

# The Bipolar Theory of The Bipolar MOS Field-Effect Transistors

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Abstract: The field-effect transistor is inherently bipolar, having simultaneously electron and hole surface and volume channels and currents. The currents are controlled by one or more externally applied transverse electric fields. It has been known as the unipolar field-effect transistor for 55-years since Shockley's 1952 invention, because the electron theory neglected the hole current, resulting in erroneous solutions of the internal and terminal electrical characteristics from the electron channel current alone, which are inaccurate when the neglected hole channel current becomes comparable to the electron channel current, both in subthreshold and strong inversion. This presentation describes the general theory, that includes both electron and hole channels and currents. The rectangular (x,y,z) parallelepiped transistors, with one or two MOS gates on thin and thick, pure and impure base, and with uniformity in width (z-axis), are used to illustrate the two-dimensional effects and the correct internal and boundary conditions for the electric and the electron and hole electrochemical potentials. Four common MOS transistor structures are analytically described: the 1-gate on semi-infinite-thick impure-base (the classical bulk transistor), the 1-gate on thin impure-silicon layer over oxide-insulated silicon bulk (SOI), the 1-gate on thin impure-silicon layer deposited on insulating glass (SOI TFT), and the 2-gates on thin pure-base and impure-base (FinFET).

## Biography of Chih-Tang Sah

Professor Chih-Tang Sah has been learning semiconductor devices and physics for 60 years and working on silicon transistor and integrated circuit manufacturing technology for 55 years. He has been with the University of Florida (UFL) for 20 years and previously, the University of Illinois in Urbana-Champaign (UIUC) for 27 years from 1961 to 1988. He earned two BS degrees, one each in Electrical Engineering and in Physics, at the University of Illinois in 1953, and the PhD from Stanford in 1956. He apprenticed with William Shockley at the Shockley Transistor Corporation for 3 years. He then worked for the Fairchild Semiconductor Corporation during 1959 to 1964, building up, leading and managing the 64-member Physics Department of the Fairchild Research and Development Laboratory. His Fairchild group developed the first generation silicon bipolar and MOS integrated circuit manufacturing technology. He has personally supervised the doctoral thesis of 50 physics and electrical engineering students and the semiconductor research of 50 academic and industrial postdoctoral associates and visiting professors at Fairchild and at UIUC and UFL, having written about 290 articles with them and delivered with them about 180 invited and keynote presentations world-wide. He authored a 3-volume undergraduate textbook on the fundamentals of solid-state electronics, published during 1991-1996 by the World Scientific Publishing Company. He was listed by the Institute of Scientific Information

as one of the world's most cited 1000 scientists during 1965 to 1978. He is a Fellow of the IEEE and the American Physical Society. He was recognized by the Asian American Manufacturing Association with its first pioneer award, the US Semiconductor Industry Association by its third annual university research award, and the Chinese Institute of Engineers-USA by its second annual Distinguished Lifetime Award. He has been a member of the US National Academy of Engineering, and an Academician of the Chinese Academy of Sciences in Beijing and the Academia Sinica in Taiwan. He is currently editing about 10 invited monographs written by the academic and industrial leading researchers and engineers on compact modeling of solid state devices, in a Series (the ASSET) published by the World Scientific Publishing Company.

### **Biography of Bin Bin Jie**

Professor Bin Bin Jie has been a graduate research professor at the Institute of Micro Electronics of the Peking University. He was in charge of the company-wide front-end quality assurance at Charter Semiconductor Manufacturing Corporation in Singapore. He earned the PhD degree from the National University of Singapore in 2000 and the BS and MS degrees in Physics from the Peking University in 1986 and 1989. He has been collaborating with Professor Chih-Tang Sah on semiconductor and device research for nearly ten years and is the co-author with Sah of about ten recent journal articles and invited presentations on the analytical theory of the MOS transistor to bench mark compact MOS transistor models.