Kinetic-Energy Transport Equation for the Modeling of Ballistic MOSFETs

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INTRODUCTION

As MOS devices are scaled down to the sub-30nm regime, carrier transport may approach the ballistic limit. It has long been recognized that ballistic transport is limited by the barrier height [1]. Natori [2] has applied Landauer's transmission method to simulate ballistic MOSFETs by assuming a Fermi-Dirac energy distribution function. The Purdue group has extended McKelvey's one-flux method to include accelerating fields and obtained a ballistic drift-diffusion equation [3]. Here, we present yet another method of describing pure ballistic transport in nanoscale MOSFETs.

KINETIC-ENERGY TRANSPORT EQUATION

We utilize the first two moment equations of the collisionless Boltzmann transport equation in one-dimension, namely,

$$\frac{d}{dx}\left(n\upsilon_x\right) = 0, \qquad (1)$$

and

$$\frac{d}{dx}\left(nU_{xx}\right) + nq\mathcal{E}_x = 0, \qquad (2)$$

where the stress tensor U_{xx} for parabolic bands is assumed to be given by $\gamma k_B T + m^*\upsilon_x^2$, and γ is a dimensionless parameter. From (1) and (2) one can obtain

$$n = \text{const.}\exp\left(-\frac{E_c+\eta}{\gamma k_B T}\right) \qquad (3)$$

and

$$\left[1 - \frac{\gamma}{2(\eta/k_B T)}\right]\frac{d}{dx}\left(\frac{\eta}{k_B T}\right) + \frac{1}{k_B T}\frac{dE_c}{dx} = 0, \qquad (4)$$

where $\eta = \frac{1}{2}m^*\upsilon_x^2$ represents the kinetic energy (K.E.) and E_c represents the conduction band edge.

The transport equation (4) for η has two solutions, η_+ and η_-, representing the two-stream K.E. of the carriers injected from the source and the drain, respectively. The corresponding carrier density in (3) is determined by the boundary conditions at the source and drain contacts.

SIMULATION RESULTS AND DISCUSSION

We have applied the above K.E. transport equation to the simulation of a cylindrical gate-all-around (G-A-A) SOI MOSFET, shown in Fig. 1. Fig. 2 shows the potential barrier for $\gamma = 2/\pi$, Vgs = 1.5V and Vds = 1.0V. The negative of kinetic energies, η_+ and η_-, are shown in Fig. 3. Fig. 4 shows the velocity of carriers injected from the source (υ^+) and drain (υ^-), as well as the average velocity of the carriers. Shown in Fig. 5 are the corresponding carrier densities. In Fig. 6, I-V curves of the ballistic G-A-A SOI MOSFET with $\gamma = 2/\pi$ and $\gamma = 1$ are compared to that of drift-diffusion transport. Furthermore, underlying approximations and limitations of this approach will be discussed and compared with that of [3].

CONCLUSION

The two-stream K.E. transport equation can be used to model ballistic MOSFETs. The drain current in pure ballistic transport is increased by a factor of more than 50%, in agreement with most published results.

REFERENCES

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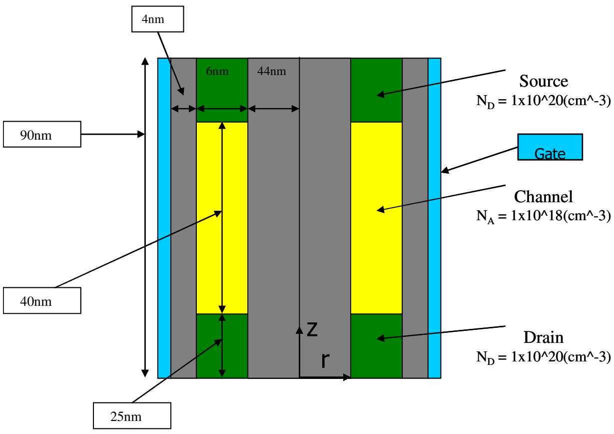

Fig. 1. Cross-section of cylindrical G-A-A SOI MOSFET

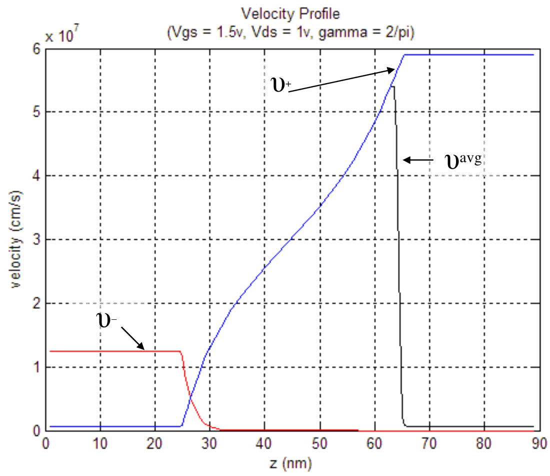

Fig. 4. Two-stream velocities for G-A-A SOI MOSFET

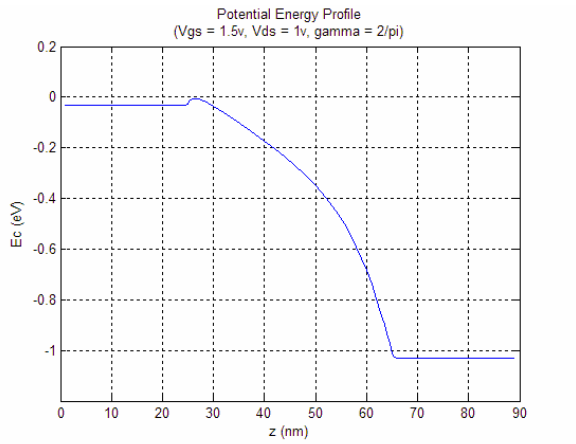

Fig. 2. Potential Energy barrier for G-A-A SOI MOSFET

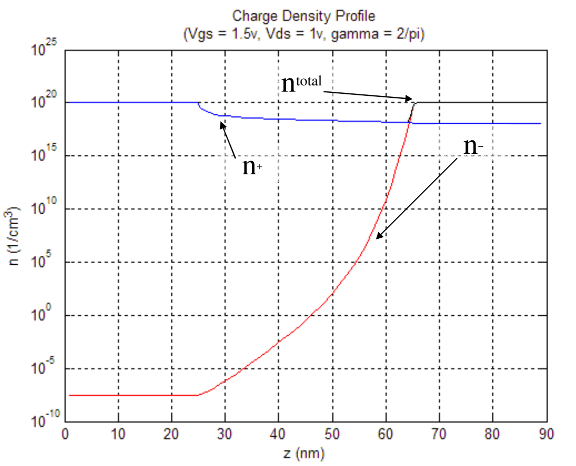

Fig. 5. Two-stream charge densities for G-A-A SOI MOSFET

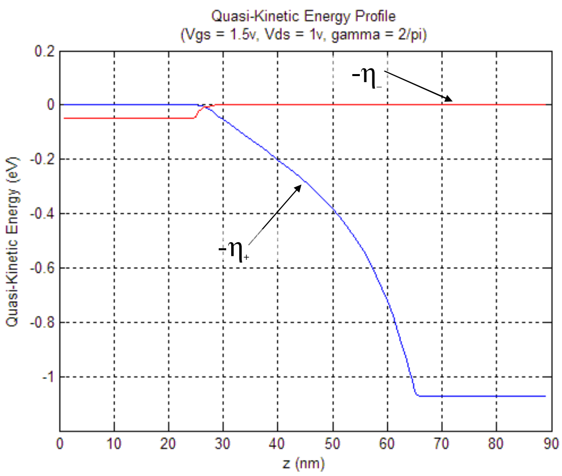

Fig. 3. Two-stream kinetic energies for G-A-A SOI MOSFET

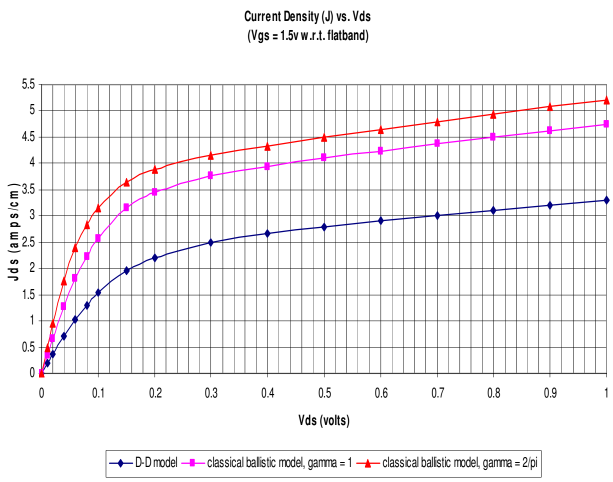

Fig. 6. I-V curves for G-A-A SOI MOSFET