Short Injector
Quantum Cascade Laser Model

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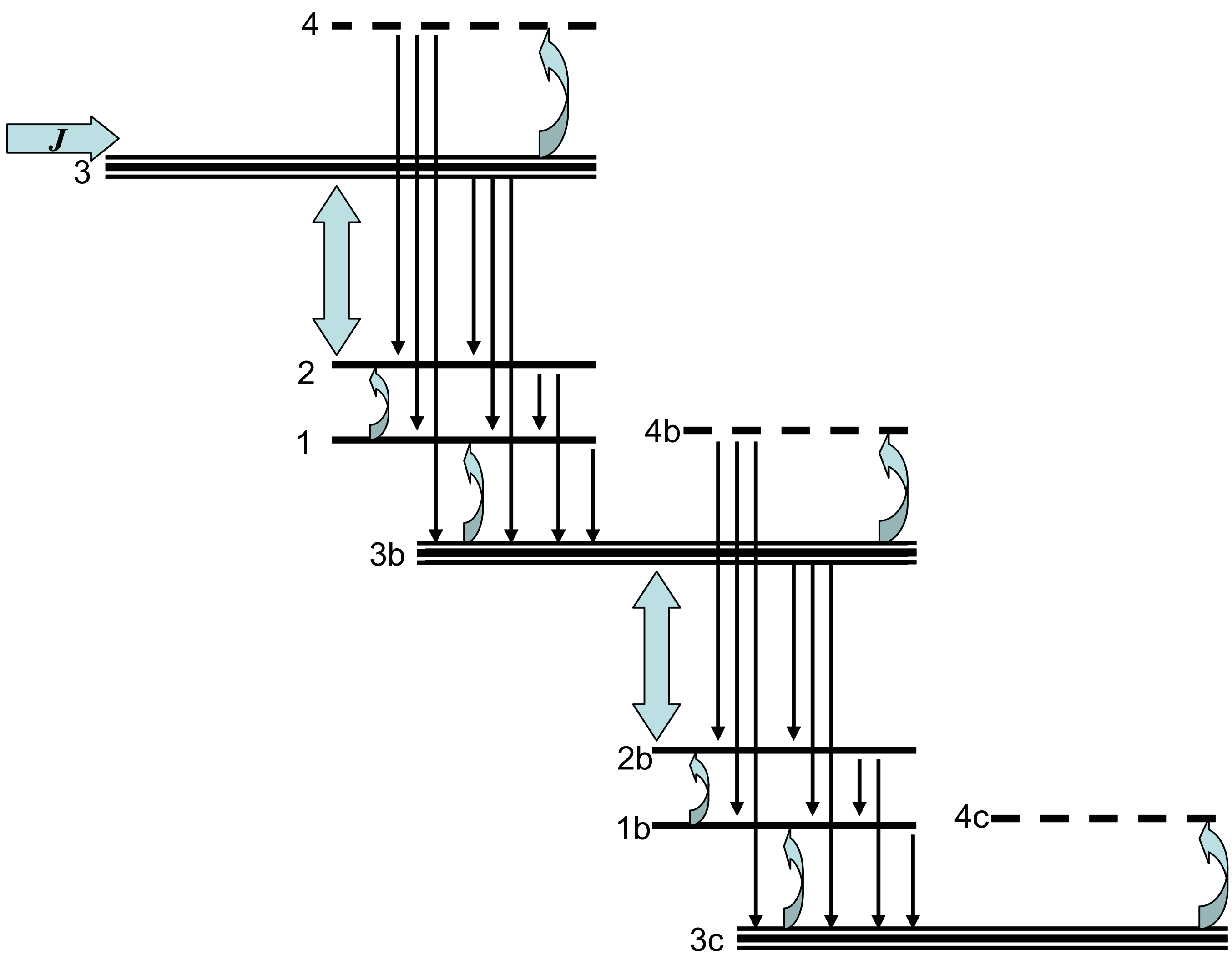

$$
\begin{aligned}
\frac{dN_3}{dt} &= \frac{J}{q} - \frac{N_3}{\tau_{32}} - \frac{N_3}{\tau_{31}} - \frac{N_3}{\tau_{33b}} - \frac{N_3\ e^{-\frac{E_{43}}{kT}}}{\tau_4} - \frac{N_3\ e^{-\frac{E_{13b}}{kT}}}{\tau_1} - \frac{1}{N_p}\frac{c_0}{n_{eff}} g N_{ph} \\
\frac{dN_2}{dt} &= \frac{N_4}{\tau_{42}} + \frac{N_3}{\tau_{32}} + \frac{N_1\ e^{-\frac{E_{21}}{kT}}}{\tau_2} - \frac{N_2}{\tau_{21}} - \frac{N_2}{\tau_{23b}} + \frac{1}{N_p}\frac{c_0}{n_{eff}} g N_{ph} \\
\frac{dN_1}{dt} &= \frac{N_4}{\tau_{41}} + \frac{N_3}{\tau_{31}} + \frac{N_2}{\tau_{21}} + \frac{(N_{3b} + n_{inj}) e^{-\frac{E_{13b}}{kT}}}{\tau_1} - \frac{N_1}{\tau_{13b}} - \frac{N_1\ e^{-\frac{E_{21}}{kT}}}{\tau_2} \\
\frac{dN_4}{dt} &= \frac{(N_{3b} + n_{inj}) e^{-\frac{E_{43b}}{kT}}}{\tau_4} - \frac{N_4}{\tau_4} \\
\frac{dN_{3b}}{dt} &= \frac{N_4}{\tau_{43}} + \frac{N_4}{\tau_{43b}} + \frac{N_3}{\tau_{33b}} + \frac{N_2}{\tau_{23b}} + \frac{N_1}{\tau_{13b}} \\
&\quad - \frac{N_3}{\tau_{32}} - \frac{N_3}{\tau_{31}} - \frac{N_3}{\tau_{33b}} - \frac{N_3\ e^{-\frac{E_{43}}{kT}}}{\tau_4} - \frac{N_3\ e^{-\frac{E_{13b}}{kT}}}{\tau_1} - \frac{1}{N_p}\frac{c_0}{n_{eff}} g N_{ph} \\
\frac{dN_{ph}}{dt} &= \Gamma \frac{c_0}{n_{eff}} g N_{ph} - \frac{N_{ph}}{\tau_{ph}} \\
g &= \frac{2q^2 E_{32} z_{32}^2}{\hbar c_0 \epsilon_0 n_{eff} L_p\ \delta E_{32}} (N_{3b} - N_2)
\end{aligned}
$$

constants
$E_{32} = 254$ meV
$E_{43} = 79$
$E_{21} = 38$
$E_{13b} = 74$

$z_{32} = 17$ Å
$L_p = 291$ Å

$\tau_{43} = 0.954$ ps
$\tau_{42} = 6.81$
$\tau_{41} = 7.21$
$\tau_{43b} = 5.42$

$\tau_{32} = 5.04$
$\tau_{31} = 3.84$
$\tau_{33b} = 8.26$

$\tau_{21} = 0.285$
$\tau_{23b} = 1.27$

$\tau_{13b} = 0.291$

all N_i have units of 1/area