**Electron transport and Minority Carrier Lifetime in HgCdSe 2013 II-VI Workshop**

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**14. ABSTRACT**

Major source of HgCdSe background electron concentration is Group VII impurities (Br, Cl, F) introduced from Se source material

Change in concentration with annealing suggests p-type Hg vacancies and n-type Se vacancies

**OMSA** suggests an inhomogeneous distribution of electrons introduced in growth, reduced with Hg-then-Se anneal.
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ABSTRACT

Major source of HgCdSe background electron concentration is Group VII impurities (Br, Cl, F) introduced from Se source material.

Change in concentration with annealing suggests p-type Hg vacancies and n-type Se vacancies.

QMSA suggests an inhomogeneous distribution of electrons introduced in growth, reduced with Hg-then-Se anneal making mobility more discrete.

Lower electron concentration allows us to see PCD transients, which suggest trap present in as-grown material that is increased with Hg-annealing but removed with Se-annealing, could be Se vacancies.

Lowering background electron concentration and increasing lifetime will require higher purity Se and optimized anneal process.
Electron transport and Minority Carrier Lifetime in HgCdSe

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HgCdSe is being investigated as an alternative IR material since it is closely lattice-matched to GaSb substrates.
As-grown HgCdSe electron concentration reduced an order of magnitude by switching to higher purity Se source material

Group VII impurities detected, particularly near the ZnTe interface. Could be acting as donors.
Reduction in electron concentration corresponds with reduction in Group VII elements detected by SIMS.
Electron Concentration vs. Temperature

- Electron concentration raised after Hg-annealing, lowered after Se annealing, suggests additional p-type Hg vacancies and n-type Se vacancies.
- Appear to have mixed conduction effects at higher temperatures

6N Se, $\lambda_c = 5 \mu m$
77K As-Grown Variable Field Hall

\[ \sigma_{xx}(B) = \frac{en_1\mu_1}{1 + (\mu_1B)^2} + \frac{en_2\mu_2}{1 + (\mu_2B)^2} + \sigma_o \]

\[ \sigma_{xy}(B) = -\frac{en_1\mu_1^2B}{1 + (\mu_1B)^2} - \frac{en_2\mu_2^2B}{1 + (\mu_2B)^2} \]

77K Annealed Variable Field Hall

<table>
<thead>
<tr>
<th>Stage</th>
<th>Element</th>
<th>Temp.</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hg</td>
<td>250 °C</td>
<td>24 hrs</td>
</tr>
<tr>
<td>2</td>
<td>Se</td>
<td>250 °C</td>
<td>24 hrs</td>
</tr>
</tbody>
</table>

\[
\sigma_{xx}(B) = \frac{en_1 \mu_1}{1 + (\mu_1 B)^2} + \frac{en_2 \mu_2}{1 + (\mu_2 B)^2} + \sigma_o
\]

\[
\sigma_{xy}(B) = -\frac{en_1 \mu_1^2 B}{1 + (\mu_1 B)^2} - \frac{en_2 \mu_2^2 B}{1 + (\mu_2 B)^2}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>As-Grown</th>
<th>Hg-Annealed</th>
<th>Se-Annealed</th>
<th>Hg, then Se Annealed</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n_1)</td>
<td>1.48</td>
<td>3.95</td>
<td>1.70</td>
<td>1.71</td>
<td>(\times10^{16}) cm(^{-3})</td>
</tr>
<tr>
<td>(\mu_1)</td>
<td>21,304</td>
<td>13,973</td>
<td>22,205</td>
<td>23,298</td>
<td>cm(^2/)Vs</td>
</tr>
<tr>
<td>(n_2)</td>
<td>4.40</td>
<td>4.21</td>
<td>1.23</td>
<td>0.85</td>
<td>(\times10^{16}) cm(^{-3})</td>
</tr>
<tr>
<td>(\mu_2)</td>
<td>4,285</td>
<td>4,279</td>
<td>6,233</td>
<td>6,429</td>
<td>cm(^2/)Vs</td>
</tr>
<tr>
<td>(\sigma_1)</td>
<td>50.51</td>
<td>88.42</td>
<td>60.47</td>
<td>63.82</td>
<td>1/(\Omega)cm</td>
</tr>
<tr>
<td>(\sigma_2)</td>
<td>30.20</td>
<td>28.86</td>
<td>12.28</td>
<td>8.75</td>
<td>1/(\Omega)cm</td>
</tr>
<tr>
<td>(\sigma_o)</td>
<td>13.66</td>
<td>7.17</td>
<td>5.87</td>
<td>4.20</td>
<td>1/(\Omega)cm</td>
</tr>
<tr>
<td>(\sigma_1)</td>
<td>53.52</td>
<td>71.05</td>
<td>76.91</td>
<td>83.13</td>
<td>%</td>
</tr>
<tr>
<td>(\sigma_2)</td>
<td>32.00</td>
<td>23.19</td>
<td>15.62</td>
<td>11.40</td>
<td>%</td>
</tr>
<tr>
<td>(\sigma_o)</td>
<td>14.47</td>
<td>5.76</td>
<td>7.47</td>
<td>5.47</td>
<td>%</td>
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78K Minority Carrier Lifetime

As-Grown

- Data
- Fit (τ = 132 ns)

Hg-Annealed

- Data
- Fit (τ = 99 ns)

Se-Annealed

- Data
- Fit (τ = 120 ns)

Hg, then Se Annealed

- Data
- Fit (τ = 220 ns)
• Transients were fitted. For samples with more than one slope, the first slope was taken as the photo-conductance lifetime.

• As electron concentration decreased with annealing, lifetime increased.

• Longest 77K lifetime was observed for sample annealed under Hg then Se (220 ns)
• Major source of HgCdSe background electron concentration is Group VII impurities (Br, Cl, F) introduced from Se source material

• Change in concentration with annealing suggests p-type Hg vacancies and n-type Se vacancies

• QMSA suggests an inhomogeneous distribution of electrons introduced in growth, reduced with Hg-then-Se anneal making mobility more discrete

• Lower electron concentration allows us to see PCD transients, which suggest trap present in as-grown material that is increased with Hg-annealing but removed with Se-annealing, could be Se vacancies

• Lowering background electron concentration and increasing lifetime will require higher purity Se and optimized anneal process
As-grown HgCdSe electron mobility comparable to HgCdTe of similar electron concentration.

Electron Mobility vs. Temperature

Electron Mobility (cm²/Vs)

1/ Temperature (1000/K)

- Electron mobility raised/lowered with concentration after anneal

- As-Grown
- Hg-Annealed
- Se-Annealed
- Hg-then-Se Annealed
Lifetime vs. Temperature

MCT Assumes:

\[ x = 0.32 \]
\[ N_d = 2.4 \times 10^{16} \text{ cm}^{-3} \]
Br concentration (SIMS)

- As-Grown
- Annealed

Concentration (cm$^{-3}$) vs. Depth (μm)
Cl concentration (SIMS)
F concentration (SIMS)

- Blue line: As-Grown
- Red line: Annealed

Concentration (cm$^{-3}$)

Depth (μm)
$\sigma_{xx}(B) = \frac{en_1\mu_1}{1+(\mu_1 B)^2} + \frac{en_2\mu_2}{1+(\mu_2 B)^2} + \sigma_o$

$\sigma_{xy}(B) = -\frac{en_1\mu_1^2 B}{1+(\mu_1 B)^2} - \frac{en_2\mu_2^2 B}{1+(\mu_2 B)^2}$

(\(\mu B\) << 1)

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77K Hg-Annealed Variable Field Hall

Stage | Element | Temp. | Duration
--- | --- | --- | ---
1 | Se | 250 °C | 24 hrs

\[
\sigma_{xx}(B) = \frac{en_1 \mu_1}{1 + (\mu_1 B)^2} + \frac{en_2 \mu_2}{1 + (\mu_2 B)^2} + \sigma_o
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\[
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