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
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
Acknowledgements!

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

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

Example:
If 1 monolayer = 1 A

$\# \text{ monolayers} = 7$

Thickness = 7 A

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
In-House Experimental ALD System
Passive Thermal Films

VO₂
ZnO
VO₂
ZnO
VO₂
VO₂
Substrate!

V₂O₅ ALD
25 nm

Amorphous to Crystaline Transformation

Au Sputter

Prototype

Hysteresis for λ = 3.5 μm

Collimated transmittance (%)

Temperature (°C)
ZnO

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

where:

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

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

\( \lambda_{\text{ZnO}} \approx 375 \text{ nm} \)
Substrate + Catalyst + Gas = CNNT!
Si,Ti, flat, 3d + Iron + Ethylene!
Blacker than NASA Z306 Paint 10X Darker!
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!
Questions?

ANY QUESTIONS?