Semiconductor Bloch Equations for GaN Heterostructures with Dynamical Screening

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The nonlinear optical absorption in low dimensional semiconductors are well described by Semiconductor Bloch Equations, derived from Green's functions or projection techniques. Different versions of these equations have quite successfully described isolated quantum wells, coupled superlattices and bulk materials.[1-3] A careful analysis within the frame of a recent many-body theory, considering in detail the interplay between Coulomb-Hartree-Fock and scattering contributions, shows e.g. that the density dependent shift of the excitonic peak depends on temperature for three-dimensional bulk samples, reproducing recent experimental findings. [3] The question is at this moment open, on what a theory at that level, including non-diagonal dephasing and dynamical screening of the Coulomb interaction might predict as the system evolves from quasi-three to quasi-two dimensions, for Nitride-based heterostructures, where the exciton binding energy is large, as a signature of strong Coulomb correlations. In a simplified notation, in which band labels are not included, the macroscopic polarization (from which the absorption is computed) at steady-state in the electron-hole picture reads,

$$\hbar\left[\omega - e_e(k) - e_h(k)\right]\, p_{eh}(k,\omega) + \left[1 - f_e(k) - f_h(k)\right]\, \Omega(k,\omega) = I_{eh}(k,\omega). \tag{1}$$

The exchange-renormalized carrier, and generalized Rabi energies are given by

$$\begin{aligned} \hbar e_\lambda(k) &= \hbar\epsilon_\lambda(k) - \sum_{\vec{q}} V_{\vec{k}-\vec{q}}\,, \\ \Omega(k,\omega) &= \mu_{eh}(k)\cdot E(\omega) + V_{\vec{k}-\vec{q}}\, p_{eh}(q,\omega)\,, \end{aligned} \tag{2}$$

while the scattering integral is given by,

$$\begin{aligned} I_{eh}(k,\omega) &= \sum_{\vec{q}} \left[\Theta_{\vec{q},\vec{k}} - \Theta_{\vec{k},\vec{q}}\right] p_{eh}(q,\omega)\,, \\ \Theta_{\vec{k},\vec{q}} &= -\sum_{a\neq b}\int \frac{d\omega'}{2\pi}\frac{\left[1 - f_a(k)\right]\, W^{>}_{\vec{k}-\vec{q}}(\omega') - f_a(k)\, W^{<}_{\vec{k}-\vec{q}}(\omega')}{\omega - e_a(k) - e_b(k) - \omega' + i\delta}. \end{aligned} \tag{3}$$

The energies $e_\lambda(k)$ are renormalized and the scattering integral I_{eh} includes both diagonal and non-diagonal dephasing. With our current theory we can "turn on and off" several different effects and compare them. We discuss under which conditions the static limit can be used as compared to the dynamically screened results, as well as the interplay between band coupling and many body effects for different limiting cases, from isolated, two-dimensional-like quantum wells to coupled three-dimensional-like superlattices. We further hope with our numerical results to stimulate detailed experimental investigations of the effects simulated here.

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