An Advanced Electro-Thermal Simulation Methodology For Nanoscale Device

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ABSTRACT
In this work, we propose an advanced electro-thermal simulation methodology for nanoscale device based on a macroscopic model for acoustic and optical phonon energy transfer, which will be demonstrated on an SOI FinFET example.

INTRODUCTION
With the continuous scaling of semiconductor transistors down to nanoscale regime, further driven by the emerging novel architecture such as FinFETs, thermal transport has become one of the major concerns for in terms of performance and reliability. Modeling and analysis of self-heating effects in nanoscale devices such as FinFETs have attracted increasingly more interests [1-3]. Recently we have developed a thermal simulation module [4], implemented in GSS ‘atomistic’ simulator GARAND [5], based on the solution of the coupled Heat Flow, Poisson, and Current Continuity Equations (CCE). In this work, we are going to further incorporate an advanced methodology into GARAND for electro-thermal simulation of FinFETs.

MODEL AND EXAMPLE
The advanced electro-thermal simulation methodology for nanoscale device is based on a macroscopic model [6]. The model for acoustic and optical phonon energy transfer involves the temperature of electrons, acoustic phonons and optical phonons $T_e, T_A$, and $T_o$, and the relaxation times between them $\tau_{e-o}$, $\tau_{e-A}$, and $\tau_{o-A}$ respectively. These can be naturally implemented in Monte Carlo (MC) simulation, however, in the cost of long computational time. If focusing on the stationary state, these equations can be simplified. Starting from the energy transfer equations, a new equation in the form of new heat flow equation can be derived, which includes the terms about $T_e$ and $T_A$.

\[ \nabla (k_T \nabla T_A) = -C_o \frac{T_o - T_A}{\tau_{o-A}} - \frac{3nkT_e - T_A}{2\tau_{e-A}} \]

where $n$ is the electron density, $v_d$ is the drift velocity, and $C_o$ is heat capacities. This can be coupled within Drift-Diffusion framework, which is more computationally efficient. The electrons temperature $T_e$ can be pre-calculated by MC simulations and a lookup table of $T_e$ with respect to $E$ can be constructed. Then the coupled Poisson, CCE, and energy transfer equations can be solved iteratively. At each iteration, $T_e$ will be refreshed as well as recalculation of $T_A$. Thermal conductivity in the refined fin region will be modeled by position and temperature dependent formula. The flow chart of the methodology is illustrated in Fig. 1. An SOI FinFET example (schematics as sown in Fig. 2) is used as a testbed for the advanced methodology. It consists of complex 3D structure and material composition, as shown in Fig. 3. Lattice temperature and potential distributions obtained from coupled Heat Flow, Poisson, and CCE will be used as the initial conditions for the advanced electro-thermal simulation, as shown in Fig. 4 (a) (b).

CONCLUSION
An advanced electro-thermal simulation methodology for nanoscale device based on a macroscopic model for acoustic and optical phonon energy transfer is being implemented in GSS ‘atomistic’ simulator GARAND. A full scale simulation on SOI FinFET will be presented following the complete implementation.
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Fig. 1. Flow chart for the advanced electro-thermal simulation methodology.

Fig. 2. Schematics of SOI FinFET

Fig. 3. (a) Lattice temperature distributions and (b) potential distribution at high drain and high gate biases resulted from coupled Heat Flow, Poisson, and Current Continuity Equations, which will be the initial conditions for the advanced electro-thermal simulation.

REFERENCES