Das Sarma and Senna Reply: The two preceding Comments [1,2] are both based on a rather naive misunderstanding of the hot electron energy loss problem in general and our recent work [3] in particular. The conclusion of these two Comments (we mention that while there are technical disagreements between the two Comments, their essential contents are similar), that there can be no net energy loss from the hot electrons to a lattice in *an isolated system* because eventually the lattice will heat up and the emitted hot phonons will have to be reabsorbed by the electron gas, is so trivial as not to merit discussion or elaboration. The immediate narrow purpose of this Reply is for us to point out the very trivial nature of these Comments, and to emphasize that we completely stand by our original results [3], which are obtained not for an isolated system but for a real experimental setup where the emitted acoustic phonons eventually give up their energy to an external heat bath, producing a net energy dissipation from the coupled electron-phonon system. A more important general purpose of our Reply is to point out the naive conceptual mistake in these Comments and to emphasize why these trivial results are irrelevant to actual experimental measurements of hot electron energy loss rates.

Consider a hot electron gas maintained at a fixed temperature T_e losing energy to a lattice via emission of phonons (either optical or acoustic phonon for the present purpose). If the emitted phonons have no coupling to an outside heat bath (i.e., if the coupled electron-lattice system is *truly isolated*), then the emitted phonons obviously never decay, and eventually (i.e., in the steady state) come to equilibrium with the hot electron gas. The inevitable result is that the isolated coupled electron-lattice system equilibrates, reducing the net energy flow from the electron system to zero. This trivial result has, in fact, been derived in a complicated fashion in the two preceding Comments. (We mention, however, that in this respect the conclusion of the first Comment [1] that there is a "suppression" of the energy loss rate is, in fact, wrong—the hot electron energy loss rate for this isolated coupled hot electron-lattice system actually *vanishes* as is correctly concluded by the authors of the second Comment [2].) The fact that the hot electron energy loss rate would trivially vanish if the emitted phonons are not removed from the system (i.e., if the emitted phonons are allowed to equilibrate with the hot electron gas) is universally known [4], and is totally independent of the system dimensionality and of whether many-body effects are included in the calculation or not. (Inclusion of many-body effects in one dimensional hot electron energy loss processes is the subject matter of our original paper [3].)

In a physical model one must not consider the coupled electron-phonon system to be isolated (if one does, then as emphasized above, one trivially gets zero energy loss rate), but must include in some manner the coupling of the system to a separate external heat bath. If the emitted phonons are LO phonons, then it is sufficient to consider their decay into acoustic phonons via anharmonic phonon-phonon coupling. Such decay of LO phonons into acoustic phonons is always implicitly assumed in *all* hot electron energy loss calculations—often an explicit phonon decay time (sometimes called the "hot phonon lifetime") is used [4,5] in the calculation. It is trivial and well known [4,5] (except possibly by the authors of the two previous Comments) that if this hot phonon lifetime is taken to be infinite (which is the basic assumption in both the Comments), then there is no hot electron energy loss. Most calculations implicitly assume a reasonably short (compared with the other characteristic time scales) hot phonon lifetime, or, explicitly incorporate this phonon bottleneck effect through a kinetic approximation. For electron energy loss to acoustic phonons, which was the subject matter of our original work [3], there must be an outside reservoir removing the emitted acoustic phonons so that they do not eventually equilibrate with the hot electron gas. Basically hot phonon reabsorption is implicitly disallowed in *all* reasonable (including ours [3]) models of energy loss rate calculations. A real nonequilibrium calculation including the *outside* heat bath is clearly beyond the scope of model energy loss calculations and is a formidable problem in quantum dissipation theory. We emphasize that any naive and simplistic nonequilibrium calculation, exemplified by the two preceding Comments, is bound to come to the trivial (and physically absurd) conclusion that the hot electron energy loss rate in an *isolated* system vanishes, independent of whether quantum many-body effects are included in the theory or not. This was first explicitly shown by Korenman [5] within a nonequilibrium Green's function formalism and has earlier been discussed in the literature [4–6]. It is important to emphasize that the decay of the emitted phonons (whether they are acoustic or LO phonons), which causes a net energy flow from the coupled electron-phonon system to the outside heat bath, does not arise from the electron-phonon many-body coupling, but from processes beyond the electron-phonon Hamiltonian which controls the energy loss rate from the hot electron gas to the lattice. For LO phonon emission, this decay process can be effectively incorporated in the theory [4,6] through a kinetic approximation using an empirical LO phonon lifetime (for decay into acoustic phonons via anharmonic interaction).

Before concluding, we summarize the essential result of our original one dimensional calculation [3] which is physically so meaningful as to transcend these nonequilibrium considerations. *Assuming* that a one dimensional quantum wire system is a Fermi liquid (i.e., a well-defined Fermi surface exists at low temperatures $T_e \ll T_F$, the Fermi temperature), it is easy to see that electron-acoustic phonon scattering will be severely (exponentially) suppressed at low temperatures due to the usual one dimensional phase space restriction (i.e., because the Fermi surface is just a collection of two points at low temperatures). Thus, the Bloch-Grüneisen low temperature power loss behavior [7] of the temperature dependence of electronic energy loss rate (and resistivity) will be invalid in a one dimensional electron phonon system with the low temperature hot electron power loss rate behaving [8] as $\exp(-2\hbar\omega_{k_F}/k_B T_e)$, where ω_{k_F} is the acoustic phonon frequency for the phonon wave vector equal to the one dimensional Fermi wave vector k_F. This is in sharp contrast to the usual T^{-n} (with $n \sim 3$–8) Bloch-Grüneisen behavior expected in a normal (higher dimensional) Fermi liquid [7]. Our original work [3] suggests a many-body electron-phonon coupling induced lifting of this severe one dimensional phase space restriction which would "enhance" the power loss rate from this exponentially suppressed behavior to a renormalized Bloch-Grüneisen type behavior, making the one dimensional hot electron energy loss rate via acoustic phonon emission essentially comparable to the corresponding higher dimensional Bloch-Grüneisen type behavior. Note that while our predictions will eventually be tested by experiments, the two preceding Comments completely miss this absolutely (and essentially) one dimensional nature of our work in the sense that their naive and trivial conclusions are totally independent of the dimensionality of the electron system. In fact, the trivial results of the two preceding Comments depend neither on the system dimensionality nor on many-body coupling, and are the immediate consequence of considering energy dissipation from hot electrons to the lattice in a truly isolated system, which, by definition, must vanish in the steady state.

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