9. Appendix D - Nomenclature

The following sections list the symbols, definitions, and units of the fundamental variables that SimWindows solves, the specified variables that the user supplies, and the computed variables that SimWindows generates. The equations in this section do not consider different units, and there are no terms in the equations that are present simply to convert between units. For example, various equations interchange electron volts (eV) with Joules (J) without including an extra q to convert between electron volts and Joules.

9.1 Fundamental Variables

$f(x)$	Electrostatic Potential (V)
$h_c(x) = (E_{fn}(x) - E_c(x))/kT_n(x)$	Electron Planck potential (unitless)
$h_v(x) = (E_v(x) - E_{fp}(x))/kT_p(x)$	Hole Planck potential (unitless)
S	Total number of photons in a mode (unitless)
$T_L(x)$	Lattice Temperature (K)
$T_n(x)$	Electron Temperature (K)
$T_p(x)$	Hole Temperature (K)

9.2 Specified Variables

A_c	Area of a laser cavity (cm^2)
B	Spontaneous recombination constant ($cm^3\ s^{-1}$)
B_{qw}	QW spontaneous recombination constant ($cm^2\ s^{-1}$)
E_D,E_A	Donor and acceptor energy level relative to nearest band (eV)
E_g	Band Gap (eV)
g_D,g_A	Donor and acceptor degeneracy factor (unitless)
L	Total length of the device (cm)
L_c	Laser cavity length (cm)
L_{qw}	Length of the quantum well (cm)
m_n^*,m_p^*	Electron and hole density of states mass (kg)
m_{cn}^*,m_{cp}^*	Electron and hole conductivity mass (kg)
n_{real}	Real part of the refractive index (unitless)
N_D,N_A	Total donor and acceptor concentrations (cm^{-3})
r_d	Device radius (cm)
r_e	Environment radius (cm)

R_l, R_r	Reflectivities of left and right mirrors (unitless)
T_{env}	Environment temperature (K)
T_l, T_r	Temperature of left and right surfaces (K)
V_l, V_r	Bias of left and right contacts (V)
x	Position (cm)
a	Absorption coefficient (cm^{-1})
a_s	Laser scattering loss (cm^{-1})
b	Fraction of spontaneous photons emitted into lasing mode (unitless)
$\in$	Dielectric permitivity ($F\ cm^{-1}$)
k	Thermal conductivity ($J\ s^{-1}\ cm^{-1}\ K^{-1}$)
k_l, k_r	Thermal conductivities of the left and right surfaces ($J\ s^{-1}\ cm^{-2}\ K^{-1}$)
m_n, m_p	Electron and hole mobilities ($cm^2\ V^{-1}\ s^{-1}$)
u_n,u_n	Power dependence of the electron and hole momentum relaxation times (unitless)
u_{opt}	External optical generation frequency (s^{-1})
t_n, t_n	Electron and hole shr recombination lifetime (s)
t_{wn}, t_{wn}	Electron and hole energy relaxation lifetime (s)
c	Electron affinity (eV)

9.3 Computed Variables

$A^*_{n,p}$	Electron and hole Richardson constants ($A\ cm^{-2}\ K^{-2}$)
$\mathbf{D}$	Electrostatic Displacement ($C\ cm^{-2}$)
$\mathcal{E}$	Electrostatic field ($V\ cm^{-1}$)
$\mathcal{E}_{stim}$	Normalized stimulated electromagnetic field ($cm^{-3/2}$)
E_c, E_v	Conduction and valence band edges (eV)
$E_{c,top}$,$E_{v,top}$	Conduction and valence band energies of the top of a QW (eV)
E_{fn}, E_{fp}	Electron and hole quasi-fermi levels (eV)
E_{gqw}	Quantum well band gap (bulk band gap plus electron and hole quantized energy levels) (eV)
E^+_j, E^-_j	Forward and reverse propagating electric fields (unitless)
$E_{n,stim}$, $E_{p,stim}$	Electron and hole stimulated emission energies (eV)
E_{qwn},E_{qwp}	Electron and hole QW quantized energy level (eV)
g	Local gain (cm^{-1})
G_{opt}	Total external optical generation rate ($cm^{-3}\ s^{-1}$)
$G_{u\ \rho pt}$	External optical generation rate at a specific frequency ($cm^{-3}\ s^{-1}$)
$\mathbf{J}_n$, $\mathbf{J}_p$	Electron and hole current density ($A\ cm^{-2}$)
$\mathbf{J}^{therm}_{n,p\longrightarrow+}$, $\mathbf{J}^{therm}_{n,p+\rightarrow-}$	Electron and hole current due to thermionic emission traveling from left to right (- to +) and right to left (+ to -) ($A\ cm^{-2}$)
$\mathbf{J}^{tun}_{n,p\longrightarrow+}$, $\mathbf{J}^{tun}_{n,p+\rightarrow-}$	Electron and hole current due to tunneling traveling from left to right (- to +) and right to left (+ to -) ($A\ cm^{-2}$)

k_o	Free space wave vector (cm^{-1})
m_{qwn}^*, m_{qwp}^*	Electron and hole DOS masses in a quantum well (kg)
m_{bulkn}^*, m_{bulkp}^*	Electron and hole DOS masses in bulk material (kg)
n, p	Total electron and hole concentration (cm^{-3})
n_b, p_b	QW bound electron and hole concentration (cm^{-3})
n_f, p_f	QW free electron and hole concentration (cm^{-3})
n_i	Bulk intrinsic carrier concentration (cm^{-3})
$n_{i,2d}$	QW intrinsic carrier concentration (cm^{-3})
n_j	Complex refractive index of region j (unitless)
n_{2d}, p_{2d}	Total QW electron and hole concentration (cm^{-2})
N_c, N_v	Effective conduction and valence bands density of states (cm^{-3})
N_{cqw}, N_{vqw}	Effective quantum well conduction and valence bands density of states (cm^{-2})
N_D^+, N_A^-	Ionized donors and acceptor concentrations (cm^{-3})
$\langle S_j \rangle$	Total Poynting vector for a propagating electromagnetic field (W cm^{-2})
$\langle S_j^+ \rangle, \langle S_j^- \rangle$	Time averaged Poynting vectors for forward and reverse propagating electromagnetic fields (W cm^{-2})
$\mathbf{S}_n^{tot}, \mathbf{S}_p^{tot}$	Electron and hole total energy flow (J cm^{-2} s^{-1})
$\mathbf{S}_{n,p}^{therm}$	Electron and hole total energy flow due to thermionic emission (J cm^{-2} s^{-1})
$\mathbf{S}_{n,p-\rightarrow+}^{therm}, \mathbf{S}_{n,p+\rightarrow-}^{therm}$	Electron and hole kinetic energy flow due to thermionic emission traveling from left to right (- to +) and right to left (+ to -) (J cm^{-2} s^{-1})
$\mathbf{S}_{n,p}^{tun}$	Electron and hole total energy flow due to tunneling (J cm^{-2} s^{-1})
$\mathbf{S}_{n,p-\rightarrow+}^{tun}, \mathbf{S}_{n,p+\rightarrow-}^{tun}$	Electron and hole kinetic energy flow due to tunneling traveling from left to right (- to +) and right to left (+ to -) (J cm^{-2} s^{-1})
$\mathbf{S}_{lat}$	Lattice energy flow (J cm^{-2} s^{-1})
$U_{c-,v-}, U_{c+,v+}$	Conduction and valence barrier heights seen from the left (-) and the right (+) (eV)
U_{tot}	Total carrier recombination rate (cm^{-3} s^{-1})
$U_{stim}, U_{b\text{-}b}, U_{shr}$	Stimulated, Band to band, and Shockley-Hall-Reed recombination (cm^{-3} s^{-1})
$\tilde{U}_{stim}, \tilde{U}_{b-b}$	Total stimulated and spontaneous recombination rates in the laser cavity (s^{-1})
u_n, u_p	Total electron and hole energy density (J cm^{-3})
$u_{n,2d}, u_{p,2d}$	Total QW electron and hole energy density (J cm^{-2})
V_{qwn}, V_{qwp}	Conduction and Valence QW heights (eV)
v_{stim}	Velocity of stimulated emission photons (cm s^{-1})
W_n^{tot}, W_p^{tot}	Total electron and hole energy loss rate (J cm^{-3} s^{-1})
$W_{n,shr}^{tot}, W_{p,shr}^{tot}$	Total electron and hole SHR energy loss (J cm^{-3} s^{-1})

$W_{n,b-b}^{tot}, W_{p,b-b}^{tot}$	Total electron and hole spontaneous energy loss (J cm^{-3} s^{-1})
$W_{n,stim}^{tot}, W_{p,stim}^{tot}$	Total electron and hole stimulated energy loss (J cm^{-3} s^{-1})
$W_{n,opt}^{tot}, W_{p,opt}^{tot}$	Total electron and hole external optical energy loss (J cm^{-3} s^{-1})
$W_{n,relax}^{tot}, W_{p,relax}^{tot}$	Total electron and hole relaxation energy loss (J cm^{-3} s^{-1})
W_{lat}^{tot}	Total lattice energy loss (J cm^{-3} s^{-1})
Z_j	relative complex impedance in region j (unitless).
a_m	Distributed mirror loss (cm^{-1})
f_0	Built-in Potential (V)
h_{c0}, h_{v0}	Charge neutral values of the electron and hole Planck potentials (eV)
k_e	Effective environment thermal conductivity (J cm^{-1} K^{-1})
u_{stim}	Stimulated emission frequency (s^{-1})
r	Total Charge (C cm^{-3})
y_n, y_p	Electron and hole QW wavefunction ($cm^{-1/2}$)
t_{ph}	Photon lifetime (s)

9.4 Constants

q - Electronic charge (1.602 x 10^{-19} C)
k - Boltzmann Constant (8.62 x 10^{-5} eV K^{-1})
h - Planck Constant (6.626 x 10^{-34} J s)
$\hbar$ - Planck Constant/2p (1.0546 x 10^{-34} J s)
i - $(-1)^{0.5}$
p - Pi (3.141592654)