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Handbook of Wafer Bonding

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Handbook of Wafer Bonding

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Preface

One may ask if we need another book on wafer bonding. The answer is a clear yes. The research and development on wafer bonding has truly sped up in the last few years, motivated by the extended use of wafer bonding in new technology areas with a variety of materials. It is very desirable to summarize the recent advances in wafer bonding fundamentals, materials, technologies, and applications in a handbook format, rather than just focusing on scientific fundamentals and/or applications.

So far there have been several books and review articles on wafer bonding, such as

- Tong, Q.-Y. and Gösele, U. (1999) *Semiconductor Wafer Bonding: Science and Technology*, John Wiley & Sons, Inc.;
- Alexe, M. and Gösele, U. (eds) (2004) *Wafer Bonding: Applications and Technology*, Springer;
- Plößl, A. and Kräuter, G. (1999) Wafer direct bonding: tailoring adhesion between brittle materials. *Materials Science and Engineering*, **R25**, 1–88.

We do need an update. The change is mainly due to the fast pace of research and development in three-dimensional (3D) integration, temporary bonding, and microelectromechanical systems (MEMS) with new functional layers.

Formerly, wafer bonding was applied for manufacturing silicon-on-insulator wafers, for fabrication of sensors and actuators, and for various fluidic systems. Today, manufacturers of IC wafers have also learnt the terminologies related to wafer bonding. As Moore's law seems to come to an end, or at least to meet some resistance, memory and logic devices are being stacked in the third dimension to increase the density of transistors and improve performance and functionality. IC manufacturers work on larger wafers and produce wafers in huge quantities, so they have truly challenged lately the vendors of wafer bonding tools. Their interest in wafer stacking has resulted in increased alignment precision, tools for larger wafers, an increased focus on new materials, lower cost and higher throughput, etc.

Based on the tremendous progress in wafer bonding in recent years, we invited world experts to contribute chapters to this wafer bonding handbook, covering a variety of technologies and applications. The wafer bonding technologies are presented in Part One. We have grouped them into (i) adhesive and anodic bonding, (ii) direct wafer bonding, (iii) metal bonding, and (iv) hybrid metal/dielectric bonding. Several other possible ways of sorting the technologies are possible, but the sorting approach taken here distinguishes the materials, the approaches, and their possible applications. In Part Two, some key wafer bonding applications are summarized, that is, 3D integration, MEMS, and temporary bonding, to give readers a flavor for where the wafer bonding technologies are significantly applied.

This handbook focuses on wafer-level bonding technologies including chip-to-wafer bonding. However, some of the technologies can also apply to chip-to-chip bonding, probably with some modifications.

Peter Ramm
James Jian-Qiang Lu
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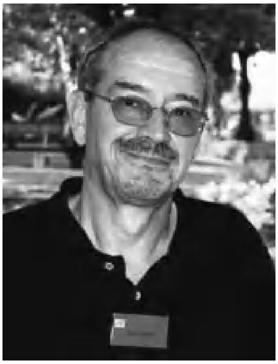
Obituary

In Honor of Ulrich Gösele (1949–2009)

The editors would like to honor Professor Ulrich Gösele for his great contributions to wafer bonding, and are proud to have his chapter on "Direct Wafer Bonding" – his last authored article – in this book.



Ulrich M. Gösele
25 January 1949–8 November 2009
The photo was taken in July 2009 (source: MPI Halle)

Professor Ulrich Gösele passed away on 8 November 2009. His death was unexpected and is a great loss for his family and his many friends and colleagues all over the world.

His research interests covered different areas and were of impact for the science and technology of wafer bonding, diffusion and defects in semiconductors, semiconductor nanoparticles and nanowires, complex oxide films on semiconductors, silicon photonics, photonic crystals, and self-organized nanoscale structures.

Ulrich M. Gösele was born on 25 January 1949, in southern Germany in the city of Stuttgart. He studied physics at the University of Stuttgart and at the Technical University of Berlin and obtained his diploma in 1973. His PhD work was carried out at the University of Stuttgart and at the Max Planck Institute for Metals Research. In 1975 he completed his PhD thesis and was afterwards a scientific staff member of the Max Planck Institute for Metals Research until 1984. During this time he was also a visiting scientist at the Atomic Energy Board, Pretoria (South Africa) in 1976–77 and at the IBM Watson Research Center, Yorktown Heights (NY, USA) in 1980–81. He finished his Habilitation in 1983 at the University of Stuttgart. From 1984 to 1985 he was with Siemens Corporation, Munich, before he accepted a professorship of materials science in 1985 at Duke University, Durham (NC, USA). In 1991 he was a visiting scientist at the NTT LSI Laboratories, Atsugi (Japan). From 1993 he was a Director and Scientific Member at the Max Planck Institute of Microstructure Physics, Halle (Germany). He was also an Adjunct Professor at the Martin-Luther University, Halle-Wittenberg (from 1994) and at Duke University (from 1998).

He started his career as a theoretician, working on topics like diffusion-controlled reaction kinetics, radiation damage in metals, and transfer of electron excitation energy in liquids and solids. In 1975 he became interested in point defects and diffusion in silicon. His first paper in this area was published together with H. Föll and B.O. Kolbesen on agglomerates of intrinsic point defects, the so-called swirl defects [1]. Especially, his time at the IBM Watson Research Center and the intensive cooperation with T.Y. Tan resulted in numerous publications about point defects and diffusion in silicon.

His theoretical education and an evolving deep understanding and appreciation of experimental work may be a reason that he started research in the field of wafer bonding in the late 1980s at Duke University. Especially, the support by Dr. Takao Abe from Shin-Etsu Handotai Co., Isobe (Japan) enabled such experiments. A first result was the construction and application of a micro-cleanroom setup in 1988 allowing the bonding of wafers in a particle-free ambient under environmental conditions [2]. The principle of the micro-cleanroom setup was the basis of one of his most important patents [3] and was transferred to Karl Süss GmbH, a manufacturer of semiconductor equipment in the city of Garching close to Munich (Germany) resulting in one of the first commercially available wafer bonding tools in the early 1990s.

The increasing number of new students in his group allowed him to study different aspects of wafer bonding. First experiments on the wafer bonding of silicon to glass or to sapphire were carried out. Furthermore, aspects of wafer thinning processes by applying etch stop layers (carbon ion-implantation, etc.) were investigated. One of the most remarkable studies at this time was the analysis of defects formed in the interface of bonded wafer pairs [4]. All these investigations resulted in a first model of (hydrophilic) silicon wafer bonding by him together with Stengl and Tan [5]. In the early 1990s his research was focused on the preparation of silicon-on-insulator wafers by wafer bonding techniques. Besides numerous publications, another important patent concerns hydrogen-induced layer transfer [6].

Gösele continued his research activities after joining the newly founded Max Planck Institute of Microstructure Physics in 1993. Based on the support given by the Max Planck Society additional activities were undertaken in the research of wafer bonding. One example was the installation of an ultrahigh-vacuum tool allowing the wafer bonding under ultrahigh-vacuum conditions. Combined with computer simulations, molecular dynamic models of interface processes during wafer bonding were developed. Furthermore, the installation of various pieces of equipment such as cleanroom facilities resulted in numerous other research activities in the field of wafer bonding. These activities included, for instance, wafer bonding via designed monolayers, the bonding of different III–V compounds, and the development of methods for low-temperature wafer bonding.

His enormous range of research activities resulted in the publication of more than 700 articles in refereed journals, and the granting of numerous patents. He was one of the organizers of the first Symposium on Semiconductor Wafer Bonding: Science, Technology, and Applications held during the Autumn Meeting of the Electrochemical Society in October 1991 in Phoenix, AZ, USA. In addition to C.E. Hunt, H. Baumgart, S.S. Iyer, and T. Abe, he was an organizer of the 3rd Symposium on Semiconductor Wafer Bonding held during the Spring Meeting of the Electrochemical Society in 1995 in Reno, NV, USA. He was coauthor and coeditor, respectively, of the famous monographs *Semiconductor Wafer Bonding: Science and Technology* [7] and *Wafer Bonding: Applications and Technology* [8].

Ulrich Gösele's work and personality were appreciated all over the world and recognized by many honors and awards. For instance, he obtained the Electronics Division Award of the Electrochemical Society (1999), he was on the Board of Directors of the Materials Research Society (USA), and was a Fellow of the American Physical Society and a Fellow of the Institute of Physics (UK).

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