts (eV)}!

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

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

\lambda_{ZnO} \approx 375 \text{ nm}!
Substrate + Catalyst + Gas = CNNT!
Si,Ti, flat, 3d + Iron + Ethylene!
!
Blacker than NASA Z306 Paint 10X Darker!
100 nm on Kapton!
1000 Cycles!
155 °C!
$\text{Al}_2\text{O}_3$!

GPM Funded an experiment!
at Glenn to determine AO effects!
on materials.!
99% mass retention after a simulated!
5 year flux!
Questions?

ANY QUESTIONS?