Molecular Beam Epitaxy

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

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.

The following blurb to be used for the AP Report and ATI only as both volumes will not appear together there.****Strained-layer superlattices have been developed as an important new form of semiconducting material with applications in integrated electro-optics and electronics. Edited by a pioneer in the field, Thomas Pearsall, this volume offers a comprehensive discussion of strained-layer superlattices and focuses on fabrication technology and applications of the material. This volume combines with Volume 32, Strained-Layer Superlattices: Physics, in this series to cover a broad spectrum of topics, including molecular beam epitaxy, quantum wells and superlattices, strain-effects in semiconductors, optical and electrical properties of semiconductors, and semiconductor devices.****The following previously approved blurb is to be used in all other direct mail and advertising as both volumes will be promoted together.****Strained-layer superlattices have been developed as an important new form of semiconducting material with applications in integrated electro-optics and electronics. Edited by a pioneer in the field, Thomas Pearsall, this two-volume survey offers a comprehensive discussion of the physics of strained-layer superlattices (Volume 32), as well as detailing fabrication technology and applications of the material (Volume 33). Although each volume is edited to stand alone, the two books combine to cover a broad spectrum of topics, including molecular beam epitaxy, quantum wells and superlattices, strain-effects in semiconductors, optical and electrical properties of semiconductors, and semiconductor devices.

Silicon Based Thin Film Solar Cells explains concepts related to technologies for silicon (Si) based photovoltaic applications. Topics in this book focus on ‘new concept’ solar cells. These kinds of cells can make photovoltaic power production an economically viable option in comparison to the bulk crystalline semiconductor technology industry. A transition from bulk crystalline Si solar cells toward thin-film technologies reduces usage of active material and introduces new concepts based on nanotechnologies. Despite its importance, the scientific development and understanding of new solar cells is not very advanced, and educational resources for specialized engineers and scientists are required. This textbook presents the fundamental scientific aspects of Si thin films growth technology, together with a clear understanding of the properties of the material and how this is employed in new generation photovoltaic solar cells. The textbook is a valuable resource for graduate students working on their theses, young researchers and all people approaching problems and fundamental aspects of advanced photovoltaic conversion.

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.

Science and art of crystal growth represent an interdisciplinary activity based on fundamental principles of physics, chemistry and crystallography. Crystal growth has contributed over the years essentially to a widening of knowledge in its basic disciplines and has penetrated practically into all fields of experimental natural sciences. It has acted, more over, in a steadily increasing manner as a link between science and technology as can be seen best, for example, from the achievements in modern microelectronics. The aim of the course "Crystal Growth in Science and Technology" being to stress the interdisciplinary character of the subject, selected fundamental principles are reviewed in the following contributions and cross links between basic and applied aspects are illustrated. It is a very well-known fact that the intensive development of crystal growth has led to a progressive narrowing of interests in highly specialized directions which is in particular harmful to young research scientists. The organizers of the course did sincerely hope that the program would help to broaden up the horizon of the participants. It was equally their wish to contribute within the traditional spirit of the school of crystallography in Erice to the promotion of mutual understanding, personal friendship and future collaboration between all those who were present at the school.

The book considers the main growth-related phenomena occurring during epitaxial growth, such as thermal etching, doping, segregation of the main elements and impurities, coexistence of several phases at the crystal surface and segregation-enhanced diffusion. It is complete with tables, graphs and figures, which allow fast determination of suitable growth parameters for practical applications.

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.

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.

This first-ever monograph on molecular beam epitaxy (MBE) gives a comprehensive presentation of recent developments in MBE, as applied to crystallization of thin films and device structures of different semiconductor materials. MBE is a high-vacuum technology characterized by relatively low growth temperature, ability to cease or initiate growth abruptly, smoothing of grown surfaces and interfaces on an atomic scale, and the unique facility for in situ analysis of the structural parameters of the growing film. The excellent exploitation parameters of such MBE-produced devices as quantum-well lasers, high electron mobility transistors, and superlattice avalanche photodiodes have caused this technology to be intensively developed. The main text of the book is divided into three parts. The first presents and discusses the more important problems concerning MBE equipment. The second discusses the physico-chemical aspects of the crystallization processes of different materials (mainly semiconductors) and device structures. The third part describes the characterization methods which link the physical properties of the grown film or structures with the technological parameters of the crystallization procedure. Latest achievements in the field are emphasized, such as solid source MBE, including silicon MBE, gas source MBE, especially metalorganic MBE, phase-locked epitaxy and atomic-layer epitaxy, photoassisted molecular layer epitaxy and migration enhanced epitaxy.

This book presents a distributed multiprocessor architecture that is faster, more versatile, and more reliable than traditional single-processor architectures. It also describes a simulation technique that provides a highly accurate means for building a prototype system in software. The system prototype is studied and analyzed using such DSP applications as digital filtering and fast Fourier transforms. The code is included as well, which allows others to build software prototypes for their own research systems. The design presented in Microprocessor-Based Parallel Architecture for Reliable Digital Signal Processing Systems introduces the concept of a dual-mode architecture that allows users a dynamic choice between either a conventional or fault-tolerant system as application requirements dictate. This volume is a "must have" for all professionals in digital signal processing, parallel and distributed computer architecture, and fault-tolerant computing.

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.

Covers both the fundamentals and the state-of-the-art technology used for MBE Written by expert researchers working on the frontlines of the field, this book covers fundamentals of Molecular Beam Epitaxy (MBE) technology and science, as well as state-of-the-art MBE technology for electronic and optoelectronic device applications. MBE applications to magnetic semiconductor materials are also included for future magnetic and spintronic device applications. Molecular Beam Epitaxy: Materials and Applications for Electronics and Optoelectronics is presented in five parts: Fundamentals of MBE; MBE technology for electronic devices application; MBE for optoelectronic devices; Magnetic semiconductors and spintronics devices; and Challenge of MBE to new materials and new researches. The book offers chapters covering the history of MBE; principles of MBE and fundamental mechanism of MBE growth; migration enhanced epitaxy and its application; quantum dot formation and selective area growth by MBE; MBE of III-nitride semiconductors for electronic devices; MBE for Tunnel-FETs; applications of III-V semiconductor quantum dots in optoelectronic devices; MBE of III-V and III-nitride heterostructures for optoelectronic devices with emission wavelengths from THz to ultraviolet; MBE of III-V semiconductors for mid-infrared photodetectors and solar cells; dilute magnetic semiconductor materials and ferromagnet/semiconductor heterostructures and their application to spintronic devices; applications of bismuth-containing III–V semiconductors in devices; MBE growth and device applications of Ga_2O_3; Heterovalent semiconductor structures and their device applications; and more. Includes chapters on the fundamentals of MBE Covers new challenging researches in MBE and new technologies Edited by two pioneers in the field of MBE with contributions from well-known MBE authors including three Al Cho MBE Award winners Part of the Materials for Electronic and Optoelectronic Applications series Molecular Beam Epitaxy: Materials and Applications for Electronics and Optoelectronics will appeal to graduate students, researchers in academia and industry, and others interested in the area of epitaxial growth.

Groundbreaking book that combines information on power electronics and optoelectronic applications of nitride semiconductors With contributions from a panel of international experts, Nitride Semiconductor Technology: Power Electronics and Optoelectronic Devices offers a state-of-the-art review of GaN-based technologies that covers the fields of both power electronics and optoelectronic devices. The authors present detailed explanations of the physical properties of materials and their growth methods. They also include information on GaN-based technology applications in high electron mobility transistors, vertical power devices, LEDs, laser diodes, and vertical-cavity surface-emitting lasers. Nitride Semiconductor Technology contains an in-depth examination of reliability issues with the materials and offers advice on integrating them with 2D materials for novel high-frequency and high-power devices. The book also contains a review of the most recent advances in the field. This important book: Presents an in-depth overview of properties, growth techniques, and applicability of nitride semiconductors Offers a one-stop resource that covers nitride semiconductor technology from materials to devices Reviews a widerange of nitride semiconductor applications in high-power and high-frequency devices Written for materials scientists, semiconductor physicists, semiconductor industry professionals, electrical engineers, and electrotechnical industry professionals, Nitride Semiconductor Technology: Power Electronics and Optoelectronic Devices combines the most recent information on power electronics and optoelectronic applications of nitride semiconductors.

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 book contains full account of the advances made in the dilute nitrides, providing an excellent starting point for workers entering the field. It gives the reader easier access and better evaluation of future trends, Conveying important results and current ideas. Includes a generous list of references at the end of each chapter, providing a useful reference to the III-V-N based semiconductors research community. The high speed lasers operating at wavelength of 1.3 ?m and 1.55 ?m are very important light sources in optical communications since the optical fiber used as a transport media of light has dispersion and attenuation minima, respectively, at these wavelengths. These long wavelengths are exclusively made of InP-based material InGaAsP/InP. However, there are several problems with this material system. Therefore, there has been considerable effort for many years to fabricate long wavelength laser structures on other substrates, especially GaAs. The manufacturing costs of GaAs-based components are lower and the processing techniques are well developed. In 1996 a novel quaternary material GaInAsN was proposed which could avoid several problems with the existing technology of long wavelength lasers. In this book, several leaders in the field of dilute nitrides will cover the growth and processing, experimental characterization, theoretical understanding, and device design and fabrication of this recently developed class of semiconductor alloys. They will review their current status of research and development. Dilute Nitrides (III-N-V) Semiconductors: Physics and Technology organises the most current available data, providing a ready source of information on a wide range of topics, making this book essential reading for all post graduate students, researchers and practitioners in the fields of Semiconductors and Optoelectronics Contains full account of the advances made in the dilute nitrides, providing an excellent starting point for workers entering the field Gives the reader easier access and better evaluation of future trends, conveying important results and current ideas Includes a generous list of references at the end of each chapter, providing a useful reference to the III-V-N based semiconductors research community

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

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 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.

The future development of electronics, optics, and, quite probably, quantum physics is being driven by advances in epitaxial materials. Band gap engineering, wafer bonding techniques, and epitaxial regrowth technology will push transistors far beyond the present speed barriers. Oxide growth within epitaxial layer structures and new advances in tunnel structures will push the development of the next generation of high-performance laser arrays and of efficient cascade laser designs. Perfection of the growth of semiconductor nitrides will move future electronics to higher powers and to suitability for extreme environments while revolutionizing lighting and display. Growth technologies to incorporate metallic particles and magnetic elements within high-quality semiconductors promise ultrafast electro-optical components for chemical and biological applications as well as electronically controlled magnetism for future memories and electrical/magnetic hybrid devices. Quantum dot materials will lead the field of signal electronics while hopefully providing a new proving and discovery ground for quantum physics. This paper dicusses the current progress in these areas.

One dimensional electronic materials are expected to be key components owing to their potential applications in nanoscale electronics, optics, energy storage, and biology. Besides, compound semiconductors have been greatly developed as epitaxial growth crystal materials. Molecular beam and metalorganic vapor phase epitaxy approaches are representative techniques achieving 0D–2D quantum well, wire, and dot semiconductor III-V heterostructures with precise structural accuracy with atomic resolution. Based on the background of those epitaxial techniques, high-quality, single-crystalline III-V heterostructures have been achieved. III-V Nanowires have been proposed for the next generation of nanoscale optical and electrical devices such as nanowire light emitting diodes, lasers, photovoltaics, and transistors. Key issues for the realization of those devices involve the superior mobility and optical properties of III-V materials (i.e., nitride-, phosphide-, and arsenide-related heterostructure systems). Further, the developed epitaxial growth technique enables electronic carrier control through the formation of quantum structures and precise doping, which can be introduced into the nanowire system. The growth can extend the functions of the material systems through the introduction of elements with large miscibility gap, or, alternatively, by the formation of hybrid heterostructures between semiconductors and another material systems. This book reviews recent progresses of such novel III-V semiconductor nanowires, covering a wide range of aspects from the epitaxial growth to the device applications. Prospects of such advanced 1D structures for nanoscience and nanotechnology are also discussed.

This book provides comprehensive coverage of the new wide-bandgap semiconductor gallium oxide (Ga_2O_3). Ga_2O_3 has been attracting much attention due to its excellent materials properties. It features an extremely large bandgap of greater than 4.5 eV and availability of large-size, high-quality native substrates produced from melt-grown bulk single crystals. Ga_2O_3 is thus a rising star among ultra-wide-bandgap semiconductors and represents a key emerging research field for the worldwide semiconductor community. Expert chapters cover physical properties, synthesis, and state-of-the-art applications, including materials properties, growth techniques of melt-grown bulk single crystals and epitaxial thin films, and many types of devices. The book is an essential resource for academic and industry readers who have an interest in, or plan to start, a new R&D project related to Ga_2O_3.

The first book to present a unified treatment of hybrid source MBE and metalorganic MBE. Since metalorganic MBE permits selective area growth, the latest information on its application to the INP/GaInAs(P) system is presented. This system has been highlighted because it is one of rising importance, vital to optical communications systems, and has great potential for future ultra-highspeed electronics. The use of such analytical methods as high resolution x-ray diffraction, secondary ion mass spectroscopy, several photoluminescence methods, and the use of active devices for materials evaluation is shown in detail.