A History of MOS Transistor Compact Modeling

Chih-Tang Sah
Assisted by Bin B. Jie
University of Florida
Gainesville, Florida 32611 U.S.A.

ABSTRACT

The MOSFET (Metal-Oxide-Silicon Field-Effect-Transistor) or MOS Transistor (MOST) is a three dimensional electronic device. It operates on the conductivity modulation principle in a thin semiconductor layer by a controlling electric field to give amplifying and switching functions between three electrical terminals (input, output and common) connected to the film. This principle was first proposed 80 years ago (1926) by Lilienfeld. A review was given by this author in 1988 on the evolution of the MOS transistor. A detailed tutorial exposition of the MOST Compact Modeling is planned. Electrical characterization experiments and mathematical theory began 45 years ago (1959) when stable silicon oxides were grown on nearly perfect (crystalline, low defect) silicon semiconductor by Atalla, Tannenbaum and Scheibner at Bell Telephone Laboratories. Simple analytical compact models of the MOS transistors are needed for computer-aided design of digital and analog integrated circuits containing millions of transistors on a silicon chip, using circuit simulators such as SPICE. This paper gives a device-physics-based description of the history of MOS transistor compact modeling, from the **threshold voltage model** used in the first versions of SPICE to the two latest advances under development, the **charge control** (or **inversion charge**) **model** and the **surface potential model**.

Keywords: MOSFET, MOST, Compact Model, Device Physics, History

EXTENDED ABSTRACT

MOSFET (Metal-Oxide-Silicon Field-Effect-Transistor) or MOS Transistor (MOST) is a three dimensional electronic device. It operates on the conductivity modulation principle in a thin semiconductor layer by a controlling electric-field electrically coupled to the surface of the layer to give amplifying and switching functions between three electrical terminals (input, output and common) connected to the layer. This principle was first proposed 80 years ago (1926) by Lilienfeld. A review was given in 1988 on the evolution of the MOS transistor by this author [1]. A tutorial exposition of MOS transistor compact modeling is planned [2]. Electrical characteri-zation experiments and mathematical theory began 45 years ago (1961) by Kahng [3] when stable silicon oxides were grown on nearly perfect (crystalline, low defect) silicon semiconductor by Atalla, Tannenbaum and Scheibner at Bell Telephone Laboratories [4]. DC current-voltage (DCIV) equations and charge-control differential capacitance-voltage and conductance-voltage equations were developed in the earlier 1960's, starting from drift current equation, then adding the current-depressing bulk-charge, and diffusion current for low current operations. These regional formulas explicitly relate the transistor-terminal voltage and current variables. They are stitched together to cover all input (gate) and output (drain and source) voltage ranges by connection equations to provide continuity to higher derivatives in order to simulate the details of switching transients in digital applications, and small-signal frequency responses, harmonic and higher order distortions and noise in analog applications. These mathematical equations are simple and fast to meet the speed limitation of early computers for simulations of circuits containing thousands or more transistors. These explicit current-voltage equations have been known as the **threshold-voltage models** and used by the first several generations of circuit simulators. As the circuit function increases with increasing number of smaller transistors, it may become desirable if not also necessary to improve the accuracy of circuit simulation. Since computer speed has also increased, one route to higher accuracy without or with few connection equations is to employ the original two equations [5], the current and voltage equations, both are implicit functions of the surface potential, i.e., the electrical potential at the gate-oxide/silicon interface [5]-[11]. The **surface potential models** could also be simplified under various approxima-tions to help the computation speed, such as the use of the conduction charge in the inversion channel of the MOS transistor as the independent variable, known as the **inversion charge models.** This presentation will describe a device-physics-based history of MOS transistor compact modeling, from the threshold-voltage model used in the first versions of the circuit simulator, to the two latest advances under development, the charge-control (or inversion-charge) model and the surface-potential model [12].

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