

Research Map: Advanced Semiconductor Devices

I. INTRODUCTION

“Advanced Semiconductor device theory” deals with the electronic and physical properties of semiconductor devices. Silicon, Germanium, Gallium Arsenide and organic semiconductors are few of the principal semiconductor materials. The first major breakthrough in the field of semiconductor devices was the invention of transistor. In last three decades, semiconductor devices have brought revolution in the field of electronics and computer sciences.

II. DEVELOPMENT OF SEMICONDUCTORS OVER THE LAST CENTURY

Figure 1 shows the major breakthroughs in Semiconductor devices in last century.

III. INFLUENTIAL AUTHORS

Given below is the list of significant Authors who contributed in the field of semiconductor devices. noitemsep

- **Asen Asenov** - University of Glasgow UK. (206 Publications)
- - University of California, Berkeley USA. (200 Publications)
- **Robert W. Dutton** - Stanford University USA. (183 Publications)
- **Wolfgang Fichtner** - Dept. of Information Technology and Electrical Engineering Switzerland. (118 Publications)
- **Siegfried Selberherr** - Vienna University of Technology, Austria. (117 Publications)
- **Michuel S. Shur** - Rensselaer Polytechnic Institute, USA. (107 Publications)
- **Luca Selmi** - University of Udine, Italy. (104 Publications)
- **Juin-jie J. Liou** - University of Central Florida (UCF), USA. (103 Publications)
- **Krishna Shenai** - University of Toledo, USA. (99 Publications)
- **Jerry G. Fossum** - University of Florida, USA. (98 Publications)
- **Andrea L. Lacaita** - University of Glasgow UK. (95 Publications)
- **Mark S. Lundstrom** - Purdue University, Indiana, USA. (94 Publications)
- **Guido E. Groeseneken** - KU Leuven, Dept. Electrical Engineering, Belgium. (93 Publications)

TABLE I: Semiconductorfield Development Timeline

1833	.....	First Semiconductor Effect is Recorded.
1940	.....	Discovery of the p-n Junction.
1947	.....	Invention of the Point-Contact Transistor.
1953	.....	Transistorized Computers Emerge.
1955	.....	Development of Oxide Masking and Photolithography.
1958	.....	Tunnel Diode Promises a High-Speed Semiconductor Switch.
1960	.....	First Planar Integrated Circuit is Fabricated.
1960	.....	Metal Oxide Semiconductor (MOS) Transistor Demonstrated.
1963	.....	Complementary MOS Circuit Configuration is Invented.
1963	.....	Standard Logic IC Families introduced. “Moore’s Law” Predicts the Future of Integrated Circuits.
1965	.....	Semiconductor Read-Only-Memory Chips Appear .
1968	.....	Silicon Gate Technology Developed for ICs. Microprocessor Integrates CPU Function onto a Single Chip.
1971	.....	General-Purpose Microcontroller Family is Announced.
1974	.....	Single Chip Digital Signal Processor Introduced.
1979	.....	First 3D Semiconductor Device Simulator (Taurus).
1998	.....

- **Gerhard Klimeck** - Purdue University, West Lafayette, Indiana. (90 Publications)
- **Christoph Jungemann** - Aachen University, Germany. (70 Publications)
- **Kaushik Roy** - Purdue University, Indiana, USA. (61 Publications)
- **David Esseni** - University of Udine, Italy. (58 Publications)
- **Jerry L. Hudgins** - University of Nebraska-Lincoln, USA. (55 Publications)

IV. DOMINANT SOCIETIES AND RESEARCH GROUPS

Semiconductor devices is one of the major fields of focus. Many societies and research groups are contributing in the field of semiconductor device theory.

A. Societies

- IEEE Solid-State Circuits society
<http://sscs.ieee.org/>
- IEEE Electron Device Society
<http://eds.ieee.org/>
- IEEE Components, Packaging & Manufacturing Technology Society
<http://cpmt.ieee.org/>
- IEEE Power Electronics Society <http://www.ieee-pels.org/>

B. Research Groups

Following are the major research groups.

- Semiconductor Materials, Devices & Nanostructures Research group at University of Oxford UK
- Semiconductor Materials Research Lab at UCLA (University of California at Los Angeles)
- The Optical and Semiconductor Devices Group at Imperial College of London
- MIT Compound Semiconductor Materials and Devices Research Group
- Semiconductor Physics Group at university of cambridge USA

V. KEY BOOKS AND REFERENCE PAPERS

A. Books

- Principles of Semiconductor Devices
Author: Bart Van Zeghbroeck
- Semiconductor Physics And Devices
Author: Donald Neamen
- Device Electronics for Integrated Circuits
Author: Muller and Kamins
- Physics of Semiconductor Devices, third ed.
Author: S.M. Sze & Kwok K. Ng
- Semiconductors
Author: K.Ferry
- Solid State and Semiconductor Physics
Author: Mc Kelvey

B. Key Reference Papers

- Wilson, A. H. "The Theory of Electronic Semiconductors II" *Proceedings of the Royal Society of London*. Series A, in Vol. 134, No. 823 (Nov. 3, 1931)
- Shockley, William. "The Theory of P-N Junctions in Semiconductors and P-N Junction Transistors" *Bell System Technical Journal* Vol. 28 No. 3 (July 1949)
- Shockley, William, Sparks, Morgan and Teal, Gordon K. "p-n Junction Transistors" *Physical Review*, Vol. 83, No. 1 (July 1951)

- Hoerni, J. A. "Planar Silicon Diodes and Transistors" *Fairchild Semiconductor Technical Paper* TP-14. (1961). Reprint of paper presented in October 1960.
- Moore, Gordon. "Cramming More Components onto Integrated Circuits" *Electronics Magazine* Vol. 38, No. 8 (April 19, 1965)
- Chenming Hu, et al. "Hot-Electron-Induced MOSFET Degradation& Amp,Model, Monitor, And Improvement". *IEEE Trans. Electron Devices* 32.2 (1985)

VI. TIER-1 CONFERENCES, JOURNALS AND WORKSHOPS

A. Conferences

- **MIXDES** - International Conference "Mixed Design of Integrated Circuits & Systems"
- **IEDM** - IEEE International Electron Devices Meeting
- **ULIS** - International Conference on Ultimate Integration on Silicon
- **EPTC** - IEEE 15th Electronics Packaging Technology Conference"
- **SISPAD** - International Conference on Simulation of Semiconductor Processes and Devices"
- **ISLPED** - ACM International Symposium on Low Power Electronics and Design
- **PVSC** - IEEE Photovoltaic Specialists Conference
- **ISSCC** - International Solid-State Circuits Conference
- **SSDM** - International Conference on Solid State Devices and Materials
- **PVSAT** - Photovoltaic Science Application and Technology Conference and Exhibition
- **CPV** - International Conference on Concentrator Photovoltaics
- **ISPD** - IEEE International Symposium on Power Semiconductor Devices and ICs.
- **CSMANTEC** - International Conference on Compound Semiconductor Manufacturing Technology.
- **ICDS** - International Conference on Defects in Semiconductors.

B. Journals

Given below is a list of Important Journals.

TABLE II: Journals.

	Journal Title	Citations	Articles
	Nature Nano Technology	33.265	128
	IEEE Transactions On Power Electronics	5.726	540
	Journal of the Electron Devices Society	3.023	480
	Journal of Photovoltaics	3	524
	IEEE Transactions on Electron Devices	2.358	616
	IEEE Journal of Quantum Electronics	2.113	134
	IEEE Trans. on Semiconductor Manufacturing	0.977	107
	ACM Journal on Emerging Technologies in CS	0.833	28
	Journal Of Nanoelectronics And Optoelectronics	0.369	100

C. Workshops

- **CVM** - ACM Workshop on Compact Variability Modeling and Characterization
CVM focuses on modelling and variation characterization in CMOS design. CVM provides a platform for current and futuristic research needs in modelling and simulation of CMOS devices.
- **ULIS** - European Workshop on Ultimate Integration of Silicon
ULIS aims to provide an international forum to present the updated research and development in the field of modelling and characterization and applications of advanced silicon diodes.
- **EDPT** - IEEE Phoenix Section CPMT Chapter & WAD Chapter Workshop on Emerging Device and Packaging Technologies
This workshop provides a platform for research on microelectronics and packaging technologies. This workshop brings together experts from academia, industry, consortia and research labs.
- **SISPAD** - Simulation of Semiconductor Processes and Devices.
This conference is among the leading platforms in Technical Computer Aided Design(TCAD) and focuses on future trends in semiconductor device process and simulation

VII. AREA SPECIFIC TERMINOLOGIES

- **CMOS:** Complimentary Metal-Oxide Semiconductor is the most widely used technology for building ICs. It uses symmetrical pmos and nmos combination to build circuits.
- **Doping:** Doping is the adding of impurities in the pure semiconductor material i.e. n-type or p-type materials to change its properties.
- **Wafers:** Slices of pure semiconductor crystals on which semiconductor devices are fabricaed.
- **Valency:** Valency is the capacity of atom to accomodate atoms in its outermost shell. We dope pure semiconductors to create valencies.
- **Depletion region:** Depletion region is a small insulating region between two conducting n-type and p-type regions.
- **Integrated circuit:** IC is a combination of electronic circuit built on a small semiconductor area and packages in ceramic or plastic body.
- **Photovoltaic:** Relating to production of electric charge at the junction of two photosensitive semiconductor materials.
- **Carriers:** Electrons or holes(vacancy of electron) which are responsible for the flow of current in the semiconductor devices.
- **Nano-Technology:** The term nanotech refers to the manipulation of matter on atomic scale. This term is often used in semiconductors. e.g. nano-lasers, nano-scale etc.

VIII. RESEARCH PAPERS WITH LARGE IMPACT

- Kresse, G, Furthmuller, J, “Efficient iterative schemes for ab in-itio totalenergy calculations using a plane-wave basis set” *The American Physical society*,vol. 54,16. 11169-11186, October 1996
- B. Oregan, M. Gratzel. “ A Low-Cost, High-Efficiency Solar Cell based on dye-sensitized colloidal TiO₂ films” , *Nature Publishing Goup*, vol353,6346. 737-740, October 1991
- Mr. Hoffmann, St. Martin “ Environmental Applications of Semi-Conductor Photocatalysis” , *Amer Chemical Society, Washington*, vol95,1. 69-96, January 1995
- AP. Alivisatos “Semiconductor clusters, nanocrystals, and quantum dots” , *Amer Assoc. for Advancement of Science*, vol.271,5251. 933-937, February 1996
- Castro Neto, A. H., Guinea, F., Peres, N. M. R., “The electronic properties of graphene” , *Reviews of Modern Phsics*, vol.81,1. 109-162, January 2009
- Huang, MH. Mao, S. Feick, H. et al., “Room-temperature ultraviolet nanowire nanolasers” , *The Science Magazine*, vol.292,5523. 1897-1899, June 2001
- Castro Neto, A. H., Guinea, F., Peres, N. M. R., “Photocatalysis on TiO₂ surfaces - Principles, Mechanism and Results” , *ACS Publications*, vol.95,3. 735-758, May 1995.
- Zhang, YB. Tan, YW. Stormer, HL, “Experimental observation of the quantum Hall effect and Berry’s phase in graphene” , *ACS Publications*, vol.438,7065. 201-204, November 2005.

IX. CURRENT RESEARCH TRENDS AND RESEARCH PROBLEMS

A. Current Research Trends

- **Dynamic Behaviour on nano-scale**
In past it wasn’t possible to study the dynamics of the semiconductor materials on nano-scale level. However the technological advancement has enabled us to observe different type of dynamics of the semiconductor material on nanoscale level.
- **3D Modelling and Simulation**
Most of the work done on semiconductor devices was on conventional tools of modeling and simulation. Those CAD tools limited the study and prediction of semiconductor devices. Recently D modelling and simulation CAD s have been developed. These softwares have enabled the researchers to fabricate and simulate different

semi conductor devices and study each property of the device in depth.

- **High Power-Rating Semiconductor Devices**

Power electronics is one of the major fields these days. It finds applications in almost all electrical devices. Due to the rapid growth of power electronics industry, current research is focused on producing high-power rated semiconductor devices in small size and low price.

- **Increasing Efficiency of Solar-Cells**

Renewable energy is one of the major needs of the current century. Lot of research work is being done Alternative-Energy. Priduction of cost effective and high efficiency solar cells is the main area of focus these days.

B. Research Problems

1) Efficiency of Photovoltaic cell

Efficiency of photovoltaic cells is a big challenge in semiconductor industry. Despite of all the research, maximum solar cell efficiency is still below 50%. This is due to the fact that each photosensitive material can operate only in a specific range of frequency. Latest researches are focused on eliminating this barrier.

2) Time Delay in ICs

Mostly silicon is used in semiconductor devices. However there is a limitation of the electron flow speed which we can achieve. This introduces a time delay in the operation of the circuit. There are few semiconductors like Gallium Arsenide which provide lesser time than silicon but are much costly than silicon. Developing of cheaper semiconductor materials is a major research problem at the present time.

3) Semiconductor device Size

Reducing the device size is a major focus in the present decade. New device fabrication procedures are being proposed. Lot of research is being done on producing more efficient semiconductor materials to decrease size and increase efficiency of the devices.

4) Band Gap Calculation

Despite of advancement in the field of semiconductors, there still is a need of focus on the material property measuring techniques. e.g Energy Band gap of the semiconductor devices can not be calculated accurately. With the increasing advancement and complexity of the semiconductor devices, there is a need of reasearch in measuring techniques.

5) Transistor Mesoscopic Effect

If the size of transistor is reduced to sub-microns, there is a significant change in its conductance. This produces mesoscopic effects which produces fluctuations in different properties which are linear in large devices. Since the major focus is on reducing the size of devices, such effects are a major research

problem which create a hurdle in decreased device size.

6) Parasitic Resistance and Electrical Coupling

The parasitic resistance between source and drain is a major issue in MOSFETS. Modern research is focused on decreasing such parasitic effects to improve the operation of transistor devices.

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