Applications of a non-parabolic Tail Electron Hydrodynamical Model to Silicon devices

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Computer aided design of modern semiconductor devices requires increasingly accurate physical models which are able to describe high-field phenomena such as hot electron effects, impact ionization, thermal self-heating, etc. Such phenomena play an important role in the degradation and breakdown of devices.

Using Monte Carlo methods (MC) is extremely CPU intensive and therefore not practical. On the other hand traditional hydrodynamical models for carrier transport in semiconductors cannot cope with hot electrons because they deal only with average values over the whole carrier population.

Several considerations suggest that electrons having energies respectively lower and higher than a suitable threshold energy may be described by two distinct thermal distributions at different temperatures [1]. This justifies the introduction of new fluid dynamical models, [2, 3], where two well-defined subpopulations of electrons are considered, each subpopulation being described by the relative macroscopic quantities.

Recentely [4], a theoretical foundation for these models has been given by utilizing the moment method and a closure by which one can obtain both the constitutive fluxes and the production terms, appearing in the moment equations, as functions of the fundamental hydrodynamical variables, without resorting to MC. However, for the sake of simplicity, a parabolic band approximation has been used also for the highly energetic electrons. Here we propose an improvement of the model attained by using the Kane dispersion relation. Starting from the Boltzmann equation and introducing a threshold energy ϵ_{thr}, (usually the threshold energy of impact ionization), we obtain a macroscopic model where the electron flow is described by the following fundamental variables: number density, average velocity, energy and energy flux of

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electrons having energy less than and greater than ϵ_{thr} (zone 1 and 2 electrons respectively),

$$\begin{cases} n_1 = \int_{\tilde{\Delta}} f \, d\mathbf{k} & n_1 \, \mathbf{u_1} = \int_{\tilde{\Delta}} \mathbf{v} f \, d\mathbf{k} \\ n_1 \, W_1 = \int_{\tilde{\Delta}} \epsilon f \, d\mathbf{k} & n_1 \, \mathbf{S_1} = \int_{\tilde{\Delta}} \epsilon \mathbf{v} f \, d\mathbf{k} \end{cases} \tag{1}$$

$$\begin{cases} n_2 = \int_{\Delta} f \, d\mathbf{k} & n_2 \, \mathbf{u_2} = \int_{\Delta} \mathbf{v} f \, d\mathbf{k} \\ n_2 \, W_2 = \int_{\Delta} \epsilon f \, d\mathbf{k} & n_2 \, \mathbf{S_2} = \int_{\Delta} \epsilon \mathbf{v} f \, d\mathbf{k} \, . \end{cases} \tag{2}$$

$f = f(\mathbf{x}, t, \mathbf{k})$ is the electron distribution function and $\mathbf{k}$ the electron wave vector. $\epsilon(\mathbf{k})$ is the electron energy in the conduction band. $\Delta = \{\mathbf{k} : \epsilon(\mathbf{k}) \geq \epsilon_{thr}\}$ and $\tilde{\Delta} = \Re^3 - \Delta$.

The necessary closure relations for fluxes and production terms are found by means of the maximum entropy principle [5].

In order to test the model, we consider applications to bulk silicon and 1-dimensional electron diodes.

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