

# Silicon-Molecular Beam Epitaxy

Volume I

Edited by

Erich Kasper, John C. Bean



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# Silicon Molecular Beam Epitaxy Volume I 1

**Anton Bayerstadler**



## **Silicon Molecular Beam Epitaxy Volume I 1:**

**Silicon-Molecular Beam Epitaxy** E. Kasper, 2018-05-04 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

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**Reinigung und Gasphasenepitaxie in einem Ultrahochvakuum-Mehrkammersystem für zukünftige CMOS-Technologien** Anton Bayerstadler, 2006-09-14 Die Arbeit beschäftigt sich mit der Reinigung und Gasphasenepitaxie in einem Ultrahochvakuum Mehrkammersystem UHV Mehrkammersystem für zukünftige CMOS Technologien Der Schwerpunkt der Arbeit liegt dabei in der Entwicklung von Prozessen für das Kontakt Engineering von Source und Drain S D für sub 100 nm MOSFETs Mögliche Anwendungen liegen in der Implementierung von erhöhten S D Kontakten zur Erniedrigung der Source Drain Anschlusswiderstände oder dem epitaktischen Auffüllen von S D Extension Gebieten zur Minimierung von Kurzkanaleffekten Im Rahmen dieser Arbeit wurde zum ersten Mal in einem Clustertool eine Wasserstoff Plasmareinigung zur in situ LT Reinigung von planaren oder vorstrukturierten Substraten mit UHV CVD Epitaxie kombiniert Die Verwendung eines SiH<sub>4</sub> GeH<sub>4</sub> Prekursorengemisches erlaubt es bei den typischen Prozessdrücken von 10<sup>-4</sup> mbar bis 10<sup>-2</sup> mbar auch ohne Chlorchemie selektive Abscheidung von Silizium und Silizium Germanium Legierungen zu gewährleisten Insgesamt lässt sich damit ein Gesamtprozess inklusive Vorreinigung und selektiver Abscheidung SEG bei Temperaturen T 800 °C für die Si UHV CVD und T 600 °C für die SiGe UHV CVD etablieren Die technologischen Rahmenbedingungen welche in der Entwicklung eines selektiven LT Epitaxieprozesses ohne chlorierte Prekursoren in Kombination mit einer in situ LT Reinigung in einem Clustertool gegeben sind wurden damit vollständig erfüllt Reinigung Es wurden grundlegende Untersuchungen von verschiedenen UHV kompatiblen Reinigungsverfahren die sich durch unterschiedliche Temperaturbereiche und die Reinigungseffizienz unterscheiden durchgeführt Ergebnisse aus Untersuchungen zur thermischen Desorption im UHV HT Reinigung konnten dabei auf die Wasserstoff Plasmareinigung LT Reinigung und die thermische Desorption in reaktiven Gasen LT Reinigung umgesetzt werden Das Hauptaugenmerk lag jeweils im Nachweis von Sauerstoff Kohlenstoff und Stickstoff Verunreinigungen

Es zeigt sich dass die thermische Desorption bei technologisch relevanten Temperaturen im UHV äquivalent zur thermischen Desorption in Inertgasumgebungen z.B. dem sog. H<sub>2</sub> bake ist. Die H<sub>2</sub> Plasmareinigung ist mit einer maximalen Prozesstemperatur von ca. 225 °C eine LT-Reinigung. Es konnte erstmals nachgewiesen werden, dass die Zersetzung des Wasserstoffplasmas auf Oxid durch die Sputterwirkung von Ar-Ionen initiiert wird. Durch Ionenbeschuss wird das Oxid geschädigt und die obersten Si-O-Bindungen werden aufgebrochen. Durch die H-Radikale erfolgt schließlich ein ganzflächiger Oxidabtrag. Gasphasenepitaxie-Untersuchungen zur Morphologie von SiGe-Schichten haben gezeigt, dass sich im Gegensatz zur thermischen Desorption bei 900 °C mit H<sub>2</sub> Plasmareinigung als Vorreinigung schon bei 500 °C mittels UHV-CVD glatte SiGe-Schichten herstellen lassen. Aufbauend auf den Ergebnissen zur ganzflächigen Epitaxie von Si und SiGe mittels UHV-CVD wurde die Selektivität bezüglich vorstrukturierter Oxid- und Nitridsubstrate untersucht. Die Inkubationszeit für das Poly-Wachstum auf Nitrid ist sehr viel geringer als für die Poly-Nukleation auf Oxid. Eine selektive Abscheidung von Si in Si-Fenstern von vorstrukturierten Nitridsubstraten ist für UHV-CVD bei 800 °C und thermischer Desorption als Vorreinigung daher nicht möglich. Weitere Untersuchungen haben gezeigt, dass die Inkubationszeit vom Silan- bzw. Germanpartialdruck abhängt. Zusätzlich wird das Nukleationsverhalten bei UHV-CVD und H<sub>2</sub> Plasmareinigung als Vorreinigung durch die Plasmaparameter z.B. der Plasmadauer bestimmt. Prozesstechnisch kommt es bei Abscheidung im massentransportabhängigen Temperaturbereich bei Si-UHV-CVD z.B. bei 800 °C unabhängig von der Vorreinigung zu bekannten Effekten wie dem chemischen Loading-Effekt und dem Facettenwachstum von Si(111) und Si(311)-Mesas. Beide Effekte sind prinzipiell unerwünscht. Zur elektrischen Charakterisierung der Kristallqualität von selektiv gewachsenen i-Si-Schichten wurden SEG-Mesen im Si-Fenster eines vorstrukturierten Oxidsubstrats gewachsen und zu einer n-p-Diode prozessiert. Die bestimmte Volumendefektdichte entspricht der Dichte von ganzflächig abgeschiedenen intrinsischen Siliziumschichten. Glatte SiGe-Schichten mit einer ausreichenden maximalen selektiven Schichtdicke von ca. 30 nm konnten schließlich mit SiGe-UHV-CVD bei 500 °C in Kombination mit der H<sub>2</sub> Plasmareinigung als Vorreinigung hergestellt werden. Damit steht ein UHV-kompatibler Prozess zur Herstellung von vertikal erweiterten Source-Drain-Gebieten in planaren MOSFETs zur Verfügung. LP-CVD ist für die Abscheidung selektiver SiGe-Schichten nicht geeignet, weshalb bei industriellen RP-CVD-Prozessen SEG nur mit chlorierten Prekursoren bzw. durch Beimischung von HCl als Zersetzungsgas funktioniert. Die Anwendung des Prozesses zur Herstellung eines epitaktischen Source-Drain-Anschlussgebietes eines MOSFETs der 90 nm-Technologie wurde ebenfalls versucht. Das Zersetzen des S-D-Extension erfolgt durch ein sequentielles H<sub>2</sub>-Plasma zersetzen des Oxids mit anschließendem Si-Zersetzen. Das Wiederauffüllen der freien Zersetzungsbereiche ist aufgrund der gezeigten Selektivität zum Spacer-Material möglich. Abstract: The dissertation deals with cleaning and gas phase epitaxy in an ultra high vacuum multi chamber system UHV cluster tool for future CMOS technologies. The emphasis of the work is the development and discussion of processes for the contact engineering of source and drain S/D for sub 100 nm MOSFETs. Appropriate applications focus on the implementation of elevated S/D contacts to

reduce S D contact resistances or an epitaxial refilling of S D extensions to minimize short channel effects In the context of this work for the first time a hydrogen plasma cleaning for the in situ LT cleaning of planar or pre structured substrates was combined with UHV CVD epitaxy in a cluster tool The use of a SiH<sub>4</sub> GeH<sub>4</sub> precursor gas mixture with typical process pressures of 10<sup>-4</sup> mbar to 10<sup>-2</sup> mbar ensures selective epitaxial growth of silicon and silicon germanium alloys even without chlorine chemistry As a conclusion one can establish a full process including pre cleaning and selective epitaxial growth SEG at temperatures T

*GeSi Strained Layers and Their Applications, A Reprint Volume* A. M. Stoneham, Suresh C. Jain, 1995 This volume presents key papers published in recent years dealing with silicon germanium strained layers and their applications Papers are presented in three groups dealing with growth and mechanical properties of strained layers electronic and optical properties and applications notably in novel diode and transistor designs and high performance optical detectors The collected papers will be an ideal source for new researchers who need quick and easy access to an authoritative selection of high quality papers An important aspect of the selection is the cross disciplinary nature of the papers presenting material from electronic engineers as well as from physicists and materials scientists An extensive bibliography gives details of a further 250 papers on the subject

*Growth of Crystals* Kh.S. Bagdasarov, E.L. Lube, 2012-12-06 Papers from the Sixth All Union Conference on Growth of Crystals comprise Volume 16 of this series The articles were chosen with a view to more fully elucidate the basic problems of crystal growth as reflected in domestic and foreign reviews and in original studies This volume consists of six parts Part I is devoted to mechanisms of crystal growth that are important for production of materials with given properties This part examines the temporal evolution of an inhomogeneous state and the array of semicellular and eutectic structures during microstructure formation the effect of impurity on the nonequilibrium vacancy concentration in a growing crystal and the role of soluble and insoluble impurities in the birth and growth of crystals Part II deals with the synthesis and electrophysical properties of novel solid electrolytes that are promising for practical use analysis and correlation of the large amount of data on growth by the Bridgman Stockbarger method of single crystals of fluorite phases far from stoichiometry and the hydrothermal chemistry and growth of hexagonal germanium dioxide

*Photorefractive Materials* G. Roosen, F. Agulló-López, O.F. Schirmer, 2013-10-22 The papers presented here reflect the core of the scientific activities that took place at the 1994 E MRS conference The contributions indicate that the field of photorefractive materials is advancing vigorously moving into new classes of compounds finding ways for the judicious tailoring of the microscopic properties of the materials based on increased insight into the features of defects or quantum wells and leading to new applications often made possible by the advances at the forefront of the materials The many papers presented by European participants emphasised the large amount of work being carried out here Stimulating contributions also came from the United States and Japan while papers presented by members from the industrial world indicate the importance of the field in this sector

Silicon Molecular Beam Epitaxy Erwin Kasper, E.H.C. Parker, 2012-12-02

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 Bacsá 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 Matthey 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      *Specimen Preparation for Transmission Electron Microscopy of Materials* ,1992

*Silicon-molecular beam epitaxy*, 1988      **Rapid Thermal and Integrated Processing**, 1991      *Growth of Crystals* E.I. Givargizov, S.A. Grinberg, 2012-12-06 This 18th volume of the series includes invited papers from the Seventh All Union Conference on the Growth of Crystals and the Symposium on Molecular Beam Epitaxy that were held in Moscow in November 1988 In choosing papers the Program Committee of the conference gave priority to studies in rapidly emerging areas of the growth and preparation of crystals and crystalline films The qualifications of the authors were also considered This ensured that the material was of a high standard and that the problems discussed covered a wide range These are the same criteria that we hope are typical of the volumes of this series The articles of the present volume are divided into four sections I Processes on the growth surface II Molecular beam epitaxy III Growth of crystals and films from solutions and fluxes N Growth of crystals from the melt Following tradition the series opens with three theoretical articles These examine problems applicable to various crystallization media instability of the crystallization front for a more general case than before and for a comparatively complicated system a solution adsorption and migration of atoms and molecules the analysis is made on a quantum chemical level and the kinetics of step and dislocation growth in the presence of surface anisotropy as well as impurity adsorption several earlier known methods are summarized The next two articles are experimental and methodical

**Synthesis and Processing of Ceramics--scientific Issues**, 1992      **Scientific and Technical Aerospace Reports**, 1986      *Shape-memory Materials and Phenomena--fundamental Aspects and Applications* Chain Tsuan Liu, 1992

**Proceedings of the 9th General Conference of the Condensed Matter Division of the European Physical Society** European Physical Society. Condensed Matter Division. General Conference, 1989      **Growth of Crystals**, 1992

Electrical, Optical, and Magnetic Properties of Organic Solid State Materials, 1992      Magnetic Surfaces, Thin Films, and Multilayers Stuart S. P. Parkin, 1992      **Preparation and Properties of Thin Films** King-Ning Tu, R. Rosenberg, 1982

**JJAP**, 2000

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