3B: Review

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Review

- 1A: Introduction to WVASE: Fun Quiz!
- 1B: Cauchy
- 2A: Pt-by-Pt and GenOsc
- 2B: Advanced GenOsc
- 3A: Non-Idealities
If the left column shows the Psi and Delta for an ideal glass substrate, can you identify the complexity of the right column data?

Q1

Ideal

Surface Roughness
If the left column shows the Psi and Delta for an ideal glass substrate, can you identify the complexity of the right column data?

Q2

Ideal

Backside Reflection
Q3

If the left column shows the Psi and Delta for a Si substrate, can you identify the complexity of the right column data?

Ideal

Backside Reflection
What is the substrate type of the following ellipsometric data?

1. Transparent substrate (dielectric)
2. Semi-absorbing substrate (semiconductor)
3. Absorbing substrate (Metal)
What does ellipsometric measurement probe?

① Size of electric field
② Shape of electric field

Less Intense

Different Size (Intensity).

Same Shape! (Polarization)

More Intense
Q6

Pseudo Optical Constants $\langle n \rangle$, $\langle k \rangle$

Which one is corresponding to a single reflection on surface?

Variable Angle Spectroscopic Ellipsometric (VASE) Data

$\langle n \rangle$ (55.00, 65.00, 75.00°)
$\langle k \rangle$ (55.00, 65.00, 75.00°)
Unknown Film on Glass
Which spectral range does the film look transparent?
Data Analysis Strategies

Substrates

S-1: Opaque Substrates
S-2: Semiconductor substrates
S-3: Transparent substrates

Films

F-1: Transparent films
F-2: Semi-Absorbing films
F-3: Absorbing films
- Psi stays near 45°
- Delta away from 0° or 180°
Opaque Substrates

Two Categories

- “Bulk” Samples → No overlayers.
  - Polished metal.
- Optically thick films.

Fit Strategy

“Invert” psi and delta for n and k.

Normal fit from reference values

Example 1: Optically Thick Cr Film
- Psi follows shape of absorption
- Delta away from 0° or 180° when absorbing
S-2 Semiconductor Substrates

- **Bulk semiconductor n&k are well known**
  - Crystalline structure insures repeatable optical/electrical properties.

- **Doping NOT important at VIS wavelengths**
  - Doping is important in the MID-IR, however (5 micron or longer).

- **Fit Strategy**
  - Use published index values.
  - Fit for oxide thickness.

Example 2 Bare Si Wafer
Psi flat and smooth - follows shape of index
Delta = 0°, 180° - except for surface films

0.5nm roughness
### S-3 Transparent Substrates

- **Fit Strategy**
  - Cauchy

- **Complexities**
  - Surface roughness (Add srough)
  - Backside reflection (Suppress or Model correction)

- **How to obtain small k-values**
  - Add Transmission data and fit k only.

**Example 3** 10mm bk7 (Two dat files: SE and T)
Each reflected wave will have a different phase and amplitude.
F-1 Thickness Effects

- Interference shifts toward red as film grows.
- More Interference oscillations as film grows.
• Index difference affects Interference oscillations (Mostly \( \Psi \) amplitude).

\[
\begin{align*}
n &= 1.5 \\
n &= 1.75 \\
n &= 2.0 \\
n &= 2.25 \\
n &= 2.5 \\
n &= 2.75 \\
n &= 3.0 \\
n &= 3.25 \\
n &= 3.5 \\
n &= 3.75 \\
n &= 4.0
\end{align*}
\]
F-1 Using This Information

- Adjust Index to match Psi peak height.
- Adjust Thickness to match oscillation period.
1. Adjust An parameter to approximate index.
   – Psi amplitude can help estimate.
2. Adjust thickness to match # of oscillations.
3. Fit Thickness, An and Bn.
4. Add Cn. Does it improve the MSE?
5. Normal dispersion???

Normal Fit IF Model is Close to Answer!

RESET if fit fails!!!

Example 4 Al2O3 on Si
- If light is absorbed before returning to surface, only top reflection is ‘seen’ (Film appears as Substrate)
Fit Cauchy to Transparent region
  – determine thickness.
Fix thickness and fit “n,k” at all wavelengths using point-by-point fit.
When in doubt, convert to Genosc to insure Kramers-Kronig consistency.
Surface roughness, grading, and anisotropy can be added if they improve MSE.

Example 5 Semi Absorbing Film on Si
Roughness sensitivity when material is absorbing or has high index.

Grading and roughness often correlated when both lower index toward surface.

When grading increases index toward surface, may also be sensitive to roughness.
Most metal films are opaque above 50-100nm thickness.

Absorption at all wavelengths prevents periodic oscillations from thickness.

Data will appear similar to absorbing substrates:

- \( \Psi \) large and never close to zero.
- \( \Delta \) between 0 and 180.
- \( \text{Pseudos} \) from different angles the same.
F-3 Multiple angles

- No new information!
**Challenge:**
More unknown sample properties than measured values.

**Solution:**
Measure additional information or reduce number of unknown properties.

**Modeling?**

![Modeling Diagram](image)
F-3 Methods for Absorbing Films

- Opaque Layer
- Transparent Region
- Optical Constant Parameterization
- Multiple Angles
- Interference Enhancement
- SE + Intensity
- Multiple-Sample
- In-Situ
- Multiple-Ambient

Multi-Layer Strategies

- **Preferred Method #1**
  - Measure n,k from single-layers: use dispersion models.
  - Fit thickness only.
  - If poor fit, add dispersion parms. for least stable film.
Multi-Layer Strategies

- **Preferred Method #2**
  - Measure n,k for each “new” layer with previous layers fixed: use dispersion models.
  - If poor fit, add thickness and then dispersion parameters for previous layers.
Example 6-poly Si on 100nm TOx on Si

- Two Film layers
  - Unknown thickness poly Si
  - ~100nm Thermal Oxide

- Build your own method to fit the data.
Thank You & Good Luck!