SOCAMS 2004, Claremont, CA.

Modeling Quantum Effects on Current/Voltage Characteristics of a MOSFET Transistor

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When the dielectric thickness of the MOSFET (metal-oxide-silicon field-effect transistor) device is reduced below 4nm, quantum mechanical (QM) effects near the silicon/silicon oxide interface become significant. QM tunneling and confinement affect the profile of the inversion charge in the direction normal to the interface, and the current is reduced. The accuracy of SPICE, the industry's circuit simulator, deteriorates rapidly when the current/voltage characteristics are incorrect.

Full solutions of the Schrödinger and Gauss equations are available, but require high-level numerical simulations, impractical for SPICE application. An alternative is provided by the density-gradient (DG) model, which may be identified as an averaged form of the Schrödinger equation. Numerical results on the DG model show that electron charge density is reduced substantially in a narrow layer close to the silicon/silicon oxide interface, but its behavior outside this layer is similar to the non-quantum, classical solution, [1]. This is a classical boundary layer phenomenon.

Analytic solutions to the DG model based on matched asymptotic expansions have been obtained [2, 3]. However, due to insufficient information in the DG model concerning boundary conditions, it was necessary to use a fitting parameter to match with data. Recent work has substituted a more acceptable model that also shows excellent results when compared with numerical data, and this model is available for use in SPICE.

[1] E. Cumberbatch *et al,* "Current-voltage characteristics from an asymptotic analysis of the MOSFET equations*,"* *J. of Engineering Mathematics*, vol. 39, pp. 25-46, 2001.

[2] H. Abebe, CGU Ph.D. Dissertation, 2002.

[3] H. Abebe and E. Cumberbatch, "Quantum mechanical effects correction models for inversion charge and current-voltage (I-V) characteristics of the MOSFET device." Proceedings 2003 Nanotechnology Conference, Vol. 2, pp 218-221, February 23-27, 2003. San Francisco, CA, USA.