

Some Aspects of Epitaxial Silicon (Based on my previous life at Okmetic Plc)

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- Epitaxy process and equipment
- Properties of epitaxial wafers
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Aspects Of Epitaxy

Axel Voigt



Aspects Of Epitaxy:

Aspects of Epitaxy Brian R. Pamplin, Robert Z. Bachrach, 1986 **Atomistic Aspects of Epitaxial Growth** Miroslav Kotrla, Nicolas I. Papanicolaou, Dimitri Vvedensky, Luc T. Wille, 2012-12-06 Epitaxial growth lies at the heart of a wide range of industrial and technological applications Recent breakthroughs experimental and theoretical allow actual atom by atom manipulation and an understanding of such processes opening up a totally new area of unprecedented nanostructuring The contributions to Atomistic Aspects of Epitaxial Growth are divided into five main sections taking the reader from the atomistic details of surface diffusion to the macroscopic description of epitaxial systems many of the papers contain substantial background material on theoretical and experimental methods making the book suitable for both graduate students as a supplementary text in a course on epitaxial phenomena and for professionals in the field **Epitaxy of Semiconductors** Udo W. Pohl, 2013-01-11 Introduction to Epitaxy provides the essential information for a comprehensive upper level graduate course treating the crystalline growth of semiconductor heterostructures Heteroepitaxy represents the basis of advanced electronic and optoelectronic devices today and is considered one of the top fields in materials research The book covers the structural and electronic properties of strained epitaxial layers the thermodynamics and kinetics of layer growth and the description of the major growth techniques metalorganic vapor phase epitaxy molecular beam epitaxy and liquid phase epitaxy Cubic semiconductors strain relaxation by misfit dislocations strain and confinement effects on electronic states surface structures and processes during nucleation and growth are treated in detail The Introduction to Epitaxy requires only little knowledge on solid state physics Students of natural sciences materials science and electrical engineering as well as their lecturers benefit from elementary introductions to theory and practice of epitaxial growth supported by pertinent references and over 200 detailed illustrations *Epitaxy* Marian A. Herman, W. Richter, Helmut Sitter, 2013-03-09 Epitaxy provides readers with a comprehensive treatment of the modern models and modifications of epitaxy together with the relevant experimental and technological framework This advanced textbook describes all important aspects of the epitaxial growth processes of solid films on crystalline substrates including a section on heteroepitaxy It covers and discusses in details the most important epitaxial growth techniques which are currently widely used in basic research as well as in manufacturing processes of devices namely solid phase epitaxy liquid phase epitaxy vapor phase epitaxy including metal organic vapor phase epitaxy and molecular beam epitaxy Epitaxy s coverage of science and texhnology thin film is intended to fill the need for a comprehensive reference and text examining the variety of problems related to the physical foundations and technical implementation of epitaxial crystallization **Crystal Growth - From Fundamentals to Technology** Georg Müller, Jean-Jacques Métois, Peter Rudolph, 2004-07-07 The book contains 5 chapters with 19 contributions form internationally well acknowledged experts in various fields of crystal growth The topics are ranging from fundamentals thermodynamic of epitaxy growth kinetics morphology modeling to new crystal materials carbon nanocrystals

and nanotubes biological crystals to technology Silicon Czochralski growth oxide growth III IV epitaxy and characterization point defects X ray imaging in situ STM It covers the treatment of bulk growth as well as epitaxy by anorganic and organic materials *Proceedings of the Symposium on III-V Opto-Electronics Epitaxy and Device Related Processes* V. G. Keramidis, Subhash Mahajan, 1983

Proceedings of the Symposium on Fundamental Aspects of Electrochemical Deposition and Dissolution Including Modeling Milan Paunovic, 1998 *Liquid Phase Epitaxy of Electronic, Optical and Optoelectronic Materials* Peter Capper, Michael Mauk, 2007-08-20

Liquid Phase Epitaxy LPE is a technique used in the bulk growth of crystals typically in semiconductor manufacturing whereby the crystal is grown from a rich solution of the semiconductor onto a substrate in layers each of which is formed by supersaturation or cooling At least 50% of growth in the optoelectronics area is currently focussed on LPE This book covers the bulk growth of semiconductors i e silicon gallium arsenide cadmium mercury telluride indium phosphide indium antimonide gallium nitride cadmium zinc telluride a range of wide bandgap II VI compounds diamond and silicon carbide and a wide range of oxides fluorides including sapphire and quartz that are used in many industrial applications A separate chapter is devoted to the fascinating field of growth in various forms of microgravity an activity that is approximately 30 years old and which has revealed many interesting features some of which have been very surprising to experimenters and theoreticians alike Covers the most important materials within the field The contributors come from a wide variety of countries and include both academics and industrialists to give a balanced treatment Builds on an established series known in the community Highly pertinent to current and future developments in telecommunications and computer processing industries *Silicon Epitaxy*, 2001-09-26

Since its inception in 1966 the series of numbered volumes known as Semiconductors and Semimetals has distinguished itself through the careful selection of well known authors editors and contributors The Willardson and Beer series as it is widely known has succeeded in producing numerous landmark volumes and chapters Not only did many of these volumes make an impact at the time of their publication but they continue to be well cited years after their original release Recently Professor Eicke R Weber of the University of California at Berkeley joined as a co editor of the series Professor Weber a well known expert in the field of semiconductor materials will further contribute to continuing the series tradition of publishing timely highly relevant and long impacting volumes Some of the recent volumes such as Hydrogen in Semiconductors Imperfections in III V Materials Epitaxial Microstructures High Speed Heterostructure Devices Oxygen in Silicon and others promise that this tradition will be maintained and even expanded *Molecular Beam Epitaxy and Heterostructures* L.L. Chang, K. Ploog, 2012-12-06

The NATO Advanced Study Institute on Molecular Beam Epitaxy MBE and Heterostructures was held at the Ettore Majorana Center for Scientific Culture Erice Italy on March 7 19 1983 the second course of the International School of Solid State Device Research This volume contains the lectures presented at the Institute Throughout the history of semiconductor development the coupling between processing techniques and device structures for both scientific investigations and

technological applications has time and again been demonstrated Newly conceived ideas usually demand the ultimate in existing techniques which often leads to process innovations The emergence of a process on the other hand invariably creates opportunities for device improvement and invention This intimate relationship between the two has most recently been witnessed in MBE and heterostructures the subject of this Institute This volume is divided into several sections Chapter 1 serves as an introduction by providing a perspective of the subject This is followed by two sections each containing four chapters Chapters 2-5 addressing the principles of the MBE process and Chapters 6-9 describing its use in the growth of a variety of semiconductors and heterostructures The next two sections Chapters 10-11 and Chapters 12-15 treat the theory and the electronic properties of the heterostructures respectively The focus is on energy quantization of the two dimensional electron system Chapters 16-17 are devoted to device structures including both field effect transistors and lasers and detectors

Metalorganic Vapor Phase Epitaxy (MOVPE) Stuart Irvine, Peter Capper, 2019-10-07 Systematically discusses the growth method material properties and applications for key semiconductor materials MOVPE is a chemical vapor deposition technique that produces single or polycrystalline thin films As one of the key epitaxial growth technologies it produces layers that form the basis of many optoelectronic components including mobile phone components GaAs semiconductor lasers and LEDs III-Vs nitrides optical communications oxides infrared detectors photovoltaics II-IV materials etc Featuring contributions by an international group of academics and industrialists this book looks at the fundamentals of MOVPE and the key areas of equipment safety precursor chemicals and growth monitoring It covers the most important materials from III-V and II-VI compounds to quantum dots and nanowires including sulfides and selenides and oxides ceramics Sections in every chapter of Metalorganic Vapor Phase Epitaxy MOVPE Growth Materials Properties and Applications cover the growth of the particular materials system the properties of the resultant material and its applications The book offers information on arsenides phosphides and antimonides nitrides lattice mismatched growth CdTe MCT mercury cadmium telluride ZnO and related materials equipment and safety and more It also offers a chapter that looks at the future of the technique Covers in order the growth method material properties and applications for each material Includes chapters on the fundamentals of MOVPE and the key areas of equipment safety precursor chemicals and growth monitoring Looks at important materials such as III-V and II-VI compounds quantum dots and nanowires Provides topical and wide ranging coverage from well known authors in the field Part of the Materials for Electronic and Optoelectronic Applications series Metalorganic Vapor Phase Epitaxy MOVPE Growth Materials Properties and Applications is an excellent book for graduate students researchers in academia and industry as well as specialist courses at undergraduate postgraduate level in the area of epitaxial growth MOVPE MOCVD MBE

Heteroepitaxy of Semiconductors John E. Ayers, 2018-10-08 Heteroepitaxy has evolved rapidly in recent years With each new wave of material substrate combinations our understanding of how to control crystal growth becomes more refined Most books on the subject focus on a specific material or material family narrowly explaining the

processes and techniques appropriate for each. Surveying the principles common to all types of semiconductor materials Heteroepitaxy of Semiconductors Theory Growth and Characterization is the first comprehensive fundamental introduction to the field. This book reflects our current understanding of nucleation growth modes relaxation of strained layers and dislocation dynamics without emphasizing any particular material. Following an overview of the properties of semiconductors the author introduces the important heteroepitaxial growth methods and provides a survey of semiconductor crystal surfaces their structures and nucleation. With this foundation the book provides in depth descriptions of mismatched heteroepitaxy and lattice strain relaxation various characterization tools used to monitor and evaluate the growth process and finally defect engineering approaches. Numerous examples highlight the concepts while extensive micrographs schematics of experimental setups and graphs illustrate the discussion. Serving as a solid starting point for this rapidly evolving area Heteroepitaxy of Semiconductors Theory Growth and Characterization makes the principles of heteroepitaxy easily accessible to anyone preparing to enter the field.

Low Dimensional Structures Prepared by Epitaxial Growth or Regrowth on Patterned Substrates K. Eberl, Pierre M. Petroff, Piet Demeester, 2012-12-06 Proceedings of the NATO Advanced Research Workshop Ringberg in Rottach Egern Germany February 20-24 1995

Materials for Optoelectronics Maurice Quillec, 1996-01-31 Optoelectronics ranks one of the highest increasing rates among the different industrial branches. This activity is closely related to devices which are themselves extremely dependent on materials. Indeed the history of optoelectronic devices has been following closely that of the materials. KLUWER Academic Publishers has thus rightly identified Materials for Optoelectronics as a good opportunity for a book in the series entitled Electronic Materials Science and Technology. Although a sound background in solid state physics is recommended the authors have confined their contribution to a graduate student level and tried to define any concept they use to render the book as a whole as self consistent as possible. In the first section the basic aspects are developed. Here three chapters consider semiconductor materials for optoelectronics under various aspects. Prof G E Stillman begins with an introduction to the field from the point of view of the optoelectronic market. Then he describes how III-V materials especially the Multi Quantum Structures meet the requirements of optoelectronic functions including the support of microelectronics for optoelectronic integrated circuits. In chapter 2 Prof

Epitaxy Marian A. Herman, W. Richter, Helmut Sitter, 2004-01-22 In a uniform and comprehensive manner the authors describe all the important aspects of the epitaxial growth processes of solid films on crystalline substrates e.g. processes in which atoms of the growing film mimic the arrangement of the atoms of the substrate. Emphasis is put on sufficiently fundamental and unequivocal presentation of the subject in the form of an easy to read review. A large part of this book focuses on the problems of heteroepitaxy. The most important epitaxial growth techniques which are currently widely used in basic research as well as in manufacturing processes of devices are presented and discussed in detail.

Lateral Alignment of Epitaxial Quantum Dots Oliver G. Schmidt, 2007-08-17 This book describes the full range of possible strategies for laterally aligning self

assembled quantum dots on a substrate surface beginning with pure self ordering mechanisms and culminating with forced alignment by lithographic positioning The text addresses both short and long range ordering phenomena and introduces future high integration of single quantum dot devices on a single chip Contributions by well known experts ensure that all relevant quantum dot heterostructures are elucidated from diverse perspectives Epitaxial Growth of SiC via CVD for Power Electronics and Quantum Applications Misagh Ghezellou, 2025-02-10 Silicon Carbide SiC is a wide bandgap semiconductor with exceptional properties that position it as a leading material for next generation power electronics and quantum technologies Its high breakdown field strength enables it to withstand much higher voltages than conventional silicon leading to more compact and efficient devices Its high thermal conductivity allows for efficient heat dissipation crucial for high power applications Furthermore SiC exhibits excellent electron mobility facilitating faster switching speeds and reduced energy losses SiC exists in over 250 polytypes each with unique characteristics Among these the 4H SiC polytype has emerged as the most promising for advanced applications Its superior properties have already led to its adoption in various applications including electric vehicles renewable energy systems and industrial motor drives SiC hosts both intrinsic and extrinsic quantum emitters or single photon sources with the possibility of operating at room temperature and being both optically and electronically addressable Moreover the ability to grow isotopically purified 4H SiC crystals has opened exciting avenues for quantum technologies Precise control of the isotopic composition enables manipulation of nuclear spin and optical properties supporting applications like quantum computing secure communication networks and highly sensitive sensors Despite the significant advancements in SiC technology in recent decades its full potential is yet to be realized particularly in the realm of ultra high power devices This requires overcoming several challenges in the epitaxial growth process The principal bottleneck lies in growing ultra thick epitaxial layers which are crucial for high voltage applications Achieving uniform quality and low defect density in thick epitaxial layers is a demanding task Another challenge is achieving low doping concentrations with precise control to fine tune the electrical properties of SiC devices The replication of basal plane dislocation BPD from the substrate is well controlled however complete elimination and prevention of new BPDs formation is critical to ensure reliable device operation Minimizing interfacial stress is also essential as stress at the interface between the thick epitaxial layer and the substrate can lead to defect formation and device performance degradation Furthermore ensuring relatively longer minority carrier lifetimes is critical to minimize forward losses in bipolar power devices This also includes a reduction in residual impurities as they can significantly impact carrier lifetime and hence device performance and reliability For quantum applications further suppression of impurities in epitaxial layers is crucial to improve coherence time Additionally wafer scale production of photonic quantum chips requires the transfer of epitaxial layers onto insulators however a wafer scale approach to prepare SiC on insulators is still missing This thesis addresses these challenges by advancing the understanding of the Chemical Vapor Deposition CVD epitaxial growth process of 4H SiC The

focus has been to understand the influence of key growth parameters and different growth chemistries to achieve superior quality material and unlock the full potential of SiC for advanced device applications in both power electronics and quantum applications. One crucial aspect explored in this thesis is the influence of boron (B) on minority carrier lifetime in as-grown epitaxial layers of 4H SiC. Paper 1: The minority carrier lifetime is a critical parameter in bipolar devices as it determines how long excess charge carriers (electrons or holes) can persist before recombination. This research reveals that beyond the well-known Z1/2 center, the shallow acceptor level of B and its associated deep D center level also limit carrier lifetime. Through employing a novel approach of comparing transient spectroscopy results and temperature-dependent time-resolved photoluminescence decays at different wavelengths, we found that B-related defects significantly affect lifetime through carrier trapping, de-trapping, and recombination. By optimizing the growth process, an exceptional 2.5 s minority carrier lifetime is achieved in a mere 25 nm thick low-doped n-type epitaxial layer. This thesis further examines the impact of different hydrocarbons on the surface morphology and underlying mechanisms of the 4H SiC epitaxy. This comparative analysis serves to further confirm the fundamental differences between the two primary carbon sources (methane and propane) and their distinct effects on the characteristics of the epitaxial layers. By meticulously analyzing the effect of various carbon sources, the research identifies characteristic surface defects associated with each hydrocarbon and explores their impact on surface quality. Paper 2: Impurity incorporation and minority carrier lifetime. Paper 3: Additionally, the formation of different deep levels linked to the precursors is also examined. The findings demonstrate that employing methane as the carbon source, in contrast to the commonly used propane, yields remarkably smooth surfaces, albeit with short-step bunching (SSB) as its characteristic morphological defect. Propane, on the other hand, leads to the formation of inclined line-like defects (ILLs), step bunching, and comparatively rougher surfaces. Furthermore, methane enables the achievement of extremely low intentional n-type doping. Moreover, the use of methane leads to a longer minority carrier lifetime across different C/Si ratios. In comparison, utilizing propane as the carbon source leads to higher incorporation of D centers and the formation of additional Cl-related deep levels. Interestingly, the latter observation may be of relevance for quantum applications, as Cl-related defects can serve as potential single-photon emitters in 4H SiC epitaxial layers. In Paper 4, the findings are applied to develop a growth process for thick epitaxial layers. This process requires careful consideration of various aspects related to both the growth dynamics and the layer quality. The principal objective is to optimize the growth rate while simultaneously maintaining excellent crystal quality and maximizing minority carrier lifetime. To achieve this, the evolution of these properties throughout the growth process is meticulously studied to identify limitations and potential avenues for further optimization. Additionally, it is observed that the surface roughness and some surface defects can be controlled by adding HCl during the epitaxial growth process, however, at the expense of reduced minority carrier lifetime. Overall, methane demonstrated significant promise for enabling the growth of extremely thick 4H SiC epitaxial layers with improved properties. Building on prior

insights this research further delves into the challenge of achieving high quality epitaxial growth for ultra thick 280 nm 4H SiC layers essential for ultra high power devices exceeding 30 kV Paper 5 By adjusting the growth parameters such as growth rate temperature and carbon source a suitable growth process was designed This process enables the growth of an extremely thick epitaxial layer structure with a voltage handling capability of over 35 kV The layer exhibits minimized stress and a zero BPD replication into the epitaxial layer In recent years a novel approach called remote epitaxy has emerged to obtain free standing semiconductor layers with varying thicknesses over 2D materials Remote epitaxy can potentially advance the eld of photonic chips on wafer scale SiC on insulators via an easier layer transfer process Furthermore remote epitaxy offers significant advantages including the potential for substantial cost reduction in SiC wafer production through substrate reusability Paper 6 investigates the feasibility of adapting the remote epitaxial growth process for the pseudo homoepitaxial growth of 4H SiC Recognizing the fundamental differences between III V graphene and SiC graphene material systems this research explores the unique challenges associated with the remote epitaxial growth of SiC Key challenges addressed include the epitaxial growth of graphene on off axis SiC substrates which are preferred for straightforward polytype replication Furthermore the preservation of graphene is investigated in the extreme environment of SiC epitaxial growth Finally the possibility of growing high quality SiC on top of a graphene layer is also explored

Multiscale Modeling in Epitaxial Growth Axel Voigt, 2006-03-30 Epitaxy is relevant for thin film growth and is a very active area of theoretical research since several years Recently powerful numerical techniques have been used to link atomistic effects at the film's surface to its macroscopic morphology This book also serves as an introduction into this highly active interdisciplinary field of research for applied mathematicians theoretical physicists and computational materials scientists

Semiconductor-On-Insulator Materials for Nanoelectronics Applications Alexei Nazarov, J.-P. Colinge, Francis Balestra, Jean-Pierre Raskin, Francisco Gamiz, V.S. Lysenko, 2011-03-03 Semiconductor On Insulator Materials for NanoElectronics Applications is devoted to the fast evolving field of modern nanoelectronics and more particularly to the physics and technology of nanoelectronic devices built on semiconductor on insulator SemOI systems The book contains the achievements in this field from leading companies and universities in Europe USA Brazil and Russia It is articulated around four main topics 1 New semiconductor on insulator materials 2 Physics of modern SemOI devices 3 Advanced characterization of SemOI devices 4 Sensors and MEMS on SOI Semiconductor On Insulator Materials for NanoElectronics Applications is useful not only to specialists in nano and microelectronics but also to students and to the wider audience of readers who are interested in new directions in modern electronics and optoelectronics

Molecular Beam Epitaxy Mohamed Henini, 2018-06-27 Molecular Beam Epitaxy MBE From Research to Mass Production Second Edition provides a comprehensive overview of the latest MBE research and applications in epitaxial growth along with a detailed discussion and how to on processing molecular or atomic beams that occur on the surface of a heated crystalline substrate in a vacuum The techniques addressed in the book can be deployed

wherever precise thin film devices with enhanced and unique properties for computing optics or photonics are required It includes new semiconductor materials new device structures that are commercially available and many that are at the advanced research stage This second edition covers the advances made by MBE both in research and in the mass production of electronic and optoelectronic devices Enhancements include new chapters on MBE growth of 2D materials Si Ge materials AlN and GaN materials and hybrid ferromagnet and semiconductor structures Condenses the fundamental science of MBE into a modern reference speeding up literature review Discusses new materials novel applications and new device structures grounding current commercial applications with modern understanding in industry and research Includes coverage of MBE as mass production epitaxial technology and how it enhances processing efficiency and throughput for the semiconductor industry and nanostructured semiconductor materials research community

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