Equilibrium Carrier Concentration

In silicon and other semiconductors,

$$n_0 = N_c \exp\left(\frac{-(E_c - E_F)}{kT} \right)$$ conduction band

$$p_0 = N_v \exp\left(\frac{-(E_F - E_v)}{kT} \right)$$ valence band

n_0: electron concentration at thermal equilibrium (cm^{-3})
p_0: hole concentration at thermal equilibrium (cm^{-3})
N_c: effective density of states for conduction band (cm^{-3})
N_v: effective density of states for valence band (cm^{-3})
E_F: Fermi energy (eV)
k: Boltzmann constant (J/K)
T: absolute temperature (K)

Semiconductor Equations

J.S. Yuan,Juin Jei Liou

Semiconductor Equations:

Semiconductor Equations Peter A. Markowich,Christian A. Ringhofer,Christian Schmeiser,2012-12-06 In recent years the mathematical modeling of charge transport in semi conductors has become a thriving area in applied mathematics The drift diffusion equations which constitute the most popular model for the simula tion of the electrical behavior of semiconductor devices are by now mathe matically quite well understood As a consequence numerical methods have been developed which allow for reasonably efficient computer simulations in many cases of practical relevance Nowadays research on the drift diffu sion model is of a highly specialized nature It concentrates on the explora tion of possibly more efficient discretization methods e g mixed finite elements streamline diffusion on the improvement of the performance of nonlinear iteration and linear equation solvers and on three dimensional applications The ongoing miniaturization of semiconductor devices has prompted a shift of the focus of the modeling research lately since the drift diffusion model does not account well for charge transport in ultra integrated devices Extensions of the drift diffusion model so called hydrodynamic models are under investigation for the modeling of hot electron effects in submicron MOS transistors and supercomputer technology has made it possible to employ kinetic models semiclassical Boltzmann Poisson and Wigner Poisson equations for the simulation of certain highly integrated devices *Transport Equations for Semiconductors* Ansgar Jüngel,2009-03-17 This volume presents a systematic and mathematically accurate description and derivation of transport equations in solid state physics in particular semiconductor devices **The Stationary Semiconductor Device Equations** P.A. Markowich,1985-12-12 In the last two decades semiconductor device simulation has become a research area which thrives on a cooperation of physicists electrical engineers and mathe maticians In this book the static semiconductor device problem is presented and analysed from an applied mathematician s point of view I shall derive the device equations as obtained for the first time by Van Roosbroeck in 1950 from physical principles present a mathematical analysis discuss their numerical solu tion by discretisation techniques and report on selected device simulation runs To me personally the most fascinating aspect of mathematical device analysis is that an interplay of abstract mathematics perturbation theory numerical analysis and device physics is prompting the design and development of new technology I very much hope to convey to the reader the importance of applied mathematics for technological progress Each chapter of this book is designed to be as selfcontained as possible however the mathematical analysis of the device problem requires tools which cannot be presented completely here Those readers who are not interested in the mathemati cal methodology and rigor can extract the desired information by simply ignoring details and proofs of theorems Also at the beginning of each chapter I refer to textbooks which introduce the interested reader to the required mathematical concepts *Semiconductor Device Physics and Simulation* J.S. Yuan,Juin Jei Liou,1998-05-31 The advent of the microelectronics technology has made ever increasing numbers of small devices on a same chip The rapid emergence of ultra large scaled integrated ULSI technology has moved device dimension into the sub

quarter micron regime and put more than 10 million transistors on a single chip While traditional closed form analytical models furnish useful intuition into how semiconductor devices behave they no longer provide consistently accurate results for all modes of operation of these very small devices The reason is that in such devices various physical mechanisms affect the device performance in a complex manner and the conventional assumptions i e one dimensional treatment low level injection quasi static approximation etc em ployed in developing analytical models become questionable Thus the use of numerical device simulation becomes important in device modeling Researchers and engineers will rely even more on device simulation for device design and analysis in the future This book provides comprehensive coverage of device simulation and analysis for various modem semiconductor devices It will serve as a reference for researchers engineers and students who require in depth up to date information and understanding of semiconductor device physics and characteristics The materials of the book are limited to conventional and mainstream semiconductor devices photonic devices such as light emitting and laser diodes are not included nor does the book cover device modeling device fabrication and circuit applications

Quasi-hydrodynamic Semiconductor Equations Ansgar Jüngel,2011-04-27 In this book a hierarchy of macroscopic models for semiconductor devices is presented Three classes of models are studied in detail isentropic drift diffusion equations energy transport models and quantum hydrodynamic equations The derivation of each of the models is shown including physical discussions Furthermore the corresponding mathematical problems are analyzed using modern techniques for nonlinear partial differential equations The equations are discretized employing mixed finite element methods Also numerical simulations for modern semiconductor devices are performed showing the particular features of the models Modern analytical techniques have been used and further developed such as positive solution methods local energy methods for free boundary problems and entropy methods The book is aimed at applied mathematicians and physicists interested in mathematics as well as graduate and postdoc students and researchers in these fields   **The Stationary Semiconductor Device Equations** P.A. Markowich,2013-03-09 In the last two decades semiconductor device simulation has become a research area which thrives on a cooperation of physicists electrical engineers and mathe maticians In this book the static semiconductor device problem is presented and analysed from an applied mathematician s point of view I shall derive the device equations as obtained for the first time by Van Roosbroeck in 1950 from physical principles present a mathematical analysis discuss their numerical solu tion by discretisation techniques and report on selected device simulation runs To me personally the most fascinating aspect of mathematical device analysis is that an interplay of abstract mathematics perturbation theory numerical analysis and device physics is prompting the design and development of new technology I very much hope to convey to the reader the importance of applied mathematics for technological progress Each chapter of this book is designed to be as selfcontained as possible however the mathematical analysis of the device problem requires tools which cannot be presented completely here Those readers who are not interested in the mathemati cal methodology and

rigor can extract the desired information by simply ignoring details and proofs of theorems Also at the beginning of each chapter I refer to textbooks which introduce the interested reader to the required mathematical concepts

Quasi-hydrodynamic Semiconductor Equations Ansgar Jüngel,2001-02-01 This book presents a hierarchy of macroscopic models for semiconductor devices studying three classes of models in detail isentropic drift diffusion equations energy transport models and quantum hydrodynamic equations The derivation of each including physical discussions is shown Numerical simulations for modern semiconductor devices are performed showing the particular features of each The author develops modern analytical techniques such as positive solution methods local energy methods for free boundary problems and entropy methods **Rate Equations in Semiconductor Electronics** John E. Carroll,J. E. Carroll,1990-03-30 This book presents a novel approach to the teaching of dynamic aspects of the operation of semiconductor and opto electronic devices Such dynamic aspects often determine the steady state conditions Also the dynamical operation of such devices is of increasing importance as modern methods of communicating data and information require electronic devices that switch electrical or optical signals at ever faster rates The author discusses the rates at which electrons and holes can reach equilibrium the rates at which transistors and diodes can switch and the rates at which electrons and holes can interact with photons and with protons He also applies the rate equations in a unified way to models of light emitting diodes injection lasers and photodiodes Finally the author discusses more advanced topics on the photon statistics of injection lasers mode locking and the application of rate equations and Maxwell s equations to opto electronic devices **Analysis and Simulation of Semiconductor Devices** S. Selberherr,2012-12-06 The invention of semiconductor devices is a fairly recent one considering classical time scales in human life The bipolar transistor was announced in 1947 and the MOS transistor in a practically usable manner was demonstrated in 1960 From these beginnings the semiconductor device field has grown rapidly The first integrated circuits which contained just a few devices became commercially available in the early 1960s Immediately thereafter an evolution has taken place so that today less than 25 years later the manufacture of integrated circuits with over 400 000 devices per single chip is possible Coincident with the growth in semiconductor device development the literature concerning semiconductor device and technology issues has literally exploded In the last decade about 50 000 papers have been published on these subjects The advent of so called Very Large Scale Integration VLSI has certainly revealed the need for a better understanding of basic device behavior The miniaturization of the single transistor which is the major prerequisite for VLSI nearly led to a breakdown of the classical models of semiconductor devices

Mathematical Problems in Semiconductor Physics Angelo Marcello Anile,Walter Allegretto,Christian Ringhofer,2003-09-16 On the the mathematical aspects of the theory of carrier transport in semiconductor devices The subjects covered include hydrodynamical models for semiconductors based on the maximum entropy principle of extended thermodynamics mathematical theory of drift diffusion equations with applications and the methods of asymptotic analysis

Introduction to Semiconductor Device Modelling Christopher M. Snowden,1998 This book deals mainly with physical device models which are developed from the carrier transport physics and device geometry considerations The text concentrates on silicon and gallium arsenide devices and includes models of silicon bipolar junction transistors junction field effect transistors JFETs MESFETs silicon and GaAs MESFETs transferred electron devices pn junction diodes and Schottky varactor diodes The modelling techniques of more recent devices such as the heterojunction bipolar transistors HBT and the high electron mobility transistors are discussed This book contains details of models for both equilibrium and non equilibrium transport conditions The modelling Technique of Small scale devices is discussed and techniques applicable to submicron dimensioned devices are included A section on modern quantum transport analysis techniques is included Details of essential numerical schemes are given and a variety of device models are used to illustrate the application of these techniques in various fields   Semiconductor Device Modelling Christopher M. Snowden,2012-12-06 Semiconductor device modelling has developed in recent years from being solely the domain of device physicists to span broader technological disciplines involved in device and electronic circuit design and develop ment The rapid emergence of very high speed high density integrated circuit technology and the drive towards high speed communications has meant that extremely small scale device structures are used in contempor ary designs The characterisation and analysis of these devices can no longer be satisfied by electrical measurements alone Traditional equivalent circuit models and closed form analytical models cannot always provide consis tently accurate results for all modes of operation of these very small devices Furthermore the highly competitive nature of the semiconductor industry has led to the need to minimise development costs and lead time associated with introducing new designs This has meant that there has been a greater demand for models capable of increasing our understanding of how these devices operate and capable of predicting accurate quantitative results The desire to move towards computer aided design and expert systems has reinforced the need for models capable of representing device operation under DC small signal large signal and high frequency operation It is also desirable to relate the physical structure of the device to the electrical performance This demand for better models has led to the introduction of improved equivalent circuit models and a upsurge in interest in using physical models   **Physics of Semiconductor Devices** J.-P. Colinge,C.A. Colinge,2005-10-03 Physics of Semiconductor Devices covers both basic classic topics such as energy band theory and the gradual channel model of the MOSFET as well as advanced concepts and devices such as MOSFET short channel effects low dimensional devices and single electron transistors Concepts are introduced to the reader in a simple way often using comparisons to everyday life experiences such as simple fluid mechanics They are then explained in depth and mathematical developments are fully described Physics of Semiconductor Devices contains a list of problems that can be used as homework assignments or can be solved in class to exemplify the theory Many of these problems make use of Matlab and are aimed at illustrating theoretical concepts in a graphical manner   **Simulation of Semiconductor Devices and Processes, Vol. 5**

Siegfried Selberherr,Hannes Stippel,Ernst Strasser,1993 **Nonlinear Evolutionary Partial Differential Equations** Xiaxi Ding,Tai-Ping Liu,1997 This volume contains the proceedings from the International Conference on Nonlinear Evolutionary Partial Differential Equations held in Beijing in June 1993 The topic for the conference was selected because of its importance in the natural sciences and for its mathematical significance Discussion topics include conservation laws dispersion waves Einstein s theory of gravitation reaction diffusion equations the Navier Stokes equations and more New results were presented and are featured in this volume Titles in this series are co published with International Press Cambridge MA *Semiconductor Physics* Sandip Tiwari,2020-09-22 The subject of semiconductor physics today includes not only many of the aspects that constitute solid state physics but also much more It includes what happens at the nanoscale and at surfaces and interfaces behavior with few interaction events and few carriers electrons and their quasi particle holes in the valence bands the exchange of energies in various forms the coupling of energetic events over short and long length scales quantum reversibility tied to macroscale linearity and eventually to nonlinearities the thermodynamic and statistical consequences of fluctuation dissipation and others This text brings together traditional solid state approaches from the 20th century with developments of the early part of the 21st century to reach an understanding of semiconductor physics in its multifaceted forms It reveals how an understanding of what happens within the material can lead to insights into what happens in its use The collection of four textbooks in the Electroscience series culminates in a comprehensive understanding of nanoscale devices electronic magnetic mechanical and optical in the 4th volume The series builds up to this last subject with volumes devoted to underlying semiconductor and solid state physics Balance Equation Approach to Electron Transport In Semiconductors Xiaolin Lei,2008 This book presents a systematic comprehensive and up to date description of the physical basis of the balance equation transport theory and its applications in bulk and low dimensional semiconductors The different aspects of the balance equation method originally proposed by C S Ting and the author of the present book were reviewed in the volume entitled Physics of Hot Electron Transport in Semiconductors edited by C S Ting World Scientific 1992 Since then this method has been extensively developed and applied to various new fields such as transport in nonparabolic systems spatially nonuniform systems and semiconductor devices miniband conduction of superlattices hot electron magnetotransport effects of impact ionization in transport microwave induced magnetoresistance oscillation radiation driven transport and electron cooling etc Due to its simplicity and effectiveness the balance equation approach has become a useful tool to tackle the many transport phenomena in semiconductors and provides a reliable basis for developing theories modeling devices and explaining experiments The book may be used as a textbook by graduate students It will also benefit researchers in the field by helping them grasp the basic principles and techniques of the method without having to spend a lot of time digging out the information from widespread literature covering a period of 30 years **Handbook of II-VI Semiconductor-Based Sensors and Radiation Detectors** Ghenadii Korotcenkov,2023-02-02 Three volumes book

Handbook of II VI Semiconductor Based Sensors and Radiation Detectors is the first to cover both chemical sensors and biosensors and all types of photodetectors and radiation detectors based on II VI semiconductors It contains a comprehensive and detailed analysis of all aspects of the application of II VI semiconductors in these devices The second volume Photodetectors of a three volume set focus on the consideration of all types of optical detectors including IR detectors visible and UV photodetectors This consideration includes both the fundamentals of the operation of detectors and the peculiarities of their manufacture and use In particular describes numerous strategies for their fabrication and characterization An analysis of new trends in development of II VI semiconductors based photodetectors such as graphene HgCdTe nanowire and quantum dot based photodetectors as well as solution processed multicolor flexible and self powered photodetectors are also given   **Semiconductors** W.M. Jr. Coughran,Julian Cole,Peter Lloyd,Jacob K. White,2012-12-06 This IMA Volume in Mathematics and its Applications SEMICONDUCTORS PART II is based on the proceedings of the IMA summer program Semiconductors Our goal was to foster interaction in this interdisciplinary field which involves electrical engineers computer scientists semiconductor physicists and mathematicians from both university and industry In particular the program was meant to encourage the participation of numerical and mathematical analysts with backgrounds in ordinary and partial differential equations to help get them involved in the mathematical as pects of semiconductor models and circuits We are grateful to W M Coughran Jr Julian Cole Peter Lloyd and Jacob White for helping Farouk Odeh organize this activity and trust that the proceedings will provide a fitting memorial to Farouk We also take this opportunity to thank those agencies whose financial support made the program possible the Air Force Office of Scientific Research the Army Research Office the National Science Foundation and the Office of Naval Research A vner Friedman Willard Miller J r Preface to Part II Semiconductor and integrated circuit modeling are an important part of the high technology chip industry whose high performance low cost microprocessors and high density memory designs form the basis for supercomputers engineering work stations laptop computers and other modern information appliances There are a variety of differential equation problems that must be solved to facilitate such mod eling   *Springer Handbook of Semiconductor Devices* Massimo Rudan,Rossella Brunetti,Susanna Reggiani,2022-11-10 This Springer Handbook comprehensively covers the topic of semiconductor devices embracing all aspects from theoretical background to fabrication modeling and applications Nearly 100 leading scientists from industry and academia were selected to write the handbook s chapters which were conceived for professionals and practitioners material scientists physicists and electrical engineers working at universities industrial R D and manufacturers Starting from the description of the relevant technological aspects and fabrication steps the handbook proceeds with a section fully devoted to the main conventional semiconductor devices like e g bipolar transistors and MOS capacitors and transistors used in the production of the standard integrated circuits and the corresponding physical models In the subsequent chapters the scaling issues of the semiconductor device technology are addressed followed by the

description of novel concept based semiconductor devices The last section illustrates the numerical simulation methods ranging from the fabrication processes to the device performances Each chapter is self contained and refers to related topics treated in other chapters when necessary so that the reader interested in a specific subject can easily identify a personal reading path through the vast contents of the handbook

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