Metal (Al) Photocathode

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Tuesday, Mar 29, 2010
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Motivation and Publication Strategy

- **Motivation for metal transmission photocathode**
  - Requirement for Mock Tile
    - Process compatible with Mock Tile
    - Externally producible / Stability in air
    - Easy to fabricate
  - Scientific interest
    - Ultra fast timing response

- **Publication Strategy**
  - Functionality-Model development to predict QE
  - Assess functionality model with various test cathode (Thickness, Work function)
  - Using test cathodes to “calibrate” the optical and electrical test equipment
  - Publication plan
    - Optimization process for transmission metal photocathode (J. Appl. Phys ?)
    - Instrumentation documentation (ex. NIM, etc)
1. Optical absorption
2. Transport of the excited electron to the surface (electron may lose energy during this process)
3. The escape of the electron across the surface into vacuum.
Theory: Physics of Photoemission from Transmission Mode Metal Cathodes
- Optical Absorption

- Aluminum is good reflector
- Thickness of Al for transmission mode cathode must be in the order of skin depth.
- Fabrication of thin layer of aluminum is not easy

Skin Depth of Aluminum at 300 nm is 2.6 nm.

\[
\delta = \sqrt{\frac{\rho}{\pi \times f \times \mu}} = \sqrt{\frac{2.65 \times 10^{-8} \Omega \cdot m}{\pi \times (9.9931 \times 10^{14} \frac{1}{s}) \times (4\pi \times 10^{-7} \frac{H}{m}) \times \left(\frac{\Omega s}{H}\right)}}
\]

\[
= 2.6 \times 10^{-9} m = 2.6nm
\]

\(\rho\) = resistivity (\(\Omega \cdot m\))
\(\mu\) = permeability (\(4\pi \times 10^{-7} \text{ H/m}\)), note: H = henries = \(\Omega \cdot s\)

http://unitmath.com/um/p/Examples/PulsedPower/SkinDepth.html
Approach: Model development to predict QE(E_{Ph}) - optical losses

- How much light will be **transmitted** through window material:
  \[ T = \frac{I}{I_0} = 10^{-\alpha \ell} \]

- How much light will be **absorbed** into metal:
  \[ A_{\lambda} = \log_{10}(I_0 / I) \]

<table>
<thead>
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<th>Film thickness (Å)</th>
<th>A %</th>
<th>R %</th>
<th>T %</th>
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<td>7</td>
<td>19</td>
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<tr>
<td>500</td>
<td>7.9</td>
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**Optical Properties of Al at λ=300 nm**

- Absorbance
- Reflectance
- Transmittance
Theory: Physics of Photoemission from Transmission Mode Metal Cathodes
- Electron Escape Depth

**Thermalization**

Electron Escape Length

Scattering probability depends (Fermi’s Golden Rule):
- Density of states (occupied and non occupied)
- Matrix element (neglecting energy dependence)

**Mean-free path of Al is approximately 15 nm at room temperature**

*Thin Solid Films, 121 (1984) 201-216*

**Potential energy is transferred to kinetic energy**

Electron Escape Length

Electron escapes if
- Kinetic (normal to surface) energy is larger than barrier
- Limited tunneling probability for lower kinetic energy

**Simplification:**
Only electrons within the slice of 1 mean free path length are considered
Model simplifications:
- Electron is considered as “free” electron; arbitrary angle distribution independent from $E_{Ph}$
- Kinetic energy normal to surface is larger than work function
- All other electrons are neglected

\[ \Phi \leq E_{nor}^{\text{kin}} = E^{\text{kin}} \ast \cos(\alpha) \]

\[ P[\%] \propto \frac{2\alpha}{4\pi} = \frac{a \cos(\frac{\phi}{E_{ph}})}{2\pi} \]
Theory : Physics of Photoemission from Transmission Mode Metal Cathodes
- Absorbed photons within escape length

- Number of absorbed photons within escape depth
  \[
  \frac{\Delta \text{ph}}{I_0} = (e^{-\mu(d-x)} - e^{-\mu d})
  \]

- Expected \(\text{QE}(E_{ph})\)

\[
\text{QE}(E_{ph}) = \frac{\Delta \text{ph}}{I_0} \cdot P[\%] = (e^{-\mu(d-x)} - e^{-\mu d}) \cdot \frac{a \cos\left(\frac{\phi}{E_{ph}}\right)}{2\pi}
\]

Model parameter can be determined by measurement of cathode with various thicknesses
Approach: Model development to predict $\text{QE}(E_{\text{ph}})$

$$\text{QE}(E_{\text{ph}}) = \frac{\Delta ph}{I_0} \cdot P[\%] = \left(e^{-\mu(d-x)} - e^{-\mu d}\right) \cdot \frac{a \cos\left(\frac{\phi}{E_{\text{ph}}}\right)}{2\pi}$$

Estimate of QE

![Graph of QE vs. Thickness of Aluminum (nm) for Incident 300nm and 275nm](image)

Estimate of QE (with B33)

![Graph of QE vs. Thickness of Aluminum (nm) for Incident 300nm and 275nm with B33](image)
Approach: Design and growth of test cathodes

- **Resources:**
  - Sputtered cathode from Dean Walter: transport on air/modification of workfunction
  - Thermally evaporated in growth and characterization chamber: continuously in UHV
  - Sample systems
    - Thickness
    - Workfunction

- **Measurement:**
  - Determination of $QE(E)$, $QE(E, \phi)$, $QE(E, d)$
  - Goals:
    - Model verification
    - Determination of escape length $x$
    - Commissioning of optical setup
Conclusions

- Developed experimental plan

- Develop simplified model for QE
  - Only non-scattered electrons are considered
  - Full optical description
  - Functional dependency: $Q_{E_x}(d, E_{ph}, \phi)$
  - Should work for $E_{ph} \gg \phi$
  - Can be generalized including tunneling effects

- Growth and test will start soon