Molecular Beam Epitaxy

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molecular beam epitaxy describes a technique in wide spread use for the production of high quality semiconductor devices it discusses the most important aspects of the mbe apparatus the physics and chemistry of the crystallization of various materials and device structures and the characterization methods that relate the structural parameters of the grown or growing film or structure to the technologically relevant procedure in this second edition two new fields have been added crystallization of as grown low dimensional heterostructures mainly quantum wires and quantum dots and in growth control of the mbe crystallization process of strained layer structures out of date material has been removed

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 AIN 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

IN THIS VOLUME THE EDITOR AND CONTRIBUTORS DESCRIBE THE USE OF MOLECULAR BEAM EPITAXY MBE FOR A RANGE OF KEY MATERIALS SYSTEMS THAT ARE OF INTEREST FOR BOTH TECHNOLOGICAL AND FUNDAMENTAL REASONS PRIOR BOOKS ON MBE HAVE PROVIDED AN INTRODUCTION TO THE BASIC CONCEPTS AND TECHNIQUES OF MBE AND EMPHASIZE GROWTH AND CHARACTERIZATION OF GAAS BASED STRUCTURES THE AIM IN THIS BOOK IS SOMEWHAT DIFFERENT IT IS TO DEMONSTRATE THE VERSATILITY OF THE TECHNIQUE BY SHOWING HOW IT CAN BE UTILIZED TO PREPARE AND EXPLORE A RANGE OF DISTINCT AND DIVERSE MATERIALS FOR EACH OF THESE MATERIALS SYSTEMS MBE HAS PLAYED A KEY ROLE BOTH IN THEIR DEVELOPMENT AND APPLICATION TO DEVICES

THE BOOK IS A HISTORY OF MOLECULAR BEAM EPITAXY MBE AS APPLIED TO THE GROWTH OF SEMICONDUCTOR THIN FILMS NOTE THAT IT DOES NOT COVER THE SUBJECT OF METAL THIN FILMS IT BEGINS BY EXAMINING THE ORIGINS OF MBE FIRST OF ALL LOOKING AT THE NATURE OF MOLECULAR BEAMS AND CONSIDERING THEIR APPLICATION TO FUNDAMENTAL PHYSICS TO THE DEVELOPMENT OF NUCLEAR MAGNETIC RESONANCE AND TO THE INVENTION OF THE MICROWAVE MASER IT SHOWS HOW MOLECULAR BEAMS OF SILANE SiH_4 WERE USED TO STUDY THE NUCLEATION OF SILICON FILMS ON A SILICON SUBSTRATE AND HOW SUCH STUDIES WERE EXTENDED TO COMPOUND SEMICONDUCTORS SUCH AS GAAS FROM SUCH SURFACE STUDIES IN ULTRA HIGH VACUUM THE TECHNIQUE DEVELOPED INTO A METHOD OF GROWING HIGH QUALITY SINGLE CRYSTAL FILMS OF A WIDE RANGE OF SEMICONDUCTORS COMPARING THIS WITH EARLIER EVAPORATION METHODS OF DEPOSITION AND WITH OTHER EPITAXIAL DEPOSITION METHODS SUCH AS LIQUID PHASE AND VAPOUR PHASE EPITAXY LPE AND VPE THE TEXT DESCRIBES THE DEVELOPMENT OF MBE MACHINES FROM THE EARLY ? HOME MADE? VARIETY TO THAT OF COMMERCIAL EQUIPMENT AND SHOW HOW MBE WAS GRADUALLY REFINED TO PRODUCE HIGH QUALITY FILMS WITH ATOMIC DIMENSIONS THIS WAS MUCH AIDED BY THE USE OF VARIOUS IN SITU SURFACE ANALYSIS TECHNIQUES SUCH AS REFLECTION HIGH ENERGY ELECTRON DIFFRACTION RHEED AND MASS SPECTROMETRY A FEATURE UNIQUE TO MBE IT LOOKS AT VARIOUS MODIFIED VERSIONS OF THE BASIC MBE PROCESS THEN PROCEED TO DESCRIBE THEIR APPLICATION TO THE GROWTH OF SO CALLED ? LOW DIMENSIONAL STRUCTURES? LDS BASED ON ULTRA THIN HETEROSTRUCTURE FILMS WITH THICKNESS OF ORDER A FEW MOLECULAR MONOLAYERS FURTHER CHAPTERS COVER THE GROWTH OF A WIDE RANGE OF DIFFERENT COMPOUNDS AND DESCRIBE THEIR APPLICATION TO FUNDAMENTAL PHYSICS AND TO THE FABRICATION OF ELECTRONIC AND OPTO ELECTRONIC DEVICES THE AUTHORS STUDY THE HISTORICAL DEVELOPMENT OF ALL THESE ASPECTS AND EMPHASISE BOTH THE OFTEN UNEXPECTED MANNER OF THEIR DISCOVERY AND DEVELOPMENT AND THE UNIQUE FEATURES WHICH MBE BRINGS TO THE GROWTH OF EXTREMELY COMPLEX STRUCTURES WITH MONOLAYER ACCURACY

MOLECULAR BEAM EPITAXY INTRODUCES THE READER TO THE USE OF MOLECULAR BEAM EPITAXY MBE IN THE GENERATION OF III V AND IV VI COMPOUNDS AND ALLOYS AND DESCRIBES THE SEMICONDUCTOR AND INTEGRATED OPTICS REASONS FOR USING THE TECHNIQUE TOPICS COVERED INCLUDE SEMICONDUCTOR SUPERLATTICES BY MBE DESIGN CONSIDERATIONS FOR MBE SYSTEMS PERIODIC DOPING STRUCTURE IN GALLIUM ARSENIDE GAAS NONSTOICHIOMETRY AND CARRIER CONCENTRATION CONTROL IN MBE OF COMPOUND SEMICONDUCTORS AND MBE TECHNIQUES FOR IV VI OPTOELECTRONIC DEVICES THE USE OF MBE TO FABRICATE INTEGRATED OPTICAL DEVICES AND TO STUDY SEMICONDUCTOR SURFACE AND CRYSTAL PHYSICS IS ALSO CONSIDERED THIS BOOK IS COMPRISED OF EIGHT CHAPTERS AND OPENS WITH AN OVERVIEW OF MBE AS A CRYSTAL GROWTH TECHNIQUE THE DISCUSSION THEN TURNS TO THE DEPOSITION OF SEMICONDUCTOR SUPERLATTICES OF GAAS BY MBE IMPORTANT FACTORS THAT MUST BE CONSIDERED IN THE DESIGN OF A MBE SYSTEM SUCH AS FLUX UNIFORMITY CRUCIBLE VOLUME HEAT SHIELDING SOURCE BAFFLING AND SHUTTERS AND

control of stoichiometry deviation in mbe growth of compound semiconductors along with the effects of such deviation on the electronic properties of the grown films the following chapters focus on the use of mbe techniques for growth of iv vi optoelectronic devices for fabrication of integrated optical devices and for the study of semiconductor surface and crystal physics the final chapter examines a superlattice consisting of a periodic sequence of ultrathin p and n doped semiconductor layers possibly with intrinsic layers in between this monograph will be of interest to chemists physicists and crystallographers

this volume describes the development of molecular beam epitaxy from its origins in the 1960s through to the present day it begins with a short historical account of other methods of crystal growth both bulk and epitaxial to set the subject in context emphasising the wide range of semiconductor materials employed this is followed by an introduction to molecular beams and their use in the stern gerlach experiment and the development of the microwave maser source inconnue

in this volume the editor and contributors describe the use of molecular beam epitaxy mbe for a range of key materials systems that are of interest for both technological and fundamental reasons prior books on mbe have provided an introduction to the basic concepts and techniques of mbe and emphasize growth and characterization of gaas based structures the aim in this book is somewhat different it is to demonstrate the versatility of the technique by showing how it can be utilized to prepare and explore a range of distinct and diverse materials for each of these materials systems mbe has played a key role both in their development and application to devices

the technology of crystal growth has advanced enormously during the past two decades among these advances the development and refinement of molecular beam epitaxy mbe has been among the msot important crystals grown by mbe are more precisely controlled than those grown by any other method and today they form the basis for the most advanced device structures in solid state physics electronics and optoelectronics as an example figure 0 1 shows a vertical cavity surface emitting laser structure grown by mbe provides comprehensive treatment of the basic materials and surface science principles that apply to molecular beam epitaxy thorough enough to benefit molecular beam epitaxy researchers broad enough to benefit materials surface and device researchers referenes articles at the forefront of modern research as well as those of historical interest

this two volume work covers recent developments in the single crystal growth by molecular beam epitaxy of materials compatible with silicon their physical characterization and device application papers are included on surface physics and related vacuum synthesis techniques such as solid phase epitaxy and ion beam epitaxy a selection of contents volume i sige superlattices sige strained layer superlattices g abstreiter optical properties of strained gesi superlattices grown on 001 ge t p pearsall et al growth and characterization of sige atomic layer superlattices j m baribeau et al optical properties of perfect and imperfect sige superlattices k b wong et al confined phonons in stained short period 001 si ge superlattices w bacsa et al calculation of energies and raman intensities of confined phonons in sige strained layer superlattices j white et al rippled surface topography observed on silicon molecular beam epitaxial and vapour phase epitaxial layers a j pidduck et al the 698 mev optical band in mbe silicon n de mello et al silicon growth doping dopant incorporation kinetics and abrupt profiles during silicon molecular beam epitaxy j e sundgren et al influence of substrate orientation on surface segregation process in silicon mbe k nakagawa et al growth and

transport properties of SiMSb1 H Jorke H Kibbel Author Index Volume II In Situ Electron Microscope Studies of Lattice Mismatch Relaxation in GeXSi1 X Si Heterostructures R Hull et al Heterogeneous Nucleation Sources in Molecular Beam Epitaxy Grown GeXSi1 X Si Strained Layer Superlattices D D Perovic et al Silicon Growth Hydrogen Terminated Silicon Substrates for Low Temperature Molecular Beam Epitaxy P J Grunthaner et al Interaction of Structure with Kinetics in Si 001 Homoepitaxy S Clarke et al Surface Step Structure of a Lens Shaped Si 001 Vicinal Substrate K Sakamoto et al Photoluminescence Characterization of Molecular Beam Epitaxial Silicon E C Lightowlers et al Doping Boron Doping Using Compound Source T Tatsumi P Type Delta Doping in Silicon MBE N L Mattey et al Modulation Doped Superlattices with Delta Layers in Silicon H P Zeindell et al Steep Doping Profiles Obtained by Low Energy Implantation of Arsenic in Silicon MBE Layers N Djebbar et al Alternative Growth Methods Limited Reaction Processing Growth of Si Si1 XGeX for Heterojunction Bipolar Transistor Applications J L Hoyt et al High Gain SiGe Heterojunction Bipolar Transistors Grown by Rapid Thermal Chemical Vapor Deposition M L Green et al Epitaxial Growth of Single Crystalline Si1 XGeX on Si 100 by Ion Beam Sputter Deposition F Meyer et al Phosphorus Gas Doping in Gas Source Silicon MBE H Hirayama T Tatsumi Devices Narrow Band Gap Base Heterojunction Bipolar Transistors Using SiGe Alloys S S Iyer et al Silicon Based Millimeter Wave Integrated Circuits J F Luy Performance and Processing Line Integration of a Silicon Molecular Beam Epitaxy System A A van Gorkum et al Silicides Reflection High Energy Electron Diffraction Study of CoSi2 Si Multilayer Structures Q Ye at al Epitaxy of Metal Silicides H von Kanel et al Epitaxial Growth of ErSi2 on 111 Si D Loretto et al Other Material Systems Oxygen Doped and Nitrogen Doped Silicon Films Prepared by Molecular Beam Epitaxy M Tabe et al Properties of Diamond Structure SnGe Films Grown by Molecular Beam Epitaxy A Harwit et al Si MBE Prospects and Challenges Prospects and Challenges for Molecular Beam Epitaxy in Silicon Very Large Scale Integration W Eccleston Prospects and Challenges for SiGe Strained Layer Epitaxy T P Pearsall Author Index

This subject is divided into two volumes Volume I is on homoepitaxy with the necessary systems techniques and models for growth and dopant incorporation three chapters on homoepitaxy are followed by two chapters describing the different ways in which MBE may be applied to create insulator Si stackings which may be used for three dimensional circuits the two remaining chapters in Volume I are devoted to device applications the first three chapters of Volume II treat all aspects of heteroepitaxy with the exception of the epitaxial insulator Si structures already treated in Volume I

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 Re search 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 innova tions 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 describ ing its use in the growth of a variety of semiconductors and heteros tructures the next two sections chapters to II 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 detec tors

this subject is divided into two volumes volume i is on homoepitaxy with the necessary systems techniques and models for growth and dopant incorporation three chapters on homoepitaxy are followed by two chapters describing the different ways in which mbe may be applied to create insulator si stackings which may be used for three dimensional circuits the two remaining chapters in volume i are devoted to device applications the first three chapters of volume ii treat all aspects of heteroepitaxy with the exception of the epitaxial insulator si structures already treated in volume i

this multi contributor handbook discusses molecular beam epitaxy mbe an epitaxial deposition technique which involves laying down layers of materials with atomic thicknesses on to substrates it summarizes mbe research and application in epitaxial growth with close discussion and a how to on processing molecular or atomic beams that occur on a surface of a heated crystalline substrate in a vacuum mbe has expanded in importance over the past thirty years in terms of unique authors papers and conferences from a pure research domain into commercial applications prototype device structures and more at the advanced research stage mbe is important because it enables new device phenomena and facilitates the production of multiple layered structures with extremely fine dimensional and compositional control the techniques can be deployed wherever precise thin film devices with enhanced and unique properties for computing optics or photonics are required this book covers the advances made by mbe both in research and mass production of electronic and optoelectronic devices it includes new semiconductor materials new device structures which are commercially available and many more which are at the advanced research stage condenses 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 coverage of mbe as mass production epitaxial technology enhances processing efficiency and throughput for semiconductor industry and nanostructured semiconductor materials research community

chemical beam epitaxy cbe is a powerful growth technique which has come to prominence over the last ten years together with the longer established molecular beam epitaxy mbe and metal organic vapour phase epitaxy movpe cbe provides a capability for the epitaxial growth of semiconductor and other advanced materials with control at the atomic limit this the first book dedicated to cbe and closely related techniques comprises chapters by leading research workers in the field and provides a detailed overview of the state of the art in this area of semiconductor technology topics covered include equipment design and safety considerations design of chemical precursors surface chemistry and growth mechanisms materials and devices from arsenide phosphide antimonide silicon and ii vi compounds doping selected area epitaxy and etching the volume provides an introduction for those new to the field and a detailed summary for experienced researchers

the book is a history of molecular beam epitaxy mbe as applied to the growth of semiconductor thin films note that it does not cover the subject of metal thin films it begins by examining the origins of mbe first of all looking at the nature of molecular beams and considering their application to fundamental physics to the development of nuclear magnetic resonance and to the invention of the microwave maser it shows how molecular beams of silane sih4 were used to study the nucleation of silicon films on a silicon substrate and how such studies were extended to compound

semiconductors such as gaas from such surface studies in ultra high vacuum the technique developed into a method of growing high quality single crystal films of a wide range of semiconductors comparing this with earlier evaporation methods of deposition and with other epitaxial deposition methods such as liquid phase and vapour phase epitaxy lpe and vpe the text describes the development of mbe machines from the early home made variety to that of commercial equipment and show how mbe was gradually refined to produce high quality films with atomic dimensions this was much aided by the use of various in situ surface analysis techniques such as reflection high energy electron diffraction rheed and mass spectrometry a feature unique to mbe it looks at various modified versions of the basic mbe process then proceed to describe their application to the growth of so called low dimensional structures lds based on ultra thin heterostructure films with thickness of order a few molecular monolayers further chapters cover the growth of a wide range of different compounds and describe their application to fundamental physics and to the fabrication of electronic and opto electronic devices the authors study the historical development of all these aspects and emphasise both the often unexpected manner of their discovery and development and the unique features which mbe brings to the growth of extremely complex structures with monolayer accuracy

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