

Mathias Schubert

# **Infrared Ellipsometry on Semiconductor Layer Structures**

Phonons, Plasmons,  
and Polaritons



Springer

# Infrared Ellipsometry On Semiconductor Layer Structures Phonons Plasmons And Polaritons

**Hiroyuki Fujiwara**



## **Infrared Ellipsometry On Semiconductor Layer Structures Phonons Plasmons And Polaritons:**

**Infrared Ellipsometry on Semiconductor Layer Structures** Mathias Schubert, 2004-11-26 The study of semiconductor layer structures using infrared ellipsometry is a rapidly growing field within optical spectroscopy This book offers basic insights into the concepts of phonons plasmons and polaritons and the infrared dielectric function of semiconductors in layered structures It describes how strain composition and the state of the atomic order within complex layer structures of multinary alloys can be determined from an infrared ellipsometry examination Special emphasis is given to free charge carrier properties and magneto optical effects A broad range of experimental examples are described including multinary alloys of zincblende and wurtzite structure semiconductor materials and future applications such as organic layer structures and highly correlated electron systems are proposed

**Handbook of Zinc Oxide and Related Materials** Zhe Chuan Feng, 2012-09-26 Through their application in energy efficient and environmentally friendly devices zinc oxide ZnO and related classes of wide gap semiconductors including GaN and SiC are revolutionizing numerous areas from lighting energy conversion photovoltaics and communications to biotechnology imaging and medicine With an emphasis on engineering a

**The Physics of Semiconductors** Marius Grundmann, 2021-03-06 The 4th edition of this highly successful textbook features copious material for a complete upper level undergraduate or graduate course guiding readers to the point where they can choose a specialized topic and begin supervised research The textbook provides an integrated approach beginning from the essential principles of solid state and semiconductor physics to their use in various classic and modern semiconductor devices for applications in electronics and photonics The text highlights many practical aspects of semiconductors alloys strain heterostructures nanostructures amorphous semiconductors and noise which are essential aspects of modern semiconductor research but often omitted in other textbooks This textbook also covers advanced topics such as Bragg mirrors resonators polarized and magnetic semiconductors nanowires quantum dots multi junction solar cells thin film transistors and transparent conductive oxides The 4th edition includes many updates and chapters on 2D materials and aspects of topology The text derives explicit formulas for many results to facilitate a better understanding of the topics Having evolved from a highly regarded two semester course on the topic The Physics of Semiconductors requires little or no prior knowledge of solid state physics More than 2100 references guide the reader to historic and current literature including original papers review articles and topical books providing a go to point of reference for experienced researchers as well

*Spectroscopic Ellipsometry* Harland G. Tompkins, James N. Hilfiker, 2015-12-16 Ellipsometry is an experimental technique for determining the thickness and optical properties of thin films It is ideally suited for films ranging in thickness from sub nanometer to several microns Spectroscopic measurements have greatly expanded the capabilities of this technique and introduced its use into all areas where thin films are found semiconductor devices flat panel and mobile displays optical coating stacks biological and medical coatings protective layers and more While several scholarly books exist on the topic

this book provides a good introduction to the basic theory of the technique and its common applications The target audience is not the ellipsometry scholar but process engineers and students of materials science who are experts in their own fields and wish to use ellipsometry to measure thin film properties without becoming an expert in ellipsometry itself Optical Techniques for Solid-State Materials Characterization Rohit P. Prasankumar, Antoinette J. Taylor, 2016-04-19 Over the last century numerous optical techniques have been developed to characterize materials giving insight into their optical electronic magnetic and structural properties and elucidating such diverse phenomena as high temperature superconductivity and protein folding Optical Techniques for Solid State Materials Characterization provides

**Spectroscopic Ellipsometry for Photovoltaics** Hiroyuki Fujiwara, Robert W. Collins, 2019-01-10 This book provides a basic understanding of spectroscopic ellipsometry with a focus on characterization methods of a broad range of solar cell materials devices from traditional solar cell materials Si CuInGaSe<sub>2</sub> and CdTe to more advanced emerging materials Cu<sub>2</sub>ZnSnSe<sub>4</sub> organics and hybrid perovskites fulfilling a critical need in the photovoltaic community The book describes optical constants of a variety of semiconductor light absorbers transparent conductive oxides and metals that are vital for the interpretation of solar cell characteristics and device simulations It is divided into four parts fundamental principles of ellipsometry characterization of solar cell materials structures ellipsometry applications including optical simulations of solar cell devices and online monitoring of film processing and the optical constants of solar cell component layers

*Spectroscopic Ellipsometry* Hiroyuki Fujiwara, 2007-09-27 Ellipsometry is a powerful tool used for the characterization of thin films and multi layer semiconductor structures This book deals with fundamental principles and applications of spectroscopic ellipsometry SE Beginning with an overview of SE technologies the text moves on to focus on the data analysis of results obtained from SE Fundamental data analyses principles and physical backgrounds and the various materials used in different fields from LSI industry to biotechnology are described The final chapter describes the latest developments of real time monitoring and process control which have attracted significant attention in various scientific and industrial fields

**Study of novel electronic materials by mid-infrared and terahertz optical Hall effect** Nerijus Armakavicius, 2017-10-23 Development of silicon based electronics have revolutionized our every day life during the last three decades Nowadays Si based devices operate close to their theoretical limits that is becoming a bottleneck for further progress In particular for the growing field of high frequency and high power electronics Si cannot offer the required properties Development of materials capable of providing high current densities carrier mobilities and high breakdown fields is crucial for a progress in state of the art electronics Epitaxial graphene grown on semi insulating silicon carbide substrates has a high potential to be integrated in the current planar device technologies High electron mobilities and sheet carrier densities make graphene extremely attractive for high frequency analog applications One of the remaining challenges is the interaction of epitaxial graphene with the substrate Typically much lower free charge carrier mobilities compared to free

standing graphene and doping due to charge transfer from the substrate is reported. Thus a good understanding of the intrinsic free charge carriers properties and the factors affecting them is very important for further development of epitaxial graphene. III group nitrides have been extensively studied and already have proven their high efficiency as light sources for short wavelengths. High carrier mobilities and breakdown electric fields were demonstrated for III group nitrides making them attractive for high frequency and high power applications. Currently, in rich InGaN alloys and AlGaIn GaN high electron mobility structures are of high interest for the research community due to open fundamental questions. Electrical characterization techniques commonly used for the determination of free charge carrier properties require good ohmic and Schottky contacts which in certain cases can be difficult to achieve. Access to electrical properties of buried conductive channels in multilayered structures requires modification of samples and good knowledge of the electrical properties of all electrical contact within the structure. Moreover, the use of electrical contacts to electrically characterize two dimensional electronic materials such as graphene can alter their intrinsic properties. Furthermore, the determination of effective mass parameters commonly employs cyclotron resonance and Shubnikov de Haas oscillations measurements which require long scattering times of free charge carriers, high magnetic fields and low temperatures. The optical Hall effect is an external magnetic field induced optical anisotropy in conductive layers due to the motion of the free charge carriers under the influence of the Lorentz force and is equivalent to the electrical Hall effect at optical frequencies. The optical Hall effect can be measured by generalized ellipsometry and provides a powerful method for the determination of free charge carrier properties in a non destructive and contactless manner. In principle, a single optical Hall effect measurement can provide quantitative information about free charge carrier types, concentrations, mobilities and effective mass parameters at temperatures ranging from few kelvins to room temperature and above. Further, it was demonstrated that for transparent samples, a backside cavity can be employed to enhance the optical Hall effect. Measurement of the optical Hall effect by generalized ellipsometry is an indirect technique requiring subsequent data analysis. Parameterized optical models are fitted to match experimentally measured ellipsometric data by varying physically significant parameters. Analysis of the optical response of samples containing free charge carriers employing optical models based on the classical Drude model which is augmented with an external magnetic field contribution provide access to the free charge carrier properties. The main research results of the graduate studies presented in this licentiate thesis are summarized in the five scientific papers. Paper I: Description of the custom built terahertz frequency domain spectroscopic ellipsometer at Linköping University. The terahertz ellipsometer capabilities are demonstrated by an accurate determination of the isotropic and anisotropic refractive indices of silicon and m-plane sapphire respectively. Further, terahertz optical Hall effect measurements of an AlGaIn GaN high electron mobility structure were employed to extract the two dimensional electron gas sheet density, mobility and effective mass parameters. Last, in situ optical Hall effect measurement on epitaxial graphene in a gas cell with controllable environment.

were used to study the effects of environmental doping on the mobility and carrier concentration Paper II Presents terahertz cavity enhanced optical Hall measurements of the monolayer and multilayer epitaxial graphene on semi insulating 4H SiC 0001 substrates The data analysis revealed p type doping for monolayer graphene with a carrier density in the low  $10^{12} \text{ cm}^{-2}$  range and a carrier mobility of  $1550 \text{ cm}^2 \text{ V s}$  For the multilayer epitaxial graphene n type doping with a carrier density in the low  $10^{13} \text{ cm}^{-2}$  range a mobility of  $470 \text{ cm}^2 \text{ V s}$  and an effective mass of  $0.14 \pm 0.03 m_0$  were extracted The measurements demonstrate that cavity enhanced optical Hall effect measurements can be applied to study electronic properties of two dimensional materials Paper III Terahertz cavity enhanced optical Hall effect measurements are employed to study anisotropic transport in as grown monolayer quasi free standing monolayer and quasi free standing bilayer epitaxial graphene on semi insulating 4H SiC 0001 substrates The data analysis revealed a strong anisotropy in the carrier mobilities of the quasi freestanding bilayer graphene The anisotropy is demonstrated to be induced by carriers scattering at the step edges of the SiC by showing that the mobility is higher along the step than across them The scattering mechanism is discussed based on the results of the optical Hall effect low energy electron microscopy low energy electron diffraction and Raman measurements Paper IV Mid infrared spectroscopic ellipsometry and mid infrared optical Hall effect measurements are employed to determine the electron effective mass in an  $\text{In}_{0.33}\text{Ga}_{0.67}\text{N}$  epitaxial layer The data analysis reveals slightly anisotropic effective mass and carrier mobility parameters together with the optical phonon frequencies and broadenings Paper V Terahertz cavity enhanced optical Hall measurements are employed to study the free charge carrier properties in a set of AlGaIn GaN high electron mobility structures with modified interfaces The results show that the interface structure has a significant effect on the free charge carrier mobility and that the sample with a sharp interface between an AlGaIn barrier and a GaN buffer layers exhibits a record mobility of  $2332.73 \text{ cm}^2 \text{ V s}$  The determined effective mass parameters showed an increase compared to the GaN value that is attributed to the penetration of the electron wavefunction into the AlGaIn barrier layer

Ellipsometry at the Nanoscale Maria Losurdo, Kurt Hingerl, 2013-03-12 This book presents and introduces ellipsometry in nanoscience and nanotechnology making a bridge between the classical and nanoscale optical behaviour of materials It delineates the role of the non destructive and non invasive optical diagnostics of ellipsometry in improving science and technology of nanomaterials and related processes by illustrating its exploitation ranging from fundamental studies of the physics and chemistry of nanostructures to the ultimate goal of turnkey manufacturing control This book is written for a broad readership materials scientists researchers engineers as well as students and nanotechnology operators who want to deepen their knowledge about both basics and applications of ellipsometry to nanoscale phenomena It starts as a general introduction for people curious to enter the fields of ellipsometry and polarimetry applied to nanomaterials and progresses to articles by experts on specific fields that span from plasmonics optics to semiconductors and flexible electronics The core belief reflected in this book is that ellipsometry applied at the nanoscale offers new ways of addressing

many current needs The book also explores forward looking potential applications Handbook of Optical Metrology Toru Yoshizawa,2009-02-25 The field of optical metrology offers a wealth of both practical and theoretical accomplishments and can cite any number of academic papers recording such However while several books covering specific areas of optical metrology do exist until the pages herein were researched written and compiled the field lacked for a comprehensive handbook one providing an overview of optical metrology that covers practical applications as well as fundamentals Carefully designed to make information accessible to beginners without sacrificing academic rigor the Handbook of Optical Metrology Principles and Applications discusses fundamental principles and techniques before exploring practical applications With contributions from veterans in the field as well as from up and coming researchers the Handbook offers 30 substantial and well referenced chapters In addition to the introductory matter forward thinking descriptions are included in every chapter that make this a valuable reference for all those involved with optical metrology **Surface Science Techniques** Gianangelo Bracco,Bodil Holst,2013-01-11 The book describes the experimental techniques employed to study surfaces and interfaces The emphasis is on the experimental method Therefore all chapters start with an introduction of the scientific problem the theory necessary to understand how the technique works and how to understand the results Descriptions of real experimental setups experimental results at different systems are given to show both the strength and the limits of the technique In a final part the new developments and possible extensions of the techniques are presented The included techniques provide microscopic as well as macroscopic information They cover most of the techniques used in surface science *Ellipsometry of Functional Organic Surfaces and Films* Karsten Hinrichs,Klaus-Jochen Eichhorn,2018-05-06 This new edition provides a state of the art survey of ellipsometric methods used to study organic films and surfaces from laboratory to synchrotron applications with a special focus on in situ use in processing environments and at solid liquid interfaces Thanks to the development of functional organic meta and hybrid materials for new optical electronic sensing and biotechnological devices the ellipsometric analysis of optical and material properties has made tremendous strides over the past few years The second edition has been updated to reflect the latest advances in ellipsometric methods The new content focuses on the study of anisotropic materials conjugated polymers polarons self assembled monolayers industrial membranes adsorption of proteins enzymes and RGD peptides as well as the correlation of ellipsometric spectra to structure and molecular interactions *Optical and Electrical Properties of Nanoscale Materials* Alain Diebold,Tino Hofmann,2022-01-10 This book covers the optical and electrical properties of nanoscale materials with an emphasis on how new and unique material properties result from the special nature of their electronic band structure Beginning with a review of the optical and solid state physics needed for understanding optical and electrical properties the book then introduces the electronic band structure of solids and discusses the effect of spin orbit coupling on the valence band which is critical for understanding the optical properties of most nanoscale materials Excitonic effects and excitons are also presented along with their effect on

optical absorption 2D materials such as graphene and transition metal dichalcogenides are host to unique electrical properties resulting from the electronic band structure This book devotes significant attention to the optical and electrical properties of 2D and topological materials with an emphasis on optical measurements electrical characterization of carrier transport and a discussion of the electronic band structures using a tight binding approach This book succinctly compiles useful fundamental and practical information from one of the fastest growing research topics in materials science and is thus an essential compendium for both students and researchers in this rapidly moving field

**Inelastic Light Scattering of Semiconductor Nanostructures** Christian Schüller,2006-09-14 The field of semiconductor nanostructures is of enormous and still growing research interest On one hand they are already realized in mass products such as high electron mobility field effect transistors and quantum well lasers On the other hand they allow in specially tailored systems the investigation of fundamental properties such as many particle interactions of electrons in reduced dimensions This book bridges the gap between general semiconductor textbooks and research articles

Developments in Surface Contamination and Cleaning, Volume 12 Rajiv Kohli,K.L. Mittal,2019-06-08 Developments in Surface Contamination and Cleaning Methods for Assessment and Verification of Cleanliness of Surfaces and Characterization of Surface Contaminants Volume Twelve the latest release in the Developments in Surface Contamination and Cleaning series provides best practices on determining surface cleanliness Chapters include an introduction to the nature and size of particles a discussion of cleanliness levels detailed coverage of measurement methods characterization methods and analytical methods for evaluating surfaces and an overview of analysis methods for various contaminants As a whole the series creates a unique and comprehensive knowledge base for those in research and development in a variety of industries Manufacturing quality control and procurement specification professionals in the aerospace automotive biomedical defense energy manufacturing microelectronics optics and xerography industries will find this book to be very helpful In addition researchers in an academic setting will also find these volumes excellent source books Includes an extensive listing with a description of available methods for the assessment of surface cleanliness Provides a single source of information on methods for verification of surface cleanliness Serves as a guide to the selection assessment and verification of methods for specific applications

**Cosmology** Dierck-Ekkehard Liebscher,2005-04-20 Cosmology deals with the current state of thinking about the basic questions at the center of the field of cosmology More emphasis than usual is put on the connections to related domains of science such as geometry relativity thermodynamics particle physics and in particular on the intrinsic connections between the different topics The chapters are illustrated with many figures that are as exact as currently possible e g in the case of geometry and relativity Readers acquire a graduate level knowledge of cosmology as it is required to understand the cosmological impact of their particular research topics as well as an introduction into the current research in the field

*Stoichiometry and Materials Science* Alessio Innocenti,Norlida Kamarulzaman,2012-04-11 The aim of this book is to provide an overview on the importance of



stoichiometry in the materials science field It presents a collection of selected research articles and reviews providing up to date information related to stoichiometry at various levels Being materials science an interdisciplinary area the book has been divided in multiple sections each for a specific field of applications The first two sections introduce the role of stoichiometry in nanotechnology and defect chemistry providing examples of state of the art technologies Section three and four are focused on intermetallic compounds and metal oxides Section five describes the importance of stoichiometry in electrochemical applications In section six new strategies for solid phase synthesis are reported while a cross sectional approach to the influence of stoichiometry in energy production is the topic of the last section Though specifically addressed to readers with a background in physical science I believe this book will be of interest to researchers working in materials science engineering and technology

Free Surface Flows under Compensated Gravity Conditions Michael Dreyer, 2007-04-17 This book considers the behavior of fluids in a low gravity environment e g spacecraft with special emphasis on application in PMD propellant management device systems Since PMD designs are not testable on ground and thus completely rely on analytical or numerical concepts this book treats three different flow problems with analytical numerical and experimental means These problems are linked together by the same set of equations and boundary conditions

Precision Electroweak Physics at Electron-Positron Colliders Stefan Roth, 2007 This up to date volume reviews the recent contributions of electron positron colliders to the precision test of the electroweak Standard Model In particular it contains a short summary of the measurements at the Z resonance and gives an overview of the electroweak processes above the Z Subsequently the measurement of the W mass at LEP is discussed in detail The implications for the precision test of the Standard Model are presented giving the status of the global electroweak fit before the startup of Large Hadron Collider The final chapters give an outlook on the electroweak physics at a future linear collider The book also features many illustrations and tables Readers obtain a coherent overview of the results of 20 years of electroweak physics conducted at electron positron colliders

**Theory of the Muon Anomalous Magnetic Moment** Kirill Melnikov, Arkady Vainshtein, 2007-01-09 The theory of the muon anomalous magnetic moment is particle physics in a nutshell It is an interesting exciting and difficult subject and this book provides a comprehensive review of it The theory of the muon anomalous magnetic moment is at the cutting edge of current research in particle physics and any deviation between the theoretical prediction and the experimental value might be interpreted as a signal of an as yet unknown new physics

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