# Modeling of Hot Carrier Effects for 0.5 Micron MOSFET's

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## *ABSTRACT*

The self-consistent calculation of impact ionization for submicron MOSFETs has been implemented in a conventional device program (PISCES). PISCES uses 2-dimensional impact ionization coefficients obtained from Monte Carlo (MC) simulation to investigate detailed characteristics of hot carrier effects. Generated hole (current) density and changes in device parameters due to impact ionization significantly affect performance of 0.5 μm MOSFETs. An energy dependent mean free path has been introduced in the analytical expression considering the nonequilibrium effect implicitly which is significant for submicron MOSFET devices. A simple analytical model has been utilized in the PISCES [1] program and predicts the substrate current values which compare well with experimental results of conventional and LDD device structures.

The MC-calculated $\alpha$ [2] values can be used to obtain the generation term in the current continuity equation. A linear interpolation scheme is used to transfer rectangular MC-calculated $\alpha$ data onto the triangular grid structure of the PISCES program in the coupling PISCES-MC scheme. A Scharfetter-Gummel formula is used to calculate the generation term associated with each element in PISCES-MC scheme and shows nearly identical results compared to a weighted average current density scheme [3] which requires an additional matrix equation.

Fig.1 (a) & (b) shows the 2-D contour plots of the avalanche generation which qualitatively indicates the place of the generated charge distribution. Generally, the ionization process from the local model [3], [4] is highly localized near the drain junction region. The MC-calculated $\alpha$ spreads into the drain region and is smaller compared to that of the local model. The nonlocal effects that are represented by a nonlocal distance and scaling factor which is interpreted as exponential function relating the ratio of static energy to nonequilibrium energy. These parameters increase as the channel become shorter as shown in Fig.2. There exists two peaks in the generated hole density along the channel. The second peak results from the existence of the $\alpha$ distribution which matches the peak of electron current density as shown in Fig.3.

Under high field conditions with steep doping gradients near the drain junction regions, the bulk mean free path cannot be applied in the impact ionization model. The lucky drift mechanism that the electrons are assumed to gain the energy by drift motion involving collisions describes the accurate hot carriers. The mean free path which can be represented by group velocity and scattering time is strong function of electron energy [5]. An analytical expression is proposed by introducing an energy dependent mean free path and incorporated with Crowell-Sze model in PISCES. The effective mean free path is used to fit experimental data for substrate current in the conventional simulator has been obtained as a function of gate bias. The mean free path should decrease due to the lowering of the peak electric field intensity as gate voltage increases. The calculated effective mean free path based on the model is in reasonable agreement with the empirical data obtained from the comparison with experimental results as shown in Fig. 4 as well as the Monte Carlo simulation.

The substrate current using analytical expression incorporates bias dependent mean free path shows good agreement with the experimental results as shown in Fig.5. The reduced $\lambda$ for submicron devices are necessary to predict accurately the local impact ionization rate and substrate current in conventional device simulation. The new analytical model is simple and physical and provides a significant computer efficiency for time savings using a conventional device simulator.

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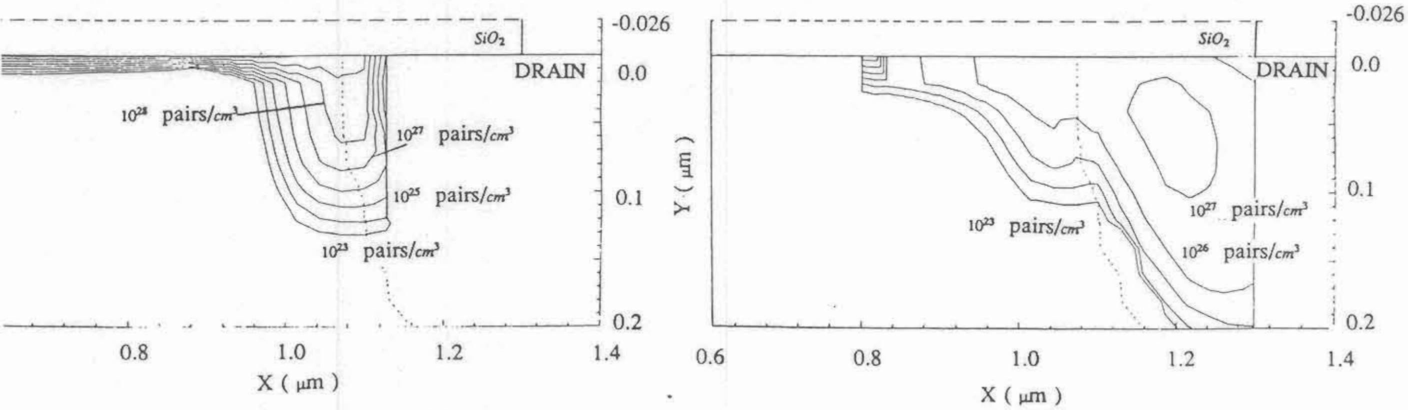

Fig.1: The 2-dimensional contour plot of avalanche generation for 0.5 μm MOSFET at $V_D$=6V. The contour line represent generated electron-hole pairs per unit cubic.
(a) Local Model (CSM) and (b) PISCES-MC Model

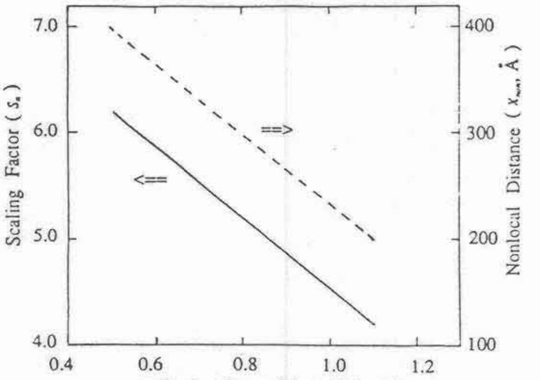

Fig.2: The channel length dependence of scaling factor and nonlocal distance

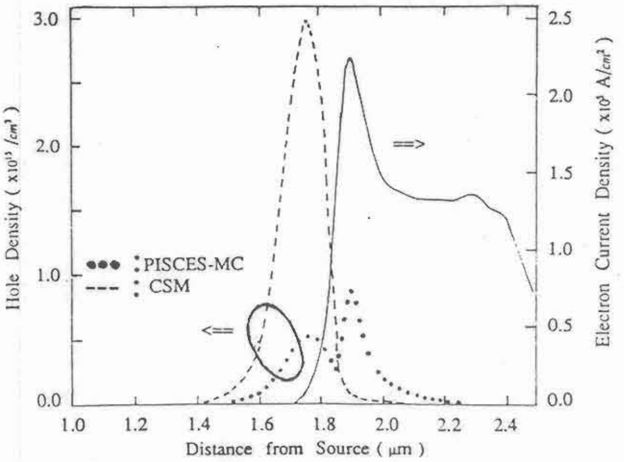

Fig.3: Generated hole density from local mode (CSM) and PISCES-MC and electron current density along the channel.

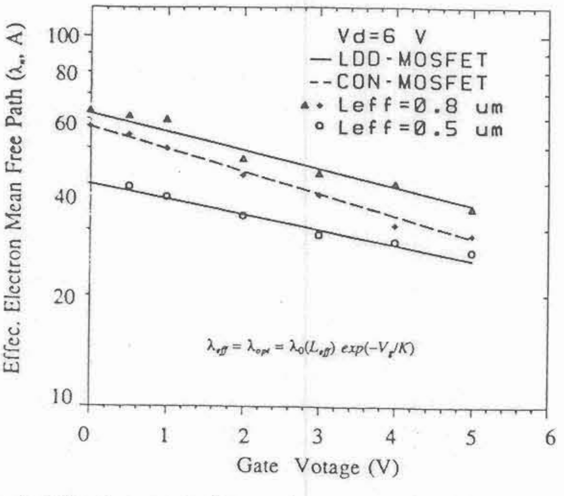

Fig.4: Effective mean free path versus gate voltage for different channel length. The solid lines represent model and points are the empirical data from experiment.

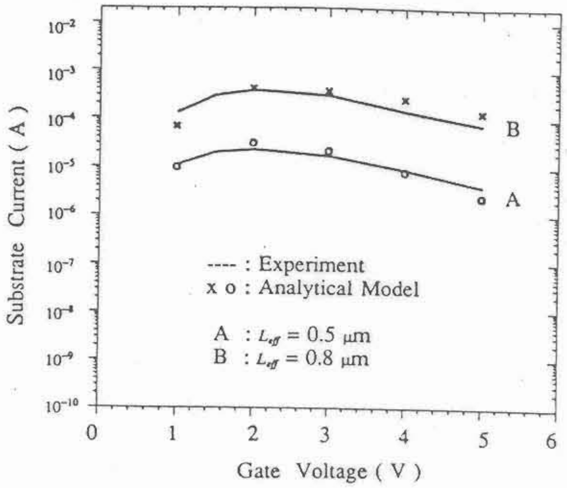

Fig.5: Calculated substrate current versus gate voltage characteristic. The result are for 0.5 μm ($V_D$=4V) and 0.8 μm ($V_D$=6V).