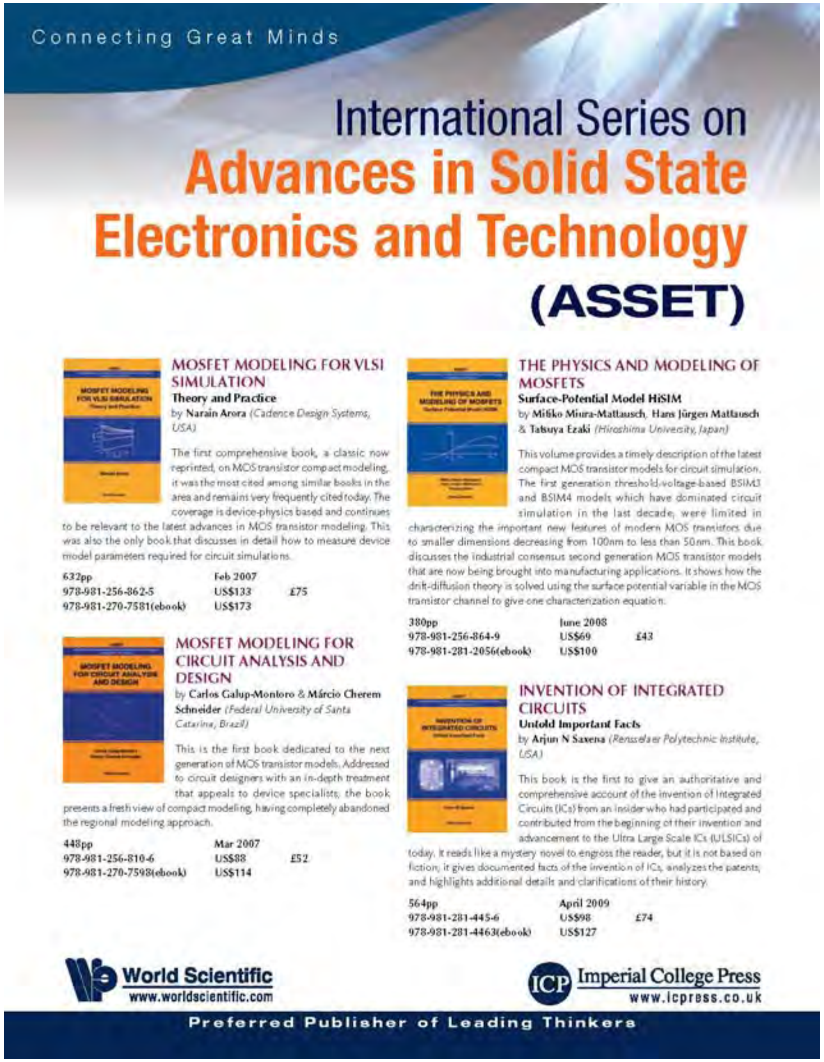
Professor Chih-Tang Sah started a book series on compact modeling, five years ago when we first came to this Workshop on Compact Modeling.

The following two slides show the flyers about this book series.

I have twenty copies of these flyers. Please contact me after this session or go to the publisher's addresses:
http://www.worldscibooks.com/catalogues/asset.pdf
http://www.worldscibooks.com/catalogues/eui.pdf



Connecting Great Minds

International Series on Advances in Solid State Electronics and Technology (ASSET)

MOSFET MODELING FOR VLSI SIMULATION

Theory and Practice

by **Narain Arora** *(Cadence Design Systems, USA)*

The first comprehensive book, a classic now reprinted, on MOS transistor compact modeling, it was the most cited among similar books in the area and remains very frequently cited today. The coverage is device-physics based and continues to be relevant to the latest advances in MOS transistor modeling. This was also the only book that discusses in detail how to measure device model parameters required for circuit simulations.

632pp	**Feb 2007**	
978-981-256-862-5	**US$133**	**£75**
978-981-270-7581(ebook)	**US$173**	

MOSFET MODELING FOR CIRCUIT ANALYSIS AND DESIGN

by **Carlos Galup-Montoro** & **Márcio Cherem Schneider** *(Federal University of Santa Catarina, Brazil)*

This is the first book dedicated to the next generation of MOS transistor models. Addressed to circuit designers with an in-depth treatment that appeals to device specialists, the book presents a fresh view of compact modeling, having completely abandoned the regional modeling approach.

448pp	**Mar 2007**	
978-981-256-810-6	**US$88**	**£52**
978-981-270-7598(ebook)	**US$114**	

THE PHYSICS AND MODELING OF MOSFETS

Surface-Potential Model HiSIM

by **Mitiko Miura-Mattausch**, **Hans Jürgen Mattausch** & **Tatsuya Ezaki** *(Hiroshima University, Japan)*

This volume provides a timely description of the latest compact MOS transistor models for circuit simulation. The first generation threshold-voltage-based BSIM3 and BSIM4 models which have dominated circuit simulation in the last decade, were limited in characterizing the important new features of modern MOS transistors due to smaller dimensions decreasing from 100nm to less than 50nm. This book discusses the industrial consensus second generation MOS transistor models that are now being brought into manufacturing applications. It shows how the drift-diffusion theory is solved using the surface potential variable in the MOS transistor channel to give one characterization equation.

380pp	**June 2008**	
978-981-256-864-9	**US$69**	**£43**
978-981-281-2056(ebook)	**US$100**	

INVENTION OF INTEGRATED CIRCUITS

Unfold Important Facts

by **Arjun N Saxena** *(Rensselaer Polytechnic Institute, USA)*

This book is the first to give an authoritative and comprehensive account of the invention of Integrated Circuits (ICs) from an insider who had participated and contributed from the beginning of their invention and advancement to the Ultra Large Scale ICs (ULSICs) of today. It reads like a mystery novel to engross the reader, but it is not based on fiction; it gives documented facts of the invention of ICs, analyzes the patents, and highlights additional details and clarifications of their history.

564pp	**April 2009**	
978-981-281-445-6	**US$98**	**£74**
978-981-281-4463(ebook)	**US$127**	

World Scientific
www.worldscientific.com

ICP Imperial College Press
www.icpress.co.uk

Preferred Publisher of Leading Thinkers

COMPACT HIERARCHICAL BIPOLAR TRANSISTOR MODELING WITH HICUM

by **Michael Schröter** *(University of Technology Dresden, Germany)* and **Anjan Chakravorty** *(Indian Institute of Technology Madras, India)*

This book aims at readers from the process development, modeling and circuit design community who are interested in the application of bipolar junction transistors (BJTs), including SiGe:C HBTs fabricated with the existing cutting-edge process technology.

350pp(approx)	**Winter 2010**	
978-981-4273-21-3	**US$95**	**£63**
978-981-4273-22-0(ebook)	**US$124**	

BSIM4: THEORY AND ENGINEERING OF MOSFET MODELING FOR IC SIMULATION

by **Weidong Liu** *(Synopsys, USA)* & **Chenming Hu** *(University of California, Berkeley, USA)*

This book presents the art of advanced MOS transistor modeling for computer-aided integrated circuit simulation and design. It provides the essential mathematical and physical analyses of all the electrical, mechanical and thermal effects in MOS transistors relevant to the operation of integrated circuits. Particular emphasis is placed on how the BSIM model evolved into the first ever industry standard SPICE MOSFET model for circuit simulation and CMOS technology development.

300pp (approx.)	**Fall 2010**	
978-981-256-863-2	**US$47**	**£31**
978-981-281-399-2(ebook)	**US$62**	

ELECTROMIGRATION IN ULSI INTERCONNECTIONS

by **Cher Ming Tan** *(Nanyang Technological University, Singapore)*

This book provides a comprehensive description of the electromigration in integrated circuits. It is intended for both beginner and advanced readers on electromigration in ULSI interconnections. It begins with the basic knowledge required for a detailed study on electromigration, and examines the various interconnected systems and their evolution employed in integrated circuit technology. The subsequent chapters provide a detailed description of the physics of electromigration in both Al- and Cu-based Interconnections, in the form of theoretical, experimental and numerical modeling studies. The differences in the electromigration of Al- and Cu-based interconnections and the corresponding underlying physical mechanisms for these differences are explained.

450pp	**Jul 2010**	
978-981-4273-32-9	**US$105**	**£69**
978-981-4273-33-6(ebook)	**US$137**	

BIOLOGICAL SENSORS - THEORY AND PRACTICE

by **M. Jamal Deen**, **M. Waleed Shinwari** and **P. Ravi Selvaganapathy** *(McMaster University, Canada)*

The first comprehensive book on the theory and practice of biological field-effect transistors (BioFETs) and BioFET-based sensing systems, in a rapidly growing field for low-cost, highly integrated and sensitive silicon-compatible bio-sensing systems. It includes chapters on cellular biology – from sensing biomolecules to microarray sensors, basic electrochemistry and electrochemical systems, semiconductor device theory applicable to "biological" transistors, a discussion of most commonly-used electrical biosensors, theory, design and applications of BioFETs and BioFET-circuits, and biosensing microsystems such as lab-on-chip and microfluidic systems, micro-biological chambers, and signal processing and transceiver circuits and systems.

Spring 2011

FUNDAMENTALS OF BULK AND SOI MOSFET MODELING

by **Francisco J. García-Sánchez** & **Adelmo Ortiz-Conde** *(Simon Bolivar University, Venezuela)*

Winter 2011

Series Introduction

This series was established to rapidly publish research monographs, edited volumes, advanced textbooks, handbooks and authoritative reviews concerning the latest developments on the theory and practice in solid-state microelectronics and now nanoelectronics. It covers materials and device physics and engineering, and circuits for microelectronic applications. It includes transistors, passive components and interconnects used in present and future generations of submicron or nanometer integrated circuits and also solid-state materials and devices that emit and detect light, transduce signals and sense pressure, temperature, chemical vapor and liquid, and biomolecules.

The nine monographs described here are part of the ASSET's subseries on Compact Device Models. They are: a reprint of the 1993 classic by Narain Arora, and the latest textbook by Carlos Galup-Montoro and Márcio C. Schneider, both published in February 2007; two comprehensive application treaties on the next (second) generation compact models: by Mitiko Miura-Mattausch, Hans Jürgen Mattausch and Tatsuya Ezaki on HiSIM, which employs the surface-potential-based approach adopted as the industrial standard of the second generation in the next decade, published in May 2008; and by Weidong Liu and Chenming Hu on BSIM4, which is the extension of the industrial standard of the first generation used in the last decade; and five recent additions, by Arjun Saxena on the history of invention of the silicon integrated circuit published in May 2009, by Michael Schröter, on HICUM for Si and GeSi:C bipolar transistors; by Cher Ming Tan on Electromigration history and interconnections state-of-the arts published in June 2010; by Jamal Deen on Bio Sensors, and by Francisco García-Sánchez and Adelmo Ortiz-Conde on Bulk and SOI MOSFET Modeling. Additional monographs are forthcoming. (CTS-YBZ)

About the ASSET Series Editor

Dr. Chih-Tang (Tom and Chihtang) Sah has been an educator, pioneer engineer and eminent applied physicist for 50 years. As the head and manager of Physics department at the Fairchild Semiconductor Corporation in Palo Alto, California, he built up and led the 64-person team which developed the first generation silicon integrated circuit technology during 1959-1964. Listed by ISI (Institute of Scientific Information) as one of the world's 1000 most cited scientists during 1965-1978, he has presented about 200 invited papers and keynotes at international conferences and seminars at universities and written about 300 journal articles on transistor physics and history, and on integrated circuit technology. With the World Scientific Publishing Company, he has authored a 3-volume best-seller undergraduate semiconductor textbook in 1991, 1993 and 1996, and edited a dozen monograph volumes in the international ASSET series (Advances in Solid-State Electronics and Technology) which he founded in 1991.

Dr. Sah is an Academician of the Chinese Academy of Sciences in Beijing and Academia Sinica in Taipei, and a Member of the U.S. National Academy of Engineering. He has been an Honorary Professor of Peking, Tsinghua and Xiamen Universities of China. For contributions in microelectronics, he was recognized by China's National Honorary Doctorate on April 6, 2010 at the 89th anniversary of Xiamen University. Professor Sah has taught for fifty years in American universities, including his undergraduate alma mater, the University of Illinois at Urbana-Champaign, as a Professor of Electrical and Computer Engineering and a Professor of Physics during 1962-1988. He has guided 50 PhD theses in Physics and in Electrical and Computer Engineering. He has also guided the investigations of 50 industrial and academic postdoctoral associates and collaborators in semiconductor physics and silicon integrated-circuit technology. Professor Sah has begun an association with the Physics Department of Xiamen University in China on research and teaching in applied, fundamental and foundation physics. (YBZ)

For enquiries, please contact our sales offices at:

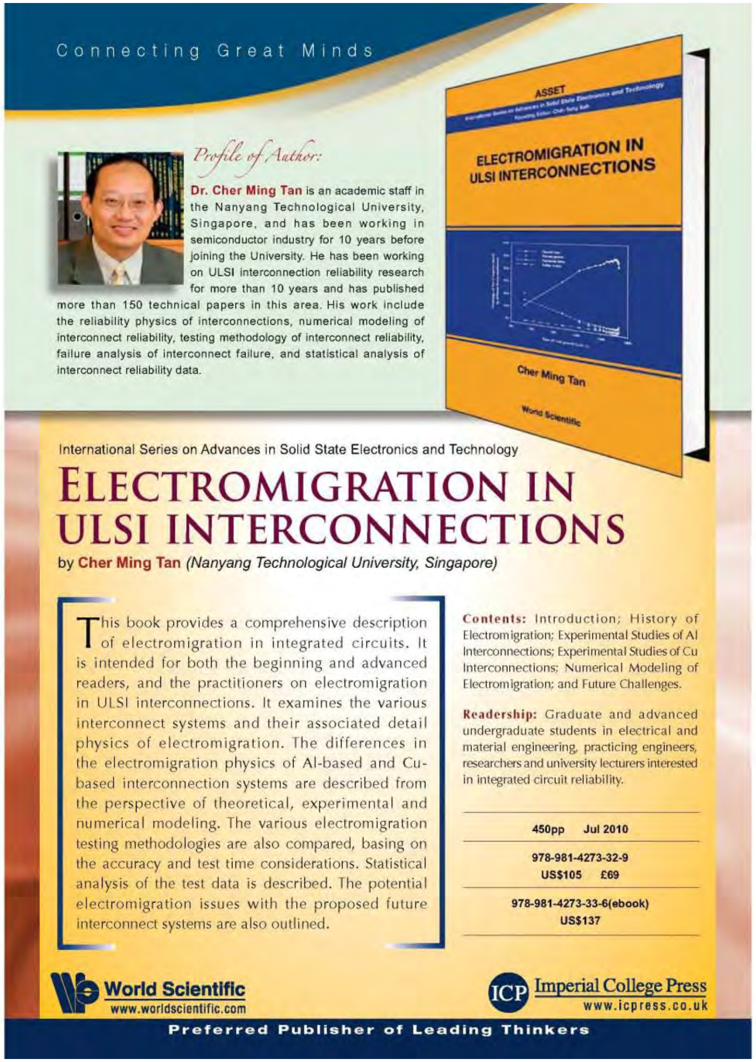
World Scientific Publishing Co. Inc.
27 Warren Street, Suite 401-402, Hackensack, NJ 07601, USA
Toll-free fax: 1 888 977 2665 Toll-free tel: 1 800 227 7562
Email: sales@wspc.com

World Scientific Publishing (UK) Ltd.
c/o Marston Book Services, P O Box 269, Abingdon, Oxon OX14 4YN, UK
Fax: 44 (0) 123 546 5555 Tel: 44 (0) 123 546 5500
Email: direct.orders@marston.co.uk

World Scientific Publishing Co. Pte. Ltd.
Farrer Road, P O Box 128, SINGAPORE 912805
Fax: 65 6467 7667 Tel: 65 6466 5775 Email: sales@wspc.com.sg

9L-US-06-10-12-W

Five published books and several addition books to be published, including the BSIM4 by Prof. Chenming Hu of UC Berkeley and Dr. Weidong Liu of Synopsys.



Connecting Great Minds

Profile of Author:

Dr. Cher Ming Tan is an academic staff in the Nanyang Technological University, Singapore, and has been working in semiconductor industry for 10 years before joining the University. He has been working on ULSI interconnection reliability research for more than 10 years and has published more than 150 technical papers in this area. His work include the reliability physics of interconnections, numerical modeling of interconnect reliability, testing methodology of interconnect reliability, failure analysis of interconnect failure, and statistical analysis of interconnect reliability data.

International Series on Advances in Solid State Electronics and Technology

ELECTROMIGRATION IN ULSI INTERCONNECTIONS

by **Cher Ming Tan** *(Nanyang Technological University, Singapore)*

This book provides a comprehensive description of electromigration in integrated circuits. It is intended for both the beginning and advanced readers, and the practitioners on electromigration in ULSI interconnections. It examines the various interconnect systems and their associated detail physics of electromigration. The differences in the electromigration physics of Al-based and Cu-based interconnection systems are described from the perspective of theoretical, experimental and numerical modeling. The various electromigration testing methodologies are also compared, basing on the accuracy and test time considerations. Statistical analysis of the test data is described. The potential electromigration issues with the proposed future interconnect systems are also outlined.

Contents: Introduction; History of Electromigration; Experimental Studies of Al Interconnections; Experimental Studies of Cu Interconnections; Numerical Modeling of Electromigration; and Future Challenges.

Readership: Graduate and advanced undergraduate students in electrical and material engineering, practicing engineers, researchers and university lecturers interested in integrated circuit reliability.

450pp Jul 2010

978-981-4273-32-9
US$105 £69

978-981-4273-33-6(ebook)
US$137

World Scientific
www.worldscientific.com

ICP Imperial College Press
www.icpress.co.uk

Preferred Publisher of Leading Thinkers

For more information, visit: www.worldscibooks.com/series/isasset_series.shtml

International Series on Advances in Solid State Electronics and Technology

MOSFET MODELING FOR VLSI SIMULATION
Theory and Practice
by **Narain Arora** *(Cadence Design Systems, USA)*

The first comprehensive book on MOS transistor compact modeling, it was the most cited among similar books in the area and remains the most frequently cited today. Discusses in detail how to measure device model parameters required for circuit simulations.

632pp Feb 2007
978-981-256-862-5 US$133 £75
978-981-270-758-1(ebook) US$173

INVENTION OF INTEGRATED CIRCUITS
Untold Important Facts
by **Arjun N Saxena** *(Rensselaer Polytechnic Institute, USA)*

This book is the first to give an authoritative and comprehensive account of the invention of Integrated Circuits (ICs) from an insider who had participated and contributed from the beginning of their invention and advancement to the Ultra Large Scale ICs (ULSICs) of today

564pp Mar 2009
978-981-281-445-6 US$98 £74
978-981-281-446-3(ebook) US$127

BIOFET
by **M. Jamal Deen**, **M. Waleed Shinwari** &
P. Ravi Selvaganapathy *(McMaster University, Canada)*

The first comprehensive book on the theory and practice of biological field-effect transistors (BioFETs) and BioFET-based sensing systems, in a rapidly growing field for low-cost, highly integrated and sensitive siliconcompatible bio-sensing systems. It includes chapters on cellular biology – from sensing biomolecules to microarray sensors, basic electrochemistry and electrochemical systems, semiconductor device theory applicable to "biological" transistors, a discussion of most commonly-used electrical biosensors, theory, design and applications of BioFETs and BioFET-circuits, and biosensing microsystems such as lab-on-chip and microfluidic systems, micro-biological chambers, and signal processing and transceiver circuits and systems.

Spring 2011

FUNDAMENTALS OF BULK AND SOI MOSFET MODELING
by **Francisco J. García-Sánchez** & **Adelmo Ortiz-Conde** *(Simon Bolivar University, Venezuela)*

Winter 2011

MOSFET MODELING FOR CIRCUIT ANALYSIS AND DESIGN
by **Carlos Galup-Montoro** & **Márcio Cherem Schneider** *(Federal University of Santa Catarina, Brazil)*

This is the first book dedicated to the next generation of MOSFET models. Addressed to circuit designers with an in-depth treatment that appeals to device specialists, the book presents a fresh view of compact modeling, having completely abandoned the regional modeling approach.

448pp Mar 2007
978-981-256-810-6 US$88 £52 978-981-270-759-8(ebook) US$114

COMPACT HIERARCHICAL BIPOLAR TRANSISTOR MODELING WITH HICUM
by **Michael Schröter** *(University of Technology Dresden, Germany)* &
Anjan Chakravorty *(Indian Institute of Technology Madras, India)*

This book aims at readers from the process development, modeling and circuit design community who are interested in the application of bipolar transistors, including SiGe:C HBTs fabricated with existing cutting-edge process technology.

350pp (approx.) Winter 2010
978-981-4273-21-3 US$95 £63 978-981-4273-22-0(ebook) US$124

THE PHYSICS AND MODELING OF MOSFETS
Surface-Potential Model HiSIM
by **Mitiko Miura-Mattausch**, **Hans Jürgen Mattausch** & **Tatsuya Ezaki** *(Hiroshima University, Japan)*

This volume provides a timely description of the latest compact MOS transistor models for circuit simulation. The first generation threshold-voltage-based BSIM3 and BSIM4 models which have dominated circuit simulation in the last decade are limited in characterizing the important new features of modern MOS transistors due to smaller dimensions decreasing from 100nm to less than 50nm. This book discusses the second generation MOS transistor models that are now being brought into manufacturing applications.

350pp Jun 2008
978-981-256-864-9 US$77 £43 978-981-281-205-6(ebook) US$100

BSIM4: THEORY AND ENGINEERING OF MOSFET MODELING FOR IC SIMULATION
by **Weidong Liu** *(Synopsys, USA)* & **Chenming Hu** *(University of California, Berkeley, USA)*

This book presents the art of advanced MOSFET modeling for integrated circuit simulation and design. It provides the essential mathematical and physical analyses of all the electrical, mechanical and thermal effects in MOS transistors relevant to the operation of integrated circuits. Particular emphasis is placed on how the BSIM model evolved into the first ever industry standard SPICE MOSFET model for circuit simulation and CMOS technology development.

300pp (approx.) Fall 2010
978-981-256-863-2 US$47 £31 978-981-281-399-2(ebook) US$62

For orders or enquiries, please contact any of our offices below or visit us at: **www.worldscientific.com**

• NORTH & SOUTH AMERICA	**World Scientific Publishing Co. Inc.** 27 Warren Street, Suite 401-402, Hackensack, NJ 07601, USA Toll-free fax: 1 888 977 2665 Toll-free: 1 800 227 7562 Email: sales@wspc.com
• EUROPE & THE MIDDLE EAST	**World Scientific Publishing (UK) Ltd.** c/o Marston Book Services, P O Box 269, Abingdon, Oxon OX14 4YN, UK Fax: 44 (0) 123 546 5555 Tel: 44 (0) 123 546 5500 Email: direct.orders@marston.co.uk
• ASIA & THE REST OF THE WORLD	**World Scientific Publishing Co. Pte. Ltd.** Farrer Road, P O Box 128, SINGAPORE 912805 Fax: 65 6467 7667 Tel: 65 6466 5775 Email: sales@wspc.com.sg

* Prices subject to change without prior notice

Printed in June 2010 *New Jersey • London • Singapore • Beijing • Shanghai • Tianjin • Sydney • Hong Kong • Taipei • Chennai* SL/JO/05/10/10/E

The latest and just published is shown on this slide, on Electromigration, written by Prof. Cher Ming Tan of Nanyang Technology University in Singapore.

Theory of Bipolar MOSFET (BiFET) with Electrically Short Channel

Bin B. Jie and Chih-Tang Sah

CTSAH Associates, Florida, USA
Department of Physics, Xiamen University, China

OUTLINE

- Bipolar MOSFET (BiFET) with a Pure Base
  - Electrically Short Channel
- Two Representations of Transistor Theory
  - Bipolar Electrochemical Current Theory
  - Bipolar Drift-Diffusion Current Theory
- Long-Channel Current and Short-Channel Correction
  - Longitudinal Gradient of Longitudinal Electric Field
- Summary

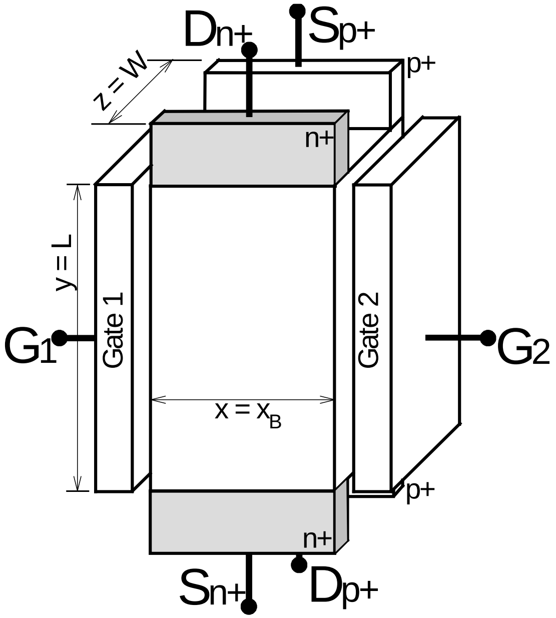
Pure-Base BiFET

- Elimination of impurity atoms is the best way to suppress the impurity concentration fluctuation in the channel, which leads to the pure base in the future silicon transistor. Two-gate pure-base nanometer MOSFET or FinFET is such a transistor.
- Silicon field-effect transistor is inherently bipolar. Pure-silicon base has both electrons and holes with equal concentration in its electrical equilibrium state. Both carriers give the terminal currents and contribute the charge distribution in the transistor.
- Pure-silicon base has a carrier screening characteristics length or intrinsic Debye length of about 25 μm. With the physical length of practical transistors, a pure-base BiFET is always a transistor with electrically short channel.

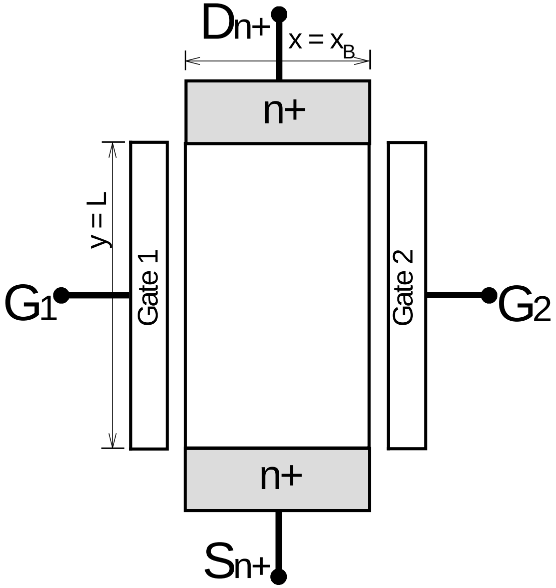
Pure-Base BiFET

- A complete semiconductor transistor was proposed by Sah-Jie at last-year's WCM keynote. It must have six terminals in order to input and output both electron and hole currents.
- A BiFET with a pure silicon base and two MOS gates has one electron contact and one hole contact at each of two ends of the rectangular box of the base. Therefore, it has six contacts: two electron contacts, two hole contacts and two MOS gate contacts.

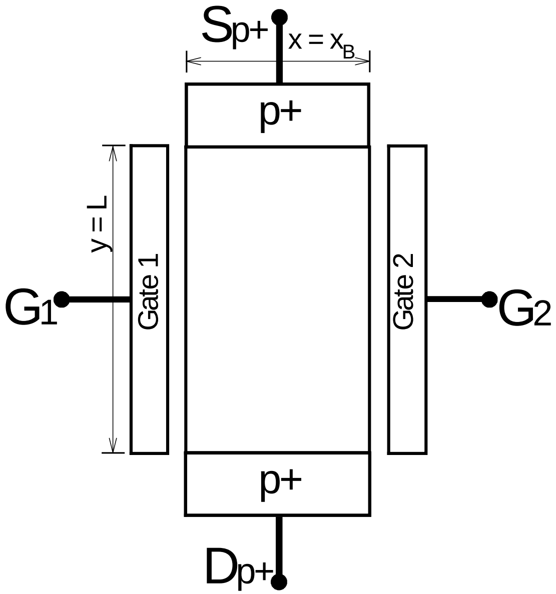
Pure-Base BiFET



3-D view



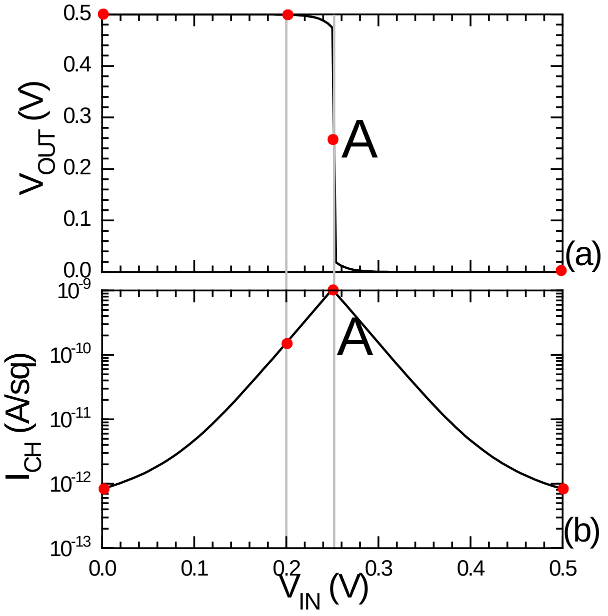
Front view



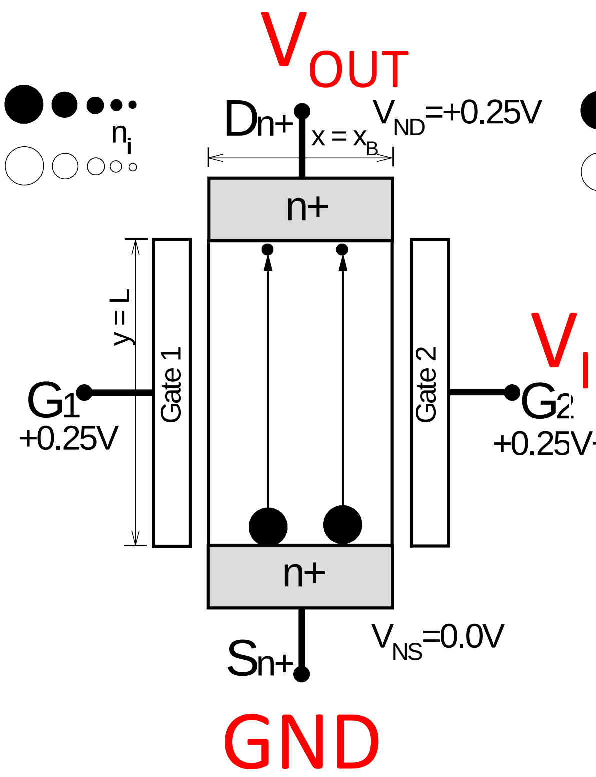
Back view

Two MOS gates G_1 and G_2 are always tied together in this presentation.

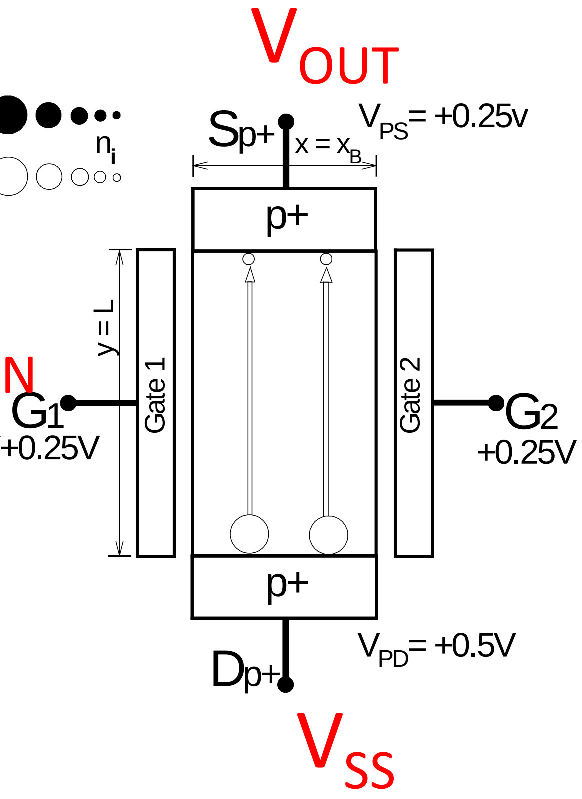
CMOS-BiFET



VV & IV curves

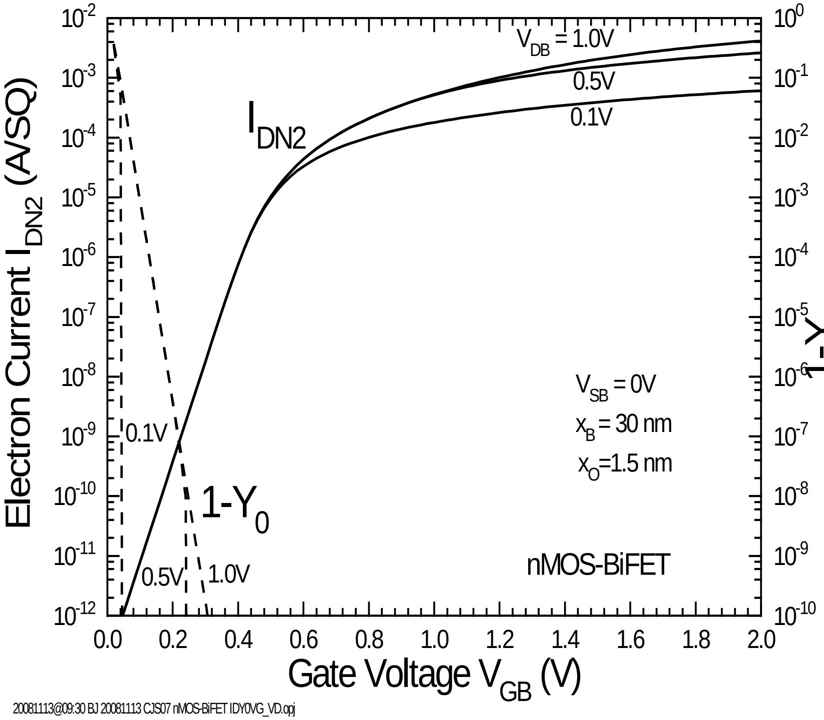


Front view

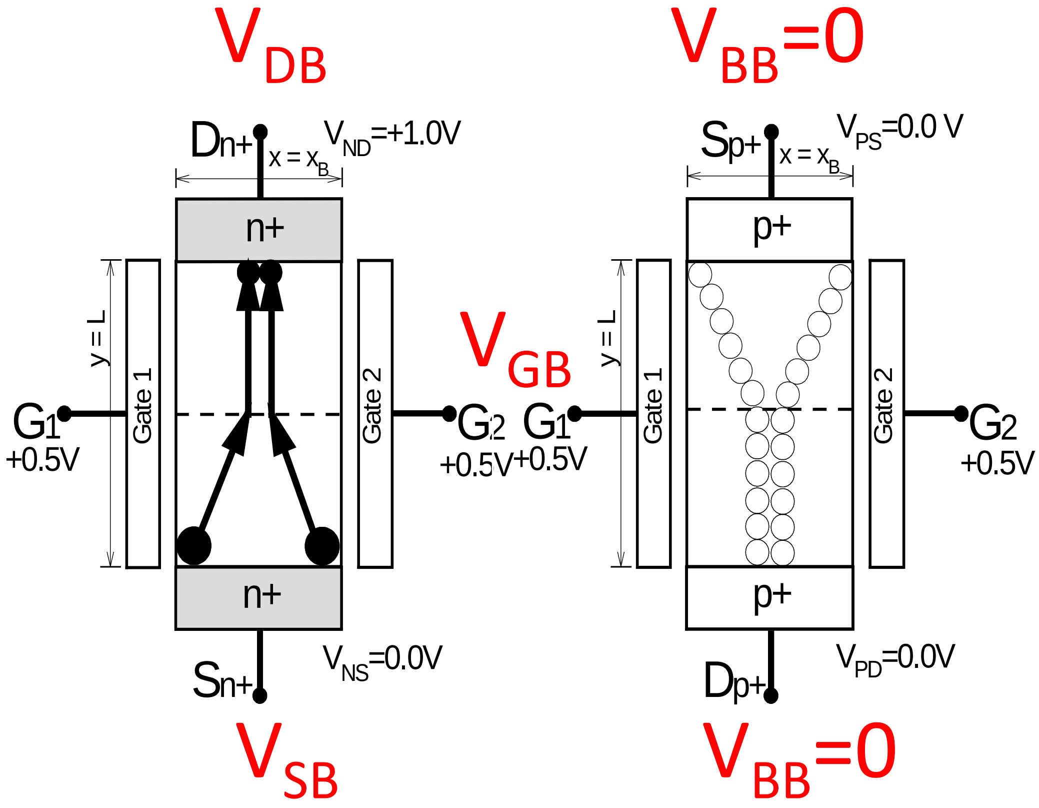


Back view

nMOS-BiFET



I_DV_G curves



Front view

Back view

The Transistor Theory

- 1949: Shockley invented p-n junction transistor theory. 1-D. Minority carrier diffusion current.
- 1952: Shockley invented unipolar junction-gate field-effect transistor theory. 1-D. Majority carrier drift current.
- 1966: Sah-Pao presented MOSFET surface potential modeling using electrochemical current. 1-D.

  One carrier species current, both drift and diffusion.
- 1996: Sah obtained MOSFET 2-D exact analytical drain current equation with drift and diffusion currents of one carrier species only.
- 2007: Sah-Jie developed bipolar MOSFET theory using both electrochemical current and drift-diffusion current. 1-D. Two-carrier drift and diffusion currents.

Surface Potential Modeling

- The 2-D transistor theory is decomposed alone the two-direction (X and Y) in two 1-D equations which are coupled through surface potential (or total energy band bending of the surface space charge layer).
- The transverse or X equations are derived from the Poisson equation with omission of longitudinal gradient of the longitudinal electric field and with assumption of X-independence of electrochemical potentials (valid for thin and long channels).
- The longitudinal or Y equations are derived from the current continuity equations. Carrier currents are expressed either by gradient of the electrochemical potentials or by sum of drift and diffusion components.

Electrochemical Current Theory

$$\mathbf{J_N} = -\,q\mu_n N\nabla V_N\ ,\ J_{NX} = 0$$

$$\mathbf{J_P} = -\,q\mu_p P\nabla V_P\ ,\ J_{PX} = 0$$

- 1966 Sah-Pao Model
- $I_{DN} = -\iint J_{NY}\partial x\partial z = +\,qD_n(\partial U_N/\partial y)\int N\partial xW$ (9A)

  $= +\,qD_n n_i(W/L)L_D(\partial U_N/\partial Y)\exp(-U_N)\int\exp(+U)\partial_X U/{\color{red}F(U,U_P,U_N,U_0,P_{IM},E_Y,E_{X1})}$ (9)
- $I_{DN} = -\iiint J_{NY}\partial x\partial y\partial z/L = +\,qD_n\int(\partial U_N/\partial y)\partial y\int N\partial x(W/L)$ (10A)

  $= +\,qD_n n_i(W/L)[L_D/(Y-Y_3)]]\int\partial_Y U_N\exp(-U_N)\int\exp(+U)\partial_X U/{\color{red}F(U,U_P,U_N,U_0,P_{IM}\ ,E_Y,E_{X1})}$ (10)

- $I_{DP} = -\iint J_{PY}\partial x\partial z = +\,qD_p(\partial U_P/\partial y)\int P\partial xW$ (11A)

  $= +\,qD_p n_i\,(W/L)L_D(\partial U_P/\partial Y)\exp(+U_P)\int\exp(-U)\partial_X U/{\color{red}F(U,U_P,U_N,U_0,P_{IM},E_Y,E_{X1})}$ (11)
- $I_{DP} = -\iiint J_{PY}\partial x\partial y\partial z/L = +\,qD_p\int\,(\partial U_P/\partial y)\partial y\int P\partial x(W/L)$ (12A)

  $= +\,qD_p n_i\,(W/L)[L_D\,/(Y-Y_3)\,\int\partial_Y U_P\exp(+U_P)\int\exp(-U)\partial_X U/{\color{red}F(U,U_P,U_N,U_0,P_{IM},E_Y,E_{X1})}$ (12)

Drift-Diffusion Current Theory

$$\mathbf{J_N} = + q\mu_n N\mathbf{E} + qD_n \nabla N \, , \, J_{NX} = 0$$

$$\mathbf{J_P} = + q\mu_p P\mathbf{E} - qD_p \nabla P \, , \, J_{PX} = 0$$

- 1996 Sah exact equation

- $I_{DN} = -kT\mu_n\, n_i L_D(W/L) \times \{ +\int(P_{IM} - P)/n_i\, (\partial U/\partial Y)\partial X$	bulk charge drift term
$+\, 2(\partial U/\partial X)_S\, (\partial U_S/\partial Y)$	carrier space-charge drift term
$+\, \partial/\partial Y\int(\partial U/\partial X)^2\partial X$	transverse electric-field drift term
$-\, (L_D/L)^2\, \partial/\partial Y\int(\partial U/\partial Y)^2\partial X\}$	short-channel drift correction
$-qD_n\, n_i L_D(W/L) \times\{-\, \partial/\partial Y \int(P_{IM} - P)/n_i\, \partial X$	bulk charge diffusion term
$-\, 2\partial/\partial Y[(\partial U/\partial X)_S]$	carrier space-charge diffusion term
$+\, 2(L_D/L)^2\, \partial/\partial Y\int(\partial^2 U/\partial Y^2)\partial X\}$	short-channel diffusion correction

(65)

- I_{DP} = similar equation to I_{DN} (66)

Long-Channel Current I_{DL}

Pure-Base nMOS-BiFET

- The Voltage Equation: (X-equation)

$$U_{GB}-U_S = \mathrm{sign}(U_S-U_0)\times(C_{Di}/C_O)\times [\exp(U_S-U_N)-\exp(U_0-U_N)+\exp(U_P-U_S)-\exp(U_P-U_0)]^{1/2}$$

- The Thickness Equation: (X-equation)

$$X_B = 2\int \mathrm{sign}(U-U_0)\ \partial_X U \times [\exp(U-U_N)-\exp(U_0-U_N)+\exp(U_P-U)-\exp(U_P-U_0)]^{-1/2}$$

- The electron current Equation: (Y-equation)

$$I_N = 2qD_n n_i L_{Di}\,(W/L) \times\int \exp(-U_N)\ \partial U_N \times \qquad U_N = U_{SB} \text{ to } U_{DB}$$

$$\int \mathrm{sign}(U-U_0)\exp(+U)\partial_X U \times \qquad U = U_0 \text{ to } U_S$$

$$[\exp(U-U_N)-\exp(U_0-U_N)+\exp(U_P-U)-\exp(U_P-U_0)]^{-1/2}$$

- The hole current Equation: (Y-equation)

$I_P = 0$

Long-Channel Current I_{DL}

Pure-Base nMOS-BiFET

From $Y=0$ to $Y=Y_1$ $(Y=y/L)$

$$
\begin{aligned}
Y_1 \times I_{DL} = {} & +2kT\,\mu_n\, n_i\, L_{Di}\,(W/L)\times \{ \\
& (C_O/C_{Di})\times[(2U_{GS}\times U_S - U_S^2)|_{Y=Y1} - (2U_{GS}\times U_S - U_S^2)|_{Y=0}] \\
& +(-1)\int[\exp(U-U_N)-\exp(U_0-U_N)+\exp(U_P-U)-\exp(U_P-U_0)]^{1/2}\partial U|_{Y=Y1} \\
& -(-1)\int[\exp(U-U_N)-\exp(U_0-U_N)+\exp(U_P-U)-\exp(U_P-U_0)]^{1/2}\partial U|_{Y=0}\} \\
& + q\,D_n\, n_i\, L_{Di}\,(W/L)\times \{(C_O/C_{Di})\times[2U_S|_{Y=Y1} - 2U_S|_{Y=0}]\}
\end{aligned}
$$

Short-Channel Correction $I_{D\text{-Short}}$

Pure-Base nMOS-BiFET

- Electrochemical potential U_N as a function of position Y from the long-channel electron current equation.
- Surface potential U_S and mid-plane potential U_0 as a function of U_N from the voltage equation and the thickness equation.
- The first and second derivatives of U_S and U_0 with respect to Y are obtained numerically.
- Estimate the two integrations in short-channel correction:

$$\int(\partial U/\partial Y)^2\partial X,\ X=0 \text{ to } X_B,\ \approx\ [(\partial U_S/\partial Y)^2 + (\partial U_0/\partial Y)^2]/2\times X_B$$

$$\int(\partial^2 U/\partial Y^2)\partial X,\ X=0 \text{ to } X_B,\ \approx\ [\partial^2 U_S/\partial Y^2 + \partial^2 U_0/\partial Y^2]/2\times X_B$$

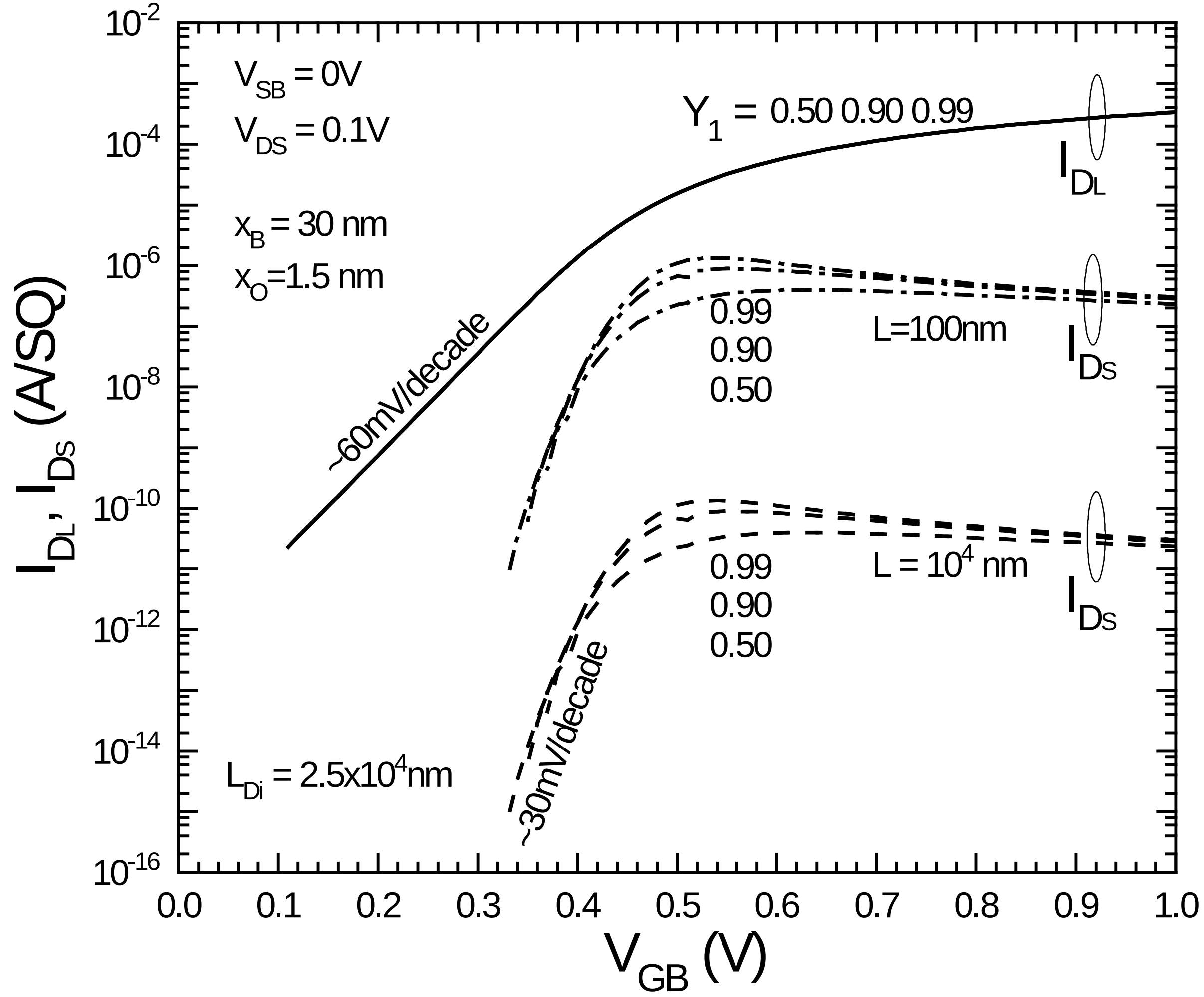
Short-Channel Correction $I_{D\text{-Short}}$

Pure-Base nMOS-BiFET

From $Y=0$ to $Y=Y_1$

$$\begin{aligned}
Y_1\times I_{DS} = {} & +2kT\,\mu_n\, n_i\, L_{Di}\,(W/L)\times \{ \\
& \qquad (L_{Di}/L)^2\,[\textstyle\int(\partial U/\partial Y)^2\partial X|_{Y=Y1} - \int(\partial U/\partial Y)^2\partial X|_{Y=0}]\ \} \\
& + 2q\, D_n\, n_i\, L_{Di}\,(W/L)\times \{ \\
& \qquad 2(L_{Di}/L)^2 \times [\textstyle\int(\partial^2 U/\partial Y^2)\partial X|_{Y=Y1} - \int(\partial^2 U/\partial Y^2)\partial X|_{Y=0}]\}
\end{aligned}$$

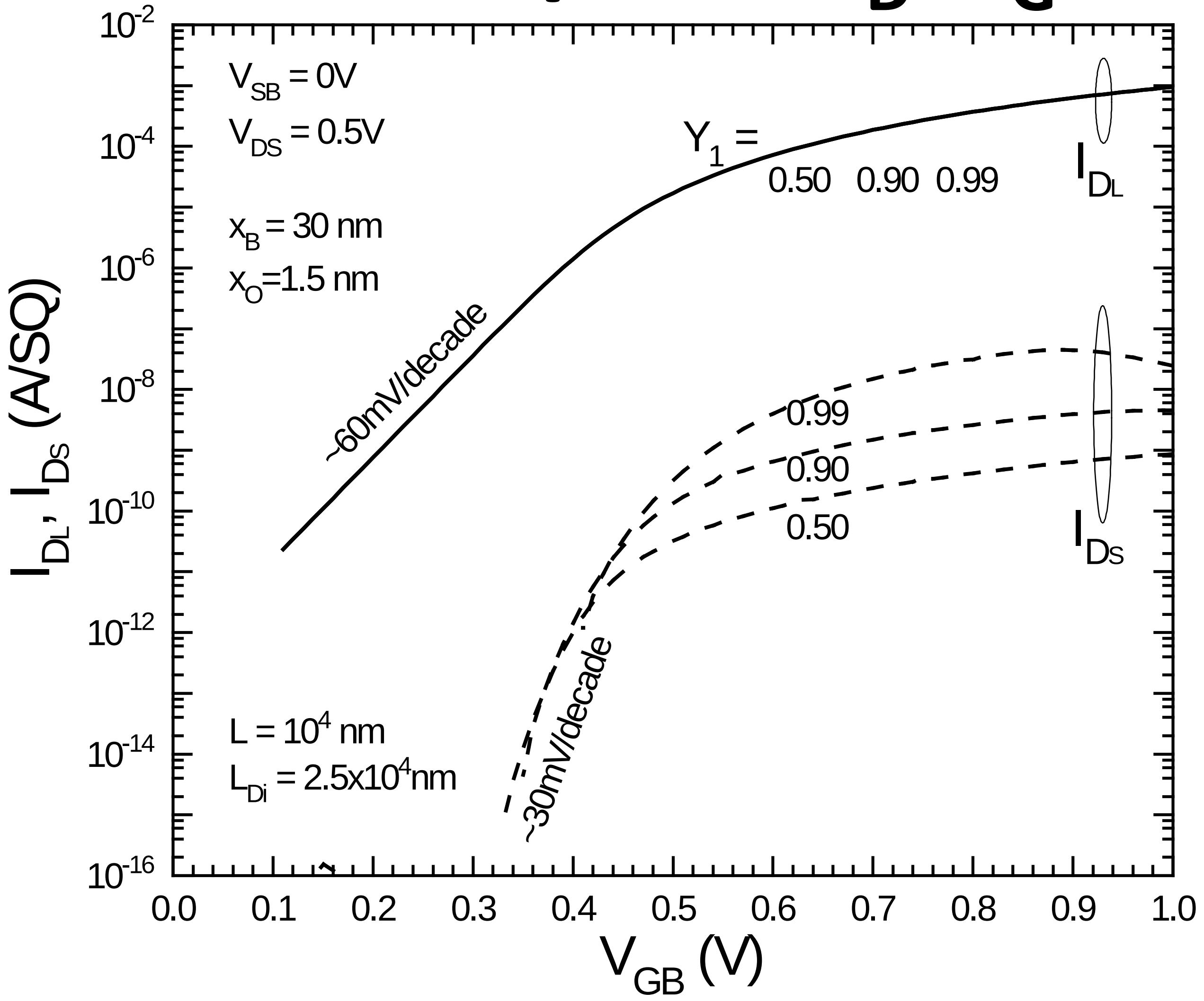
Computed I_D-V_G curves



20100614@22:02 BJ 201000410_nMOS_BiFET_IDVG_Y_VD01.opj

- I_{DL} is independent of Y_1
- I_{DS} depends on Y_1 strongly
- Subthreshold slope of I_{DS} is about half of that of I_{DL}.
- I_{DS} shifts up vertically as L decreases. Scaled as L^{-2}.

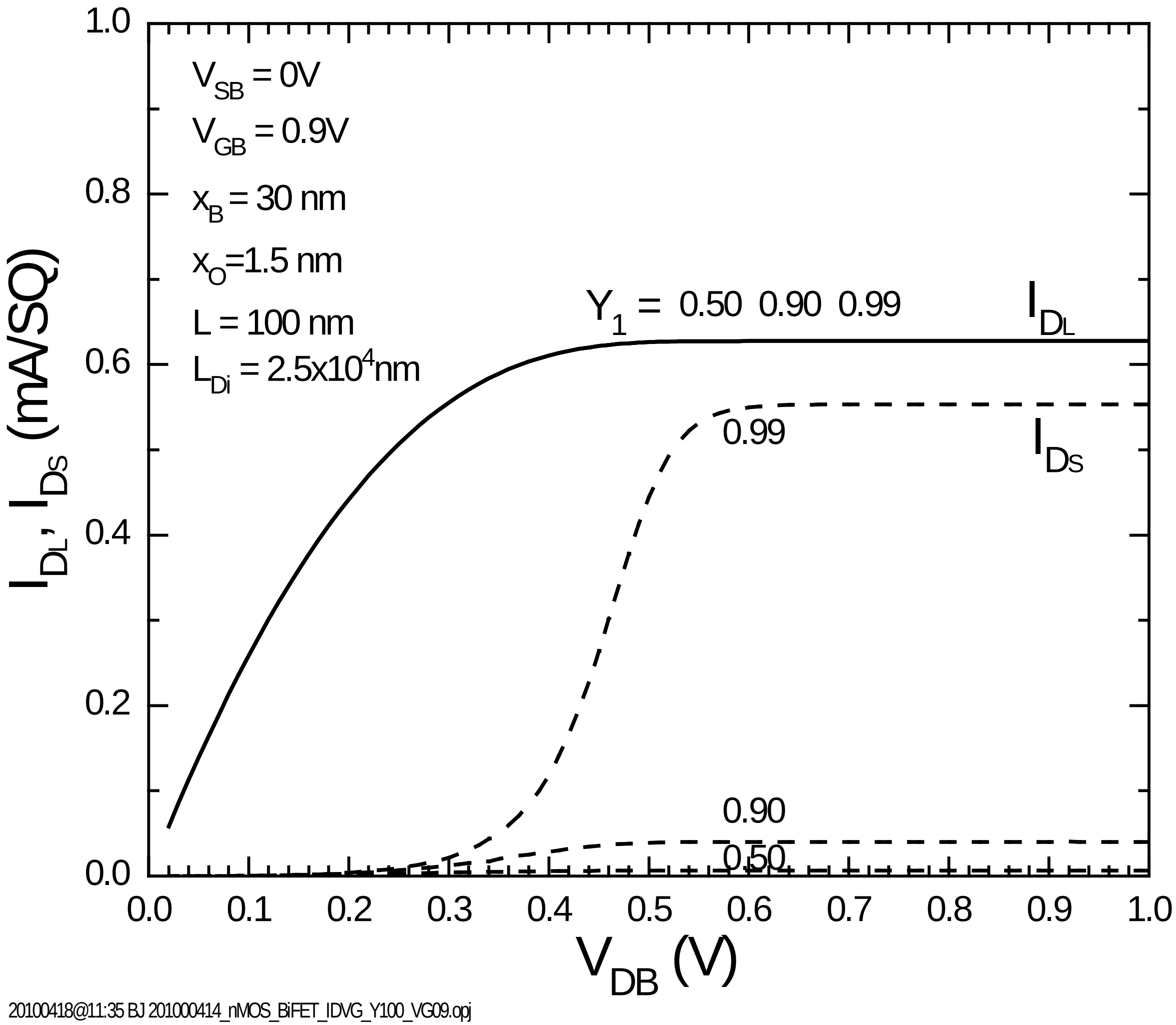
Computed I_D-V_G curves



20100418@11:20 BJ 20100331_nMOS_BiFET_IDVG_Y_VD05.opj

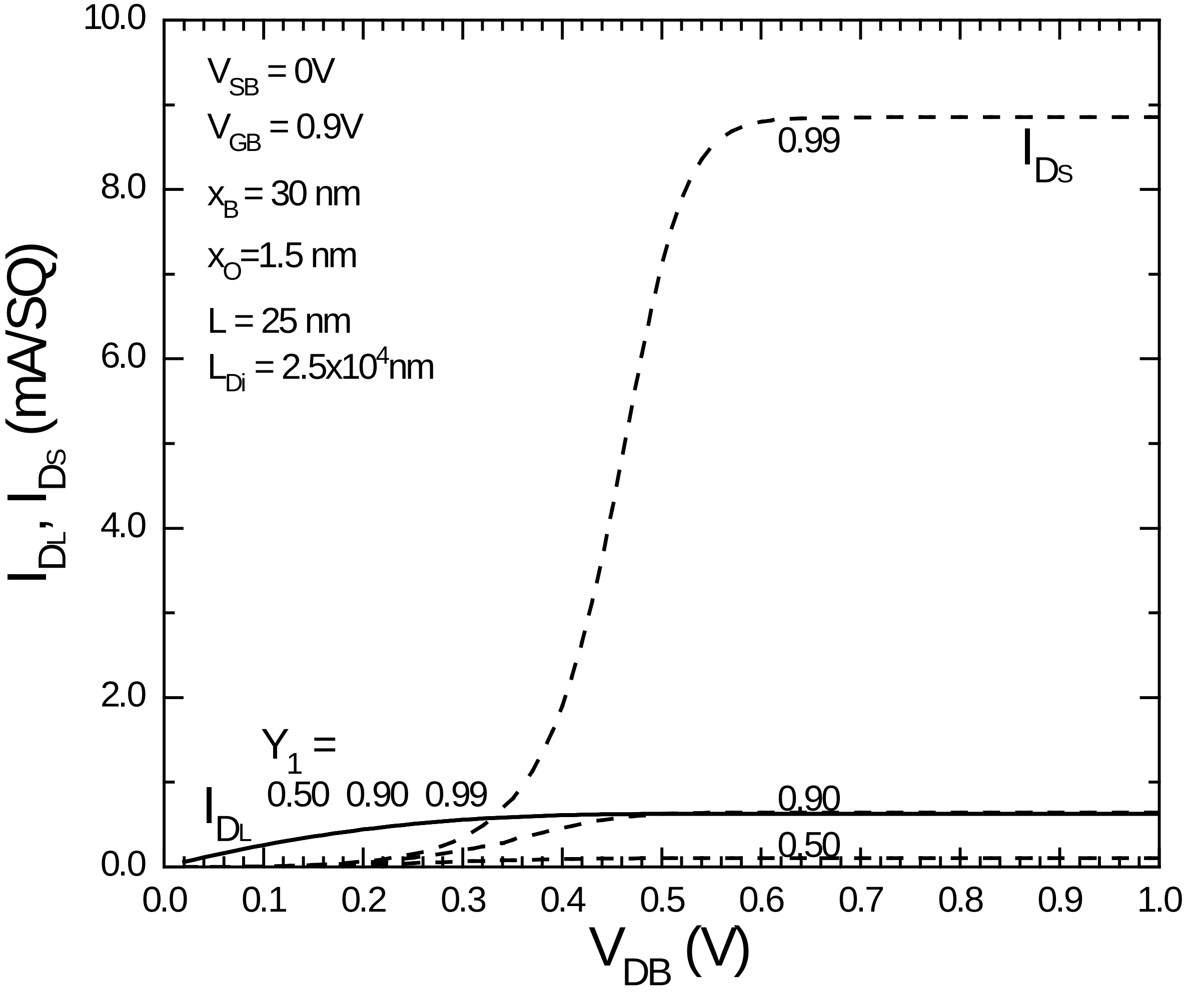
- I_{DL} is independent of Y_1
- I_{DS} depends on Y_1 strongly
- Subthreshold slope of I_{DS} is half of that of I_{DL}.
- I_{DS} decreases when $V_{GB} - V_{DB} > 0.4$V.

Computed I_D-V_D curves



- I_{DL} is independent of Y_1
- I_{DS} depend on Y_1 strongly
- I_{DS} at Y_1 = 0.99 is still less than I_{DL}at L =100nm
- I_{DS} decreases when $V_{GB} - V_{DB}$ >~ 0.4V.

Computed I_D-V_D curves



20100418@11:47 BJ 201000414_nMOS_BiFET_IDVG_Y025_VG09.opj

- I_{DL} is independent of Y_1
- I_{DS} depend on Y_1 strongly
- I_{DS} at Y_1 = 0.99 is 10 times larger than I_{DL} at L =25nm.
- I_{DS} decreases when $V_{GB} - V_{DB}$ >~ 0.4V.

Summary

- The Pure-Base BiFET with electrically short channel is introduced. The structures and biases of CMOS-BiFET and nMOS-BiFET are given.

- The transistor theory is reviewed. Surface potential modeling, electrochemical current formula and drift-diffusion current formula are described.

- Long-channel current and short-channel correction formula for nMOS-BiFET are derived.

- Computed I_DV_G and I_DV_D curves of the long-channel current and short-channel correction are computed. When the physical channel length L > 100nm, the long-channel current is still a good approximation for the nMOS-BiFET. When the physical length <= 25nm, the long-channel current characteristics is modified significantly by the short-channel correction from Ey^2.

References

- Jie Binbin and Sah Chih-Tang, “The Bipolar Field-Effect Transistor: VI. The CMOS Voltage Inverter Circuit (Two-MOS-Gates on Pure-Base),” Journal of Semiconductors, 29(11), 2079-2087, November 2008
- Jie Binbin and Sah Chih-Tang, “The Bipolar Field-Effect Transistor: VII. The Unipolar Current Mode for Analog-RF Operation (Two-MOS-Gates on Pure-Base),” Journal of Semiconductors, 30(3), 031001-1-8, March 2009
- Jie Binbin and Sah Chih-Tang, “The Bipolar Field-Effect Transistor: VIII. Longitudinal Gradient of Longitudinal Electric Field (Two-MOS-Gates on Pure-Base),” Journal of Semiconductors, 31(7), 071001-1-7, July 2010
- Sah Chih-Tang and Jie Binbin, “The Theory of Field-Effect Transistors: XI. The Bipolar Electrochemical Currents (1-2-MOS-Gates on Thin-Thick Pure-Impure Base),” Chinese Journal of Semiconductors, 29(3), 397-409, March 2008
- Jie Binbin and Sah Chih-Tang, “The Theory of Field-Effect Transistors: XII. The Bipolar Drift and Diffusion Currents (1-2-MOS-Gates on Thin-Thick Pure-Impure Base),” Journal of Semiconductors, 29(7), 1227-1241, July 2008”