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

CVD Process

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

Sputtering Gas
Thin Film

Vacuum Chamber

Heated Material

Sputtering Target
Sputtered Target Atom

Wafers

Rough Pump
Cryo or Turbo Pump

Air Inlet
Valve
Valve

U-
• 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!**

(a) Conformal step coverage, with constant thickness on horizontal and vertical surfaces.
(b) Poor step coverage, here thinner for vertical surfaces.

Step coverage of metal over non-planar topography!
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 = \( T \) (# monolayers)

Example:
If 1 monolayer = 1 A
# monolayers = 7
Thickness = 7 A

Reproducibility
Advantageous Property

Substrate Independence
Epitaxial Growth

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

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.

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

Batch Process
Commercial Options
In-House Experimental ALD System
\[ E = \frac{hc}{\lambda} \]

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} \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!
Atomic Oxygen Protection

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?