Temperature Dependence of SiO$_2$ Cathodoluminescence

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Outline

• Experimental set-up
• Theory and Results
  – Band theory of crystals
  – Electron excitation
    • One relaxation energy
    • Multiple relaxation energy’s
  – Qualitative temperature dependent model
Experimental Set-Up
Band Theory of (Crystalline) Conductors, Insulators and Semiconductors

- **Conductor**
  - Partially filled bands

- **Insulator**
  - Completely filled bands

- **Semiconductor**
  - Insulators at finite $T$
Disorder introduces localized states

![Diagram showing the effect of disorder on wave functions in real and momentum space](image)

**Delocalized in real space**
- Wave function $\psi(r)^2$ is spread out over position $r$.
- Wave function $\psi(q)^2$ is delocalized over momentum $q$.

**Localized in real space**
- Wave function $\psi(r)^2$ is localized at position $r$.
- Wave function $\psi(q)^2$ is localized at momentum $q$.

**Localized in momentum space**
- Wave function $\psi(r)^2$ is narrow and localized in real space.
- Wave function $\psi(q)^2$ is wide and delocalized in momentum space.

**Delocalized in momentum space**
- Wave function $\psi(r)^2$ is wide and delocalized in real space.
- Wave function $\psi(q)^2$ is narrow and localized in momentum space.
Cathodoluminescence of SiO$_2$ Mirror

Beam off

Beam on
Luminescence: Excitation and Relaxation

Injected Charge

$E_F$  
$E_F^{\text{eff}}$

$e^-$  
photon
Effect of Beam Energy
Multi-Photon Luminescence

![Image of luminescence](image)

![Graph showing counts versus wavelength](graph)

- Counts
- Wavelength
- Peaks at 280, 450, 500, and 610
Multi-Photon Relaxation

Injected Charge

$E_F$

$E_F^{\text{eff}}$

CB

VB

photon

photon
Temperature Dependent Luminescence

-4°C  -80°C  -110°C
SLR Spectral Radiance vs Temperature
Temperature Dependent UV-Vis Spectra
Temperature Model for Multiphonon Luminescence

\[ T = 0 \]

Injected Charge

\[ E_F \]

\[ E_F^{\text{eff}} \]
Low Temperature Model

Low T

Injected Charge

$e^{-}$

$E_{F}$

$E_{F}$

$E_{F}$

0 1
High Temperature Model

High T

Injected Charge

$E_F$

$E_F^{\text{eff}}$

$\text{e}^-$
Luminescence: Conclusions

- Identify specific defect mechanisms
- Quantify luminescence intensities, peak positions, and peak shifts with $T$
- Study initial time dependence as traps fill to $E_f^{\text{eff}}$
- Make lower $T$ (<30 K) and higher (<400 K) $T$ measurements

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Gaussian Energy State</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Blue →0</td>
<td>Red →max</td>
</tr>
<tr>
<td>Low</td>
<td>in between</td>
<td>in between</td>
</tr>
<tr>
<td>High</td>
<td>→half max</td>
<td>→half max</td>
</tr>
</tbody>
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Future Work

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