Energy flux measurements during sputter deposition as a tool to evaluate the properties of ZnO:Al

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A crash course on thin film growth
- Structure zone models
- Zone examples
- Energy flux contributions
- Energy per arriving species
- Concepts applied to TiN
**Structure zone models**

For evaporation:
Movchan and Demchishin (1969)

For sputter deposition:
Thornton (1974)

Homologous temperature ($T/T_m$)
Surface diffusion
Grain boundary diffusion

Argon pressure
Energy control of the sputtered particles

Mobility of the adspecies

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**Example: Zone T**

Examples of Zone T growth for TiN

$\Rightarrow$ intergrain diffusion $\Rightarrow$ competitive overgrowth
Example: Zone II

Recrystallization during grain growth by ripening, coalescence, or grain boundary migration

Example of Zone II growth for TiN

Energy contributions

$$E_{\text{tot}} = E_{\text{cond}} + E_{\text{pl}} + E_{\text{sp}} + E_{\text{refl}} + E_{\text{el}} + E_{\text{ion}}$$
Energy per arriving particle (EPA)

\[
\ln(D) = \left(\frac{-E}{kT}\right) = \left(\frac{-E}{E_{\text{tot}}}\right)
\]

Both diffusion rate (D) and diffusion length (L) depend on the total energy per incoming metallic particle.

- Total energy measurements allow to calculate the energy flux

Passive thermal probe[1]:

- Deposition rate allows to calculate the material flux

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An example: TiN

Direct relation between microstructure/orientation and diffusion length.
The growth of ZnO

Two sources: comparison
- Experimental conditions
- Properties and literature
- Texture
- Properties and diffusion length

Two sources

Circular planar magnetron
2 inch diameter cathode
Supplier: K. Lesker
Composition: AZO (Al 2 wt%)

Rotating cylindrical magnetron
Tube dimensions: 18 cm x 4 cm
Supplier: Soleras Advanced Coatings
Composition: AZO (Al 2 wt%)

Interesting to know:
The negative oxygen ion angular distribution differs strongly between both targets

S. Mahieu, W.P. Leroy, K. Van Acken, D. Depla
Angular distribution of high energy ($eV_o$) negatively charged oxygen and sputtered Al as simulated by SIMTRA with an acceptance angle of ± 90°.

Separation in 2 zones:
1. Mix of sputtered material and high energy particles (like planars).
2. Only sputtered materials without high energy particles (zone of silence).

The energy flux is strongly different between both magnetron configurations.
Comparing the two sources: Deposition rate

The deposition rate (at almost equal target power density) is higher for the planar magnetron.

Experimental conditions

Influence thickness

All samples (for both sources) have a thickness ranging between 500 to 750 nm.
A crash course
Growth of ZnO
A model
Conclusions

Optical band gap

Example: Substrate temperature
Rotating cylindrical magnetron

Comparison with literature
Experimental values are consistent with results published by different research groups

XRD analysis

Rotating cylindrical magnetron

Planar magnetron

Grain size

All experimental results
Diffusion length connects to the texture, and the functional properties of AZO.

A model

- ZnO: habitus and energy considerations
- Zone T and Zone II

OK, assign the answer a value of X. 'X minus' means multiply, so take the numerator (the left term) and put that on the other side of the equation.
ZnO habitus

The (001) surface is a polar surface with high surface energy.
The (100) and (101) are non-polar and low surface energy planes.

Fast growing direction

During the initial phase we expect random nucleation. An evolutionary overgrowth mechanism explains the (002) preferential orientation for thicker films.
High EPA: preferential nucleation

Typical morphology for a zone II structure

Connection to electrical properties: (002) well aligned crystals in plane
Other directions: grains are non well aligned

SEM taken from PhD thesis from A. Lejars (Nancy, 2012)

Conclusions

Energy flux measurements are valuable tool to study the growth of thin films, and it allows to link deposition conditions to fundamental growth parameters.

The AZO thin films grown by magnetron sputtering at DRAFT have similar properties as published in literature.

At low EPA: (002) preferential orientation
At high EPA: (110) starts to compete
This defines the properties of the obtained AZO thin film.