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
Other Deposition Techniques

1. Precursor gas phase reaction
2. Diffusion
3. Adsorption
4. Surface process
5. Desorption
6. Diffusion
7. Purge
• 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 (ALD) is a thin film “nanomanufacturing” tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control. It is 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!

- Elam, Jeffrey (2007). ALD Thin Film Materials. Argonne National Laboratory!
Precise Thickness Control
Thicknness = $F (\# \text{ monolayers})$

Example:
If 1 monolayer = 1 Å
# monolayers = 7
Thicknness = 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
- TiN - 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.

Batch Process

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

Building off a Commercial Reactor
Passive Thermal Films

V2O5 ALD 25 nm
Amorphous to Crystalline Transformation
Au Sputter
Prototype

Substrate!

VO2
ZnO
VO2
ZnO
VO2
VO2

hysteresis for λ = 3.5 μm

Collimated transmittance (%)

Temperature (°C)
ZnO

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

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

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

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

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

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

\[ E_{\text{ZnO}} = 3.3 \text{ eV} \]

\( \lambda_{\text{ZnO}} \approx 375 \text{ nm} \)
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!
Al$_2$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?