Auger Recombination

\[ R_{\text{Auger}} = \left( C_n \, n + C_p \, p \right) \left( np - n_i^2 \right) \]

How to determine C for InGaN QWs?

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Direct Experimental Evidence

- hot Auger electrons detected
- magnitude of effect on droop unclear (C= ?)
- disputed by other authors based on fast p-side carrier relaxation
Experimental Results for C of InGaN QWs

On the uncertainty of the Auger recombination coefficient extracted from InGaN/GaN light-emitting diode efficiency droop measurements

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(Received 23 December 2014; accepted 28 February 2015; published online 10 March 2015)

TABLE I. Recombination parameter sets extracted from the measurements in Fig. 2 using different models.

<table>
<thead>
<tr>
<th>Model</th>
<th>A/10^6 s^-1</th>
<th>B/10^-12 cm^3/s</th>
<th>C/10^-31 cm^6/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC model</td>
<td>2.6</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>ABC model with n=2p</td>
<td>3.9</td>
<td>1.5</td>
<td>0.16</td>
</tr>
<tr>
<td>APSYS</td>
<td>14^a</td>
<td>(17)^a</td>
<td>2.5^a</td>
</tr>
<tr>
<td>Quatra/Cels</td>
<td>3.1</td>
<td>4.1^b</td>
<td>1.7^b</td>
</tr>
<tr>
<td>Quatra/Cels (hot carriers)</td>
<td>3.1</td>
<td>4.1^b</td>
<td>0.8^b</td>
</tr>
<tr>
<td>Quatra/Cels (no polarization)</td>
<td>5.9</td>
<td>17.7</td>
<td>7.0</td>
</tr>
</tbody>
</table>

^a Electron-hole separation is considered separately.
^b Values B(i) and C(i) given at i>=c = 5A/cm^2.

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atomistic model calculations of the Auger parameter

- $C = 3 \times 10^{-34} \text{ cm}^6/\text{s}$ (QW, direct) [Hader et al., APL 2008] KP band structure
- $C < 2 \times 10^{-30} \text{ cm}^6/\text{s}$ (bulk, direct) [Delaney et al., APL 2009] inter conduction-band transitions
- $C < 5 \times 10^{-33} \text{ cm}^6/\text{s}$ (bulk, direct) [Bertazzi et al., APL 2010] inter conduction-band transitions
- $C < 2 \times 10^{-31} \text{ cm}^6/\text{s}$ (bulk, indirect) [Kioupakis et al., APL 2011] indirect
- $C < 1 \times 10^{-31} \text{ cm}^6/\text{s}$ (bulk, indirect) [Bertazzi et al., APL 2012] indirect
- $C < 9 \times 10^{-31} \text{ cm}^6/\text{s}$ (QW, direct) [Vaxenburg et al., APL 2013] KP, zinc-blende
- $C < 5 \times 10^{-31} \text{ cm}^6/\text{s}$ (QW, direct) [Bertazzi et al., APL 2013] strong d-dependence
- $C < 7 \times 10^{-31} \text{ cm}^6/\text{s}$ (QW, direct, 2MV/cm) [Bertazzi et al., NUSOD 2014]
strong dependence on QW width and field

C varies with carrier density \((C_n^3 \text{ not correct})\)
What do we need to do?

Develop theory for Auger recombination in InGaN and AlGaN quantum wells which includes the influence of:

- *indirect transitions*
- *polarization field*
- *composition*
- *thickness & shape*
- *non-uniformities*