## Comment on "Nature of Coupled-Mode Contributions to Hot-Electron Relaxation in Semiconductors"

In a recent Letter [1] Dharma-wardana explicitly calls into question the earlier work of Jain, Jalabert, and Das Sarma [2] by stating that quasiparticlelike modes do not contribute to the energy-loss rate of hot electrons. This conclusion is by no means supported by the arguments presented. The bulk of Ref. [1] is a heuristic derivation of well-known expressions [2-4] for the relaxation rate, followed by a purported evaluation which leads to the stated conclusion. A serious analysis of the parameters needed for this evaluation would indeed be an important contribution, but here their relative magnitudes are simply stated, with the barest of handwaving justifications. At best, the true content of Ref. [1] is simply the claim that its author's guess is better than that of Ref. [2]. If so, the paper is written in a misleading way. To the extent that the thesis of Ref. [1] is considered "proved" therein, it reflects a serious misunderstanding of the actual physical situation. The misunderstanding of Ref. [1] is the noninclusion of the decay of the emitted LO phonons *into acoustic phonons* (or, the so-called phonon bottleneck or hot-phonon lifetime) without which no energy can escape from the coupled electron-LO-phonon system. The phonons interact with an electron gas maintained at a fixed temperature, but (as Ref. [1] insists) have no other mechanism for decay (and thus no coupling to a separate heat bath). The inevitable result is that the phonons must equilibrate with the electrons, reducing the energy flow from the electron system to zero. The *real* phonon modes obviously decay into acoustic phonons, and thus do couple to the heat bath, relieving the bottleneck [2-4] to some extent—a process totally ignored in Ref. [1].

The energy-loss-rate expression, as given in Ref. [2] (and subsequently derived semirigorously by one of us [3]) appears in Eq. (6) of Ref. [1] as

$$\mathrm{ELR} = \sum_q \int (d\omega/\pi)\omega M_q^2 \times [-\mathrm{Im}\chi_e(\mathbf{q},\omega)]\mathrm{Im}D(\mathbf{q},\omega)\Delta\bar{N}_{\mathrm{CM}}\,, \quad (1)$$

$$\Delta\bar{N}_{\mathrm{CM}} = \bar{N}(\beta_e,\omega) - \bar{N}_{\mathrm{CM}}(\beta_p,\beta_e,\omega)\,, \quad (2)$$

where $\chi_e$, $D$, and $M_q^2$ are, respectively, the electron-density response function, the dressed phonon Green's function, and the Fröhlich interaction. The quantities $\bar{N}$ and $\bar{N}_{\mathrm{CM}}$ are the Bose factor at $\beta_e$ and the effective Bose factor for phononlike excitations, respectively, where $\beta_e$ and $\beta_p$ are inverse temperatures for the electrons and lattice. Reference [2] pointed out that there is weight in $\mathrm{Im}D(q,\omega)$ at low $\omega$, greatly enhancing the ELR if, as assumed, the phononlike excitations could simply be regarded as being at the lattice temperature. The thesis of Ref. [1] is that "bottleneck" or "hot-phonon" effects bring the low-frequency coupled modes almost precisely to the electronic temperature, so that Eq. (2) gives zero at those frequencies, suppressing the enhancement completely.

$\Delta\bar{N}_{\mathrm{CM}}$ is given by [1,3]

$$\Delta\bar{N}_{\mathrm{CM}} = \frac{[\bar{N}(\beta_e,\omega) - \bar{N}(\beta_p,\omega)]p_2(q,\omega)}{p_2(q,\omega) + 2\omega_{\mathrm{LO}}M_q^2\chi_2(q,\omega)}\,. \quad (3)$$

Here $p_2(q,\omega)$ is the imaginary part of the bare phonon self-energy [5], which gives the rate of its decay to the heat bath, while $\chi_2$ is the imaginary part of $\chi_e$, and the denominator determines the lifetime of the electron density excitation against decay to phonons. Equation (3) was also derived heuristically in Ref. [4], where $p_2(q,\omega)$ was approximated by the constant value $-2\omega_{\mathrm{LO}}/\tau_{\mathrm{ph}}$.

The presence or absence of a bottleneck obviously hinges on the relative sizes of $p_2$ and $\chi_2$ at the frequency of the coupled mode. While $\chi_2$ is known theoretically, the calculation of $p_2$ would require a very detailed analysis involving LO and acoustic phonons in a nonequilibrium environment, which has not been accomplished. Reference [2] assumed a frequency-independent value, given by the empirical lifetime of the phonons, and found that the bottleneck did not exist. Reference [1] assumes a very long (actually, infinite) lifetime for the phonon-coupled modes, simply stating that it is of order $1/\omega$ as compared to $1/\omega_{\mathrm{LO}}$ for the electronic time. There is no justification for this statement, and thus no basis for the paper's conclusion.

The correct choice of lifetimes is not yet accessible to theory. It should be noted, however, that the choice in Ref. [2] has the virtue of resolving a number of experimental puzzles, which remain unresolved if the other choice is made. Additional experiments are needed to clarify the situation further.

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[4] S. Das Sarma, in "Hot Carriers in Semiconductor Microstructures: Physics and Applications," edited by J. Shah (Academic, New York, to be published); P. Kocevar, Physica (Amsterdam) **134B**, 155 (1985); W. Cai *et al.*, Phys. Rev. B **34**, 8573 (1986); J. R. Senna and S. Das Sarma, Solid State Commun. **64**, 1397 (1987).
[5] By "bare" phonon we mean in the absence of interaction with the electron system. Coupling to acoustic phonons is included, which provides the coupling to the lattice heat bath, and thus an outlet for energy from the LO-phonon system. If one takes $p_2$ to be infinitesimal, in the spirit of Ref. [1], the energy loss is trivially (and, incorrectly) zero.