Crystal Growth Technology

HANS J. SCHEEL
SCHEEL CONSULTING, Groenstrasse, CH-3803 Beatenberg BE, Switzerland
hans.scheel@bluewin.ch

TSUGUO FUKUDA
Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai 980-8577, Japan
t-fukuda@tagen.tohoku.ac.jp

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CONTRIBUTORS

Abe, Takao
Shin-Etsu Handotai, Isobe R&D Center, 2-13-1 Isobe, Annaka-shi, Gunma-ken 379-01, Japan

Asahi, T.
Central R&D Laboratory, Japan Energy Corporation, 3-17-35 Niizo-Minami, Toda, Saitama 335-8502, Japan

Brandon, Simon
Department of Chemical Engineering, Tianjin University, Tianjin 300072, P.R China

Chani, Valery I.
Department of Materials Science and Engineering, McMaster University, 1280 Main Street West, Hamilton, Ontario, L85 4M1, Canada

Ciszek, T. F.
National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

Derby, Jeffrey J.
Department of Chemical Engineering and Materials Science, Army HPC Research Center & Minnesota Supercomputing Institute, University of Minnesota, Minneapolis, MN 55455-0132, USA

Falster, R.
MEMC Electronic Materials SpA, Viale Gherzi 31, 28100 Novara, Italy

Fukuda, Tsuguo
Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, 2-1-1 Katahiraa, Aoba-ku, Sendai 980 8577, Japan

Gektin, A. V.
Institute for Single Crystals, Lenin Av 60, 310001 Kharkov, Ukraine

Hauser, C. (Retired)
HCT Shaping Systems SA, 1033 Cheseaux, Switzerland

Hirose, Kikuji
Department of Precision Science and Technology, Department of Electrical Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita 565-0871, Osaka, Japan

Inagaki, Kohji
Dept of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Itsumi, Manabu
NTT Lifestyle & Environmental Technology Laboratories, 3-1 Morinosato Wakamiya, Atsugi-Shi, Kanagawa, 243-0198, Japan

Jurisch, M.
Freiberger Compound Materials GmbH, Am Junger Löwe Schacht, D-09599 Freiberg, Germany

Kainosho, K.
Central R&D Laboratory, Japan Energy Corporation, 3-17-35 Niizo-Minami, Toda, Saitama 335-8502, Japan

Kakimoto, Koichi
Institute of Advanced Material Study, Kyushu University, 6-1 Kasuga-Koen, Kasuga 816-8580, Japan

Kakiuchi, Hiroaki
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita 565-0871, Osaka, Japan

Kawase, Tomohiro
Sumitomo Electric Industries, Ltd., 1-1-1, Koya-kita, Itami, Hyogo 664-0016, Japan

Kohiro, K.
Central R&D Laboratory, Japan Energy Corporation, 3-17-35 Niizo-Minami, Toda, Saitama 335-8502, Japan

Lal, Krishnan
National Physical Laboratory, Dr K. S. Krishnan Road, New Delhi 110012, India

Lebeau, Michel
CERN, 1211 Geneva 23, Switzerland

Liu, Yongcai
Department of Chemical Engineering, Tianjin University, Tianjin 300072, P.R. China

Lomonova, E. E.
Laser Materials and Technology Research Center, General Physics Institute of the Russian Academy of Sciences, Moscow, Russia

Lytvynov, Leonid A.
Institute of Single Crystals, Lenin Av., 60, Kharkov, 61001, Ukraine

Mimura, Hidekazu
Department of Precision Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871

Miyazawa, Shintaro
Shinkosha Co. Ltd., 3-4-1 Kosugaya, Sakae-ku, Yokohama, Kanagawa 247-0007, Japan

Mori, Yusuke
Department of Electrical Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita 565-0871, Osaka, Japan

Mori, Yuzo
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita 565-0871, Osaka, Japan

Mutti, P.
MEMC Electronic Materials SpA, Via Nazionale 59, 39012 Merano, Italy

Nasch, P. M.
HCT Shaping Systems SA, Route de Genève 42, Cheseaux Sur-Lausanne CH-1033, Switzerland

Nishida, Yasuhiro
Sumitomo Electric Industries Ltd., 1-1-1, Koya-kita, Itami, Hyogo 664-0016, Japan

Noda, A.
Central R&D Laboratory, Japan Energy Corporation, 3-17-35 Niizo-Minami, Toda, Saitama 335-8502, Japan

Oda, O.
Central R&D Laboratory, Japan Energy Corporation, 3-17-35 Niizo-Minami, Toda, Saitama 335-8502, Japan

Osiko, V. V.
Laser Materials and Technology Research Center, General Physics Institute of the Russian Academy of Sciences, Vavilov str. 38, Moscow 119991, Russia

Polezhaev, V. I.
Institute for Problems in Mechanics, Russian Academy of Sciences, Prospect Vernadskogo 101, 117526 Moscow, Russia

Rudolph, Peter
Institute for Crystal Growth, Rudower Chaussee 6, D-12489 Berlin, Germany

Sano, Yasuhisa
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Sasaki, Takatomo
Department of Electrical Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita 565-0871, Osaka, Japan

Sato, K.
Central R&D Laboratory, Japan Energy Corporation, 3-17-35 Niizo-Minami, Toda, Saitama 335-8502, Japan

Scheel, Hans J.
SCHEEL CONSULTING, Groenstrasse, CH-3803 Beatenberg BE, Switzerland

Shimamura, Kiyoshi,
Kagami Memorial Laboratory for Materials Science and Technology, Waseda University, 2-8-26 Nishiwaseda, Shinjuku 169-0051, Japan

Sugiyama, Kazuhisa
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Tatsumi, M.
Sumitomo Electric Industries Ltd., 1-1-1, Koya-kita, Itami, Hyogo 664-0016, Japan

Terashima, Kazutaka
Silicon Melt Advanced Project, Shonan Institute of Technology, 1-1-1 Tsujido-Nishikaigan, Fujisawa, Kanagawa 251, Japan

Triboulet, R.
Laboratoire de Physique des Solides de Bellevue CNRS, 1, Place A. Briand, F-92195 Meudon Cedex, France

Virozub, Alexander
Department of Chemical Engineering, Tianjin University, Tianjin 300072, P.R. China

Voronkov, V. V.
MEMC Electronic Materials SpA, Via Nazionale 59, 39012 Merano, Italy

Yamamura, Kazuya
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Yamauchi, Kazuto
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Yasutake, Kiyoshi
Department of Material and Life Science, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Yeckel, Andrew
Department of Chemical Engineering and Materials Science, Army HPC Research Center & Minnesota Supercomputing Institute, University of Minnesota, Minneapolis, MN 55455-0132, USA

Yoshii, Kumayasu
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Yoshimura, Masashi
Department of Electrical Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita 565-0871, Osaka, Japan

Zaslavsky, B. G.
Institute for Single Crystals, Lenin Av 60, 310001 Kharkov, Ukraine

PREFACE

This volume deals with the technologies of crystal fabrication, of crystal machining, and of epilayer production and is the first book on industrial aspects of crystal production. Therefore, it will be of use to all scientists, engineers, professors and students who are active in these fields, or who want to study them. Highest-quality crystals and epitaxial layers (epilayers) form the basis for many industrial technological advances, including telecommunications, computer and electrical energy technology, and those technologies based on lasers and nonlinear-optical crystals. Furthermore, automobile electronics, audiovisual equipment, infrared night-vision and detectors for medicine (tomography) and large nuclear-physics experiments (for example in CERN) are all dependent on high-quality crystals and epilayers, are as novel technologies currently in development and planned for the future. Crystals and epilayers will gain special importance in energy saving and renewable energy. Industrial crystal and epilayer production development has been driven by the above technological advances and also by the needs of the military and a multibillion-dollar industry. From the nearly 20 000 tons of crystals produced annually, the largest fraction consists of the semiconductors silicon, gallium arsenide, indium phosphide, germanium, and cadmium telluride. Other large fractions are optical and scintillator crystals, and crystals for the watch and jewellery industries.

For most applications the crystals have to be machined, i.e. sliced, lapped, polished, etched, or surface-treated. These processes have to be better understood in order to improve yields, reduce the loss of valuable crystal, and improve the performance of machined crystals and wafers.

Despite its importance, the scientific development and understanding of crystal and epilayer fabrication is not very advanced, and the education of specialized engineers and scientists has not even started. The first reason for this is the multidisciplinarity of crystal growth and epitaxial technology: neither chemical and materials engineering departments on the preparative side, nor physics and electrical engineering on the application side feel responsible, or capable of taking care of crystal technologies. Other reasons for the lack of development and recognition are the complexity of the multi-parameter growth processes, the complex phase transformation from the the mobilized liquid or gaseous phase to the solid crystal, and the scaling problem with the required growth-interface control on the nm-scale within growth systems of m-scale.

An initial workshop, named ‘First International School on Crystal Growth Technology ISCGT-1’ took place between September 5–14, 1998 in Beatenberg, Switzerland, and ISCGT-2 was held between August 24–29, 2000 in Mount

Zao Resort, Japan with H. J. Scheel and T. Fukuda action as the co-chairmen. Extended lectures were given by leading specialists from industries and universities, and the majority of crystal-producing factories were represented. This book contains 29 selected review papers from ISCGT-1 and discusses scientific and technological problems of production and machining of industrial crystals for the first time. Thus, it is expected that this volume will serve all scientists and engineers involved in crystal and epilayer fabrication. Furthermore, it will be useful for the users of crystals, for teachers and graduate students in materials sciences, in electronic and other functional materials, chemical and metallurgical engineering, micro- and optoelectronics including nano-technology, mechanical engineering and precision-machining, microtechnology, and in solid-state sciences. Also, consultants and specialists from funding agencies may profit from reading this book, as will all those with an interest in crystals, epilayers, and their production, and those concerned with saving energy and in renewable energy.

In Section I, general aspects of crystal growth are reviewed: the present and future of crystal growth technology, thermodynamic fundamentals of phase transitions applied to crystal-growth processes, interface and faceting effects, striations, modeling of crystal growth from melts and from solutions, and structural characterization to develop the growth of large-diameter crystals, In Section II, the problems relating to silicon are discussed: structural and chemical characteristics of octahedral void defects, intrinsic point defects and reactions in silicon, heat and mass transfer in melts under magnetic fields, silicon for photovoltaics, and slicing and novel precision-machining methods for silicon. Section III treats problems of the growth of large, rather than perfect, crystals of the compound semiconductors GaAs, InP, and CdTe. Section IV discussed oxides for surface-acoustic-wave and nonlinear-optic applications and the growth of large halogenide scintillator crystals. Section V deals with crystal machining: crystal orientation, sawing, lapping, and polishing and also includes the novel technologies EEM and CVM. Finally, Section VI treats the control of epitaxial growth modes to achieve highest-performance optoelectronic devices, and a novel, fast deposition process for silicon from high-density plasmas is presented.

The editors would like to thank the contributors for their valuable reviews, the referees (especially D. Elwell), and the sponsors of ISCGT-1. Furthermore, the editors acknowledge the competent copy-proof reading of P. Capper, and the work from J. Cossham, L. James and L. Bird of John Wiley & Sons Ltd, the publishers: also for pleasant collaboration and their patience.

It is hoped that this book may contribute to the scientific development of crystal technologies, and that it is of assistance for the necessary education in this field.

HANS J. SCHEEL and TSUGUO FUKUDA

Part 1

General Aspects of Crystal Growth Technology