Session 7
Review of Absorbing Films

U. Utah WVASE at JAW, Oct 2010

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**Absorbing Films**

- **Challenge:**
  More unknown sample properties than measured values.

- **Issues:** Thickness can be correlated with optical properties – no unique answer
Methods on Absorbing Films

- **Reducing unknowns**
  - Opaque Layer
  - Optical Constant Parameterization
  - Extrapolation from Transparent Region

- **Adding information**
  - SE + Transmission
  - Interference Enhancement
  - Multi-Sample Analysis
  - In-Situ

Above methods are often combined!

Opaque Layers

- Sample absorbs light in the entire measured range.
- Typical for metal substrates, thick metal films (>50-100nm)
- Model assumptions affect accuracies of final optical properties.

### Method

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque layers</td>
<td>Simplified data analysis – ignore the film thickness.</td>
<td>Ignores surface films (oxide and/or roughness).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Opaque layer may have different “n,k” from thin layers.</td>
</tr>
</tbody>
</table>

Parameterization

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Parameterization

- **Use dispersion equations to describe sample optical properties.**
- **Often combined with other techniques**

Parameterization

\[ \varepsilon_2(\lambda) = F(p_1, p_2, \ldots, p_m) \]

\[ \varepsilon_1(\lambda) = F(\varepsilon_2(\lambda)) \text{ - KK relation} \]

Uniqueness fit

<table>
<thead>
<tr>
<th>Method</th>
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</thead>
<tbody>
<tr>
<td>Optical Constant Parameteri-</td>
<td>Reduce # of Fit Parameters</td>
<td>By itself, results can often be correlated</td>
</tr>
<tr>
<td>zation</td>
<td>Smooth, continuous curves for n,k that are often KK consistent</td>
<td>Need to choose best of many different options.</td>
</tr>
<tr>
<td></td>
<td>Transferrable to similar samples</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work better for well-known and well-defined optical properties, such as a-Si or DLC</td>
<td></td>
</tr>
</tbody>
</table>
Extrapolation from Transparent region

- Sample is transparent in some measured region
  - Get thickness and $n$ in the transparent region ($k=0$)
  - Extend to absorbing region to get $n$, $k$ and thickness
- Correct model should fit both transparent and absorbing regions

Parameterization
- Wavelength expansion
- Cauchy
## Extrapolation from Transparent Region Cont.

<table>
<thead>
<tr>
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<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrapolation from Transparent Region</td>
<td>- High sensitivity to thickness in transparent region.</td>
<td>- Requires film to be transparent over some measured wavelengths.</td>
</tr>
<tr>
<td></td>
<td>- Increased sensitivity to model accuracy at cross-over between transparent and absorbing region.</td>
<td>- Possible for NK to get lost in absorbing region if:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Model not accurate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- More than 1 mathematical solution (branch-cut)</td>
</tr>
</tbody>
</table>
SE + Intensity

Parameterization
Including intensity
Uniqueness fit

\[ n(\lambda), k(\lambda) \]
\[ d \]

\[ \Psi(\lambda), \Delta(\lambda) \]
\[ \%R(\lambda) \]

\[ \%T(\lambda) \]

Method

Advantages

Disadvantages

SE + Transmission

- Extra information from Intensity breaks correlation.

- Not for absorbing substrates.
- Need accurate Intensity measurements.

Interference Enhancement

\[ \Psi(\lambda), \Delta(\lambda) \times 2 \text{ Angles} \]

- \( n(\lambda), k(\lambda) \)
- \( d_2 \uparrow \)
- Thick Transparent Film
- \( d_1 \)

Known Substrate

Method | Advantages | Disadvantages
--- | --- | ---
Interference Enhancement | ▪ Extra info. from multi-angle data.  
▪ Effective “substrate” features enhance sensitivity to correct film thickness/\( n,k \).  
▪ Great method for absorbing substrates. | ▪ Requires extra, thick dielectric layer.  
▪ Increases complexity

Demonstrated on a-C:H films

Multi-Sample and in-situ Analysis

Parameterization

Multi-sample analysis

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</tr>
</thead>
<tbody>
<tr>
<td>Multi-Sample and in-situ</td>
<td>▪ More information about same material.</td>
<td>▪ Requires consistent optical constants</td>
</tr>
<tr>
<td>Analysis</td>
<td>▪ Easy to achieve from map of non-uniform sample.</td>
<td>▪ In-situ requires ellipsometer integration into system.</td>
</tr>
</tbody>
</table>

Combining Methods

Real-time studies of metal films during sputter-deposition.
- In-situ
- n,k parameterization
- SE + Transmission intensity

Summary – Absorbing Films

Parameterization
\{GenOsc - \\
\varepsilon_2(\lambda) = F(p_1, p_2, ..., p_m) \\
\varepsilon_1(\lambda) = F(\varepsilon_2(\lambda)) - KK relation\}

Pt by pt
Uniqueness fit
Multi-data/sample fit
In-situ