

Photon-assisted transport and gain clamping

Photon-assisted transport

Photon-assisted transport can be modeled by considering electromagnetic (EM) modes at specific energies.

```
<EMfield>  
<EMmode>  
<PhotonEnergy unit="mV">253.0</PhotonEnergy>  
</EMmode>  
</EMfield>
```

Note that in the current version (2022-03-30), only a single EM mode is supported at a time (i.e. multi-mode lasing operation is not supported).

The electric field in this EM mode can be either imposed (detection mode) or calculated self-consistently (gain clamping).

The detection mode is relevant to study quantum cascade detectors and/or to study the role of photon-assisted transport.

The electric field can be set in the following way:

```
<EMfield>  
<EMmode>  
<PhotonEnergy unit="mV">253.0</PhotonEnergy>  
<ElectricField unit="V.m^-1">1.0e6</ElectricField>  
</EMmode>  
</EMfield>
```

Relation to gain calculation

The gain feature calculates the linear response to an a.c. incoming field. In this case, the d.c. current is not modified. On the other hand, the photon-assisted transport is modeled through the use of a self-energy (self-consistent Born approximation) to describe both absorption and stimulated emission processes, and has an influence on the d.c. transport. In the case of the electron-photon self-energy, a gain is also calculated at the specified EM mode energy. However, the calculated gain slightly differ from the one calculated using linear response, even for small intensities, as broadening effects are not treated within the same level of approximations in the two cases. This is all the more the case when going to small photon energy (i.e. long wavelengths). Hence this method can produce unreliable results in terahertz devices where broadening effects are comparable to the photon energy.

Gain clamping

Gain clamping is relevant to the simulation of quantum cascade lasers above threshold. Indeed, when

the modal gain g_c reaches the cavity losses, lasing starts and the gain is clamped to the cavity losses, that is $g_c = \alpha$. The modal gain (or cross-section gain), is defined as $g_c = \Gamma g$ where g is the material gain in the active region and Γ the overlap factor between the cavity mode and the active region.

To simulate gain clamping, the following command should be used:

```
<Gain>
...
<Cavity_Losses unit="cm^{-1}">2.76</Cavity_Losses>
<GainClamping>yes</GainClamping>
<OverlapFactor>0.9</OverlapFactor>
</Gain>
```

If not specified, the default value for the overlap factor Γ is assumed to be 1.0 (i.e. perfect overlap between the active region and the cavity mode).

Note that in the case of gain clamping, the EM electric field value should be either not specified or set to zero:

```
<EMfield>
<EMmode>
<PhotonEnergy unit="mV">253.0</PhotonEnergy>
<ElectricField unit="V.m^{-1}">0.0</ElectricField>
</EMmode>
```

Indeed, for gain clamping, the electric field in the cavity is adjusted self-consistently so that the modal gain g_c for this photon energy matches the specified cavity losses α .

Wall plug efficiency

The internal wall plug efficiency (WPE) is calculated when gain clamping occurs. It is defined as $\eta_{\text{WPE}}^{\text{internal}} = \frac{P_{\text{stimulated emission}} - P_{\text{absorption}}}{UI}$

If the front mirror losses are specified, the external WPE is output as

$\eta_{\text{WPE}}^{\text{external}} = \eta_{\text{WPE}}^{\text{internal}} \frac{\alpha_{\text{fm}}}{\alpha_{\text{cavity}}}$ where α_{fm} is the front mirror losses, which can be defined using the command:

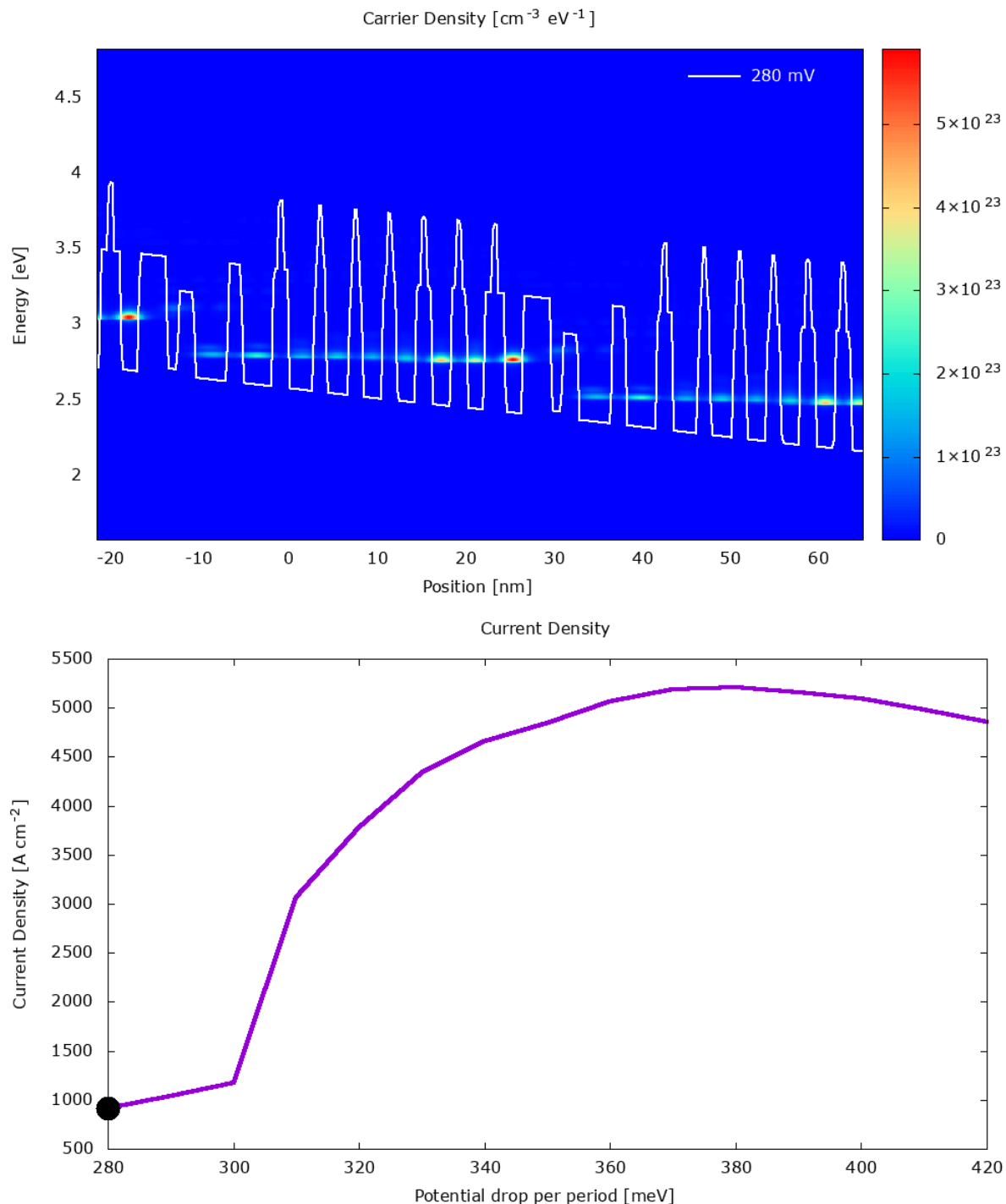
```
<Gain>
...
<Cavity_Losses unit="cm^{-1}">2.76</Cavity_Losses>
<FrontMirror_Losses unit="cm^{-1}">2.26</FrontMirror_Losses>
...
</Gain>
```

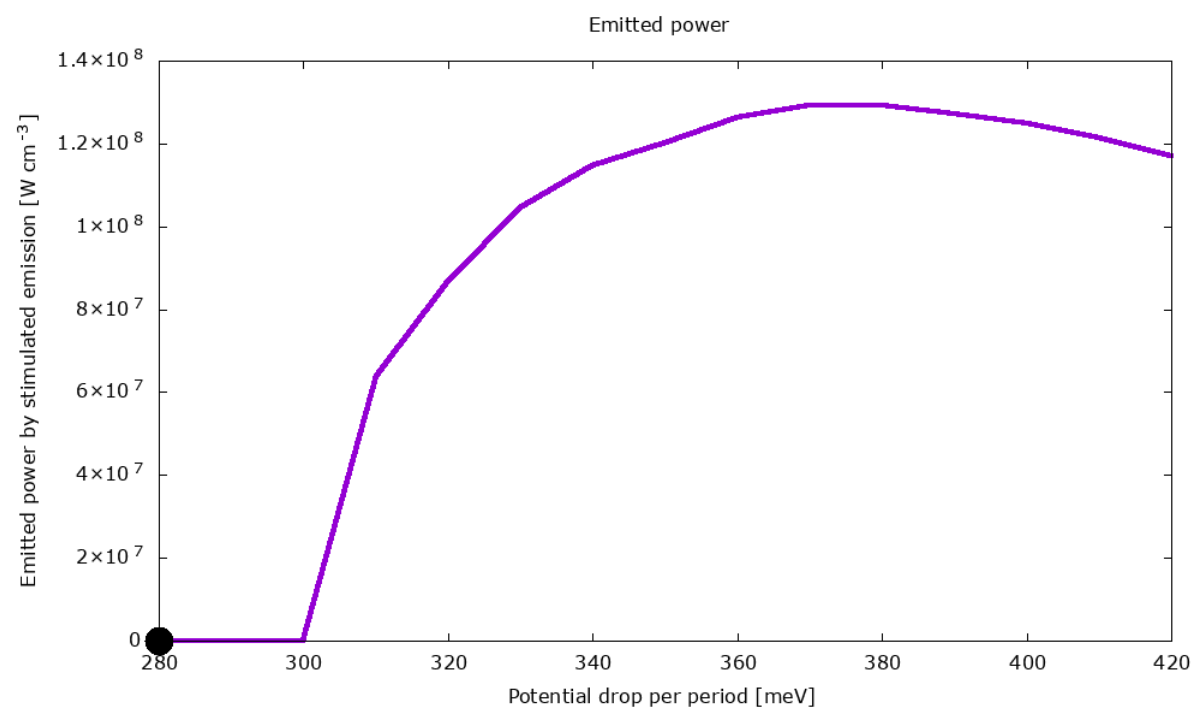
Note that the relation between the specified cavity losses and the front mirror one reads $\alpha_{\text{fm}} = \alpha_{\text{cavity}} \frac{\eta_{\text{WPE}}^{\text{external}}}{\eta_{\text{WPE}}^{\text{internal}}}$

$\alpha_{\text{cavity}} = \alpha_{\text{fm}} + \alpha_{\text{bm}} + \alpha_{\text{waveguide}}$ where α_{bm} are the losses due to the back mirror and $\alpha_{\text{waveguide}}$ are the waveguide losses.

Example: Mid-infrared QCL

The following animated gifs show the electron density, current density and output as the voltage is swept. Above the threshold bias (around 300 meV), the clamping of the gain to the cavity losses results a rapid increase in the internal electric field in the cavity. The photon-assisted transport results in a discontinuity in the slope of the current-voltage characteristics at the threshold bias/current: above threshold, the current increases much faster as stimulated emission reduces the upper laser level lifetime.





From: <https://nextnano-docu.northeurope.cloudapp.azure.com/dokuwiki/> - **nextnano.NEGF - Software for Quantum Transport**

Permanent link: https://nextnano-docu.northeurope.cloudapp.azure.com/dokuwiki/doku.php?id=qcl:photon-assisted_transport_and_gain_clamping

Last update: 2022/03/30 18:19

