Abstract

With the passage of time the semiconductor research community around the globe has progressed from a nearly four decades of dominating Silicon research to look for newer transistor materials, in the pursuit of more operating speed along with reduced power, area and cost. Low effective mass materials like III-V compounds are the best examples of such transistor materials. In order to use those materials in real life transistor design and electronic applications an engineer must have a set of mathematical models ready to use- which accurately predict various electronic characteristics of the devices. Therefore, the development of canonical compact models for low effective mass channel material transistors is of prime importance for bringing these wonder materials into real life use.

Compact modelling is necessarily the art of translating the highly cumbersome and complicated physics within an electronic device into a set of predictable, portable, robust and computationally efficient analytical equations | that can be used in real-time circuit design. Existing compact models on low effective mass channel materials have a number of critical limitations, e.g. dealing with only symmetric oxide thickness, excessive use of unphysical approaches and empirical fitting parameters etc. Through our work | for the first time a fully physical, robust, portable compact model of low effective mass channel Common Double Gate MOSFET has been proposed and implemented. This compact model is a combination of accurate yet computationally efficient Surface Potential Equation (SPE) having analytical solution of coupled Schrodinger-Poisson equation, a Quantum Drift-Diffusion (QDD) based current transport and terminal charge model along with inclusion of DIBL effect. Due to enormous quantum confinement, the quasi-Fermi levels of each energy sub-band remains distant from each other because the carriers remain in the thermal equilibrium in their respective sub-bands. This segregation in quasi-Fermi levels, caused by strong quantum confinement, severely affects the transport in the semiconductor channel | thus changing the transport from normal Drift-Diffusion as in Silicon MOSFETs to QDD in low effective mass channel MOSFETs.

The model development starts with a couple of rightfully logical assumptions, which are compensated in subsequent stages to the best possible extent. The wave-function corresponding to a particular sub-band in the channel is derived only under at-band condition. It is used throughout in model development, and in the last stage the model is compensated by introducing an analytically derived correction factor. Individual sub-band energies are also derived initially underground state, and in later stages their bias dependence is addressed through perturbation technique. While modelling the transport, channel charge density for an individual sub-band is shown to be varying linearly with sub-band energy along the channel, resulting into a square law current versus channel charge density model. The uniqueness of the proposed model lies in its precise handling of multiple issues like asymmetry in oxide layer thickness, wave function penetration, bias dependent diffusivity, Quantum Drift-Diffusion transport, multi-sub-band carrier occupancy and wide range of material effective mass, device thickness along with input voltages | without ever using a single unphysical polynomial fitting or empirical constant, while preserving the mathematical lucidity of industry standard Silicon MOSFET models. The proposed model is validated against numerical TCAD simulation for various device geometries, oxide asymmetries, material properties and successfully implemented in professional circuit simulator through its verilog-A interface. Through this work, the fundamental Quantum Drift-Diffusion transport is for the first time introduced into circuit simulation, which earlier was limited within device simulation only | thus opening the possibility of designing circuits using low effective mass materials.