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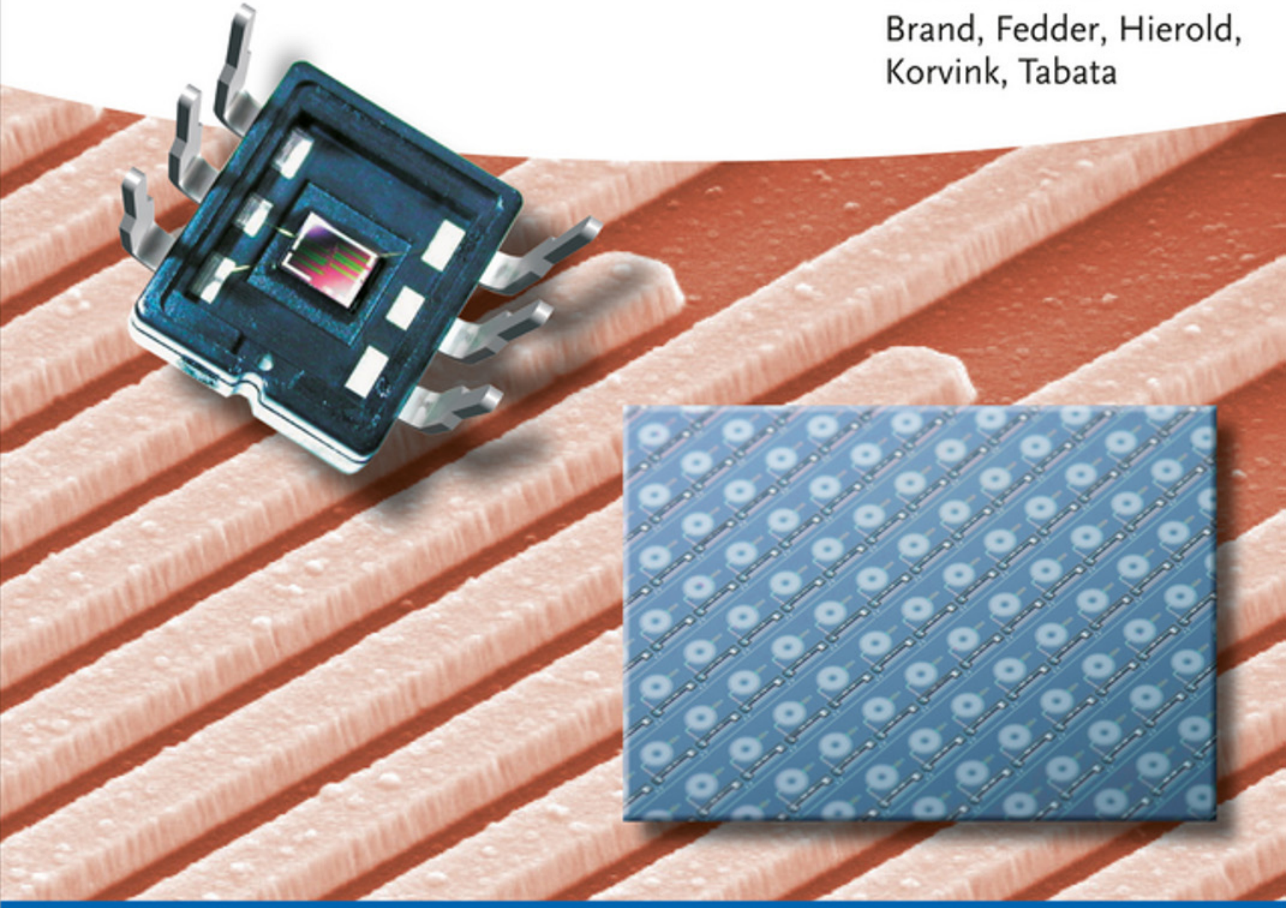

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Preface

Reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period of time. For commercial products, reliability is one of the most important features. Since reliability often dominates the device designs, its maximum performance may be traded off in return for reliability. Reliability evaluation and control, however, also in turn contributes to the improvement of device performance. At the present day, industrial products are distributed all over the world and used in a broad range of environments, making reliability evaluation of the products more important than ever.

MEMS devices, which are micromechanical devices fabricated using semiconductor fabrication technologies, are core products for future integrated systems for miniaturization and advanced functionalities. Due to their compactness and portability, MEMS devices are being employed even in mobile applications. The reliability of MEMS devices are thought to be high because of the size effect with the miniaturization of their dimensions and the precision of micro-fabrication, which is confirmed by numerous commercially available devices, such as pressure sensors, accelerometers, inkjet printer heads, and projection displays. Although their high reliability has been established by the continuous development effort of many researchers and engineers, numerous reliability issues and their related phenomena still remain, and considerable effort is being spent to find a generalized theory on MEMS reliability both in devices and materials. In the near future, the knowledge on the MEMS reliability will be organized into a whole and every engineer will be able to design MEMS device of high performance and high reliability through this knowledge.

The mechanical reliability of micromaterials for MEMS structures is the principle part of the MEMS reliability, being the entirely new aspect which was not as important by far in classic microelectronic devices. The development of evaluation methods, experimental procedures and analysis of results measured has been forcefully driven forward in the past decade, resulting in much significant new knowledge.

In this volume of Advanced Micro and Nanosystems, entitled “MEMS Reliability,” we aim to summarize and clarify latest cutting-edge knowledge on the mechanical reliability evaluation methods, their measurement results and use of measured data towards reliability and performance enhancement.

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The first part of the volume is devoted to mechanical property evaluation methods and their contribution to reliability assessment. Chapter one is of introductory nature, explaining to the reader the relationship between MEMS reliability and mechanical properties, and standardization of measurements, respectively. Chapters two, three and four cover the measurement methods, featuring nanoindentation, the bulge method and the uni-axial tensile test for determining fundamental mechanical properties of micromaterials. Reliability evaluation using device-like structures is described in chapter five, which is a useful method to evaluate the effects of fabrication methods and particular device design on the reliability properties.

The second part of the book gives a broad overview of MEMS devices which are highly reliable commercial products to demonstrate by example the importance of reliability assurance during product development. In chapters six, seven and eight the most successful MEMS-based mechanical sensors – pressure sensors, accelerometers, and angular rate sensors (vibrating gyros) – are described in detail. Particular emphasis is on the packaging and assembling, demonstrating the importance of these steps for device reliability. In chapters nine and ten, we turn to optical MEMS devices such as variable optical attenuators for fiber optical communication and two-dimensional optical scanners, both operated in torsional deformations. These optical devices operated in high frequency, mostly in resonance, are requested to have long lifetime in their operations because of their applications, such as telecommunication system, safety system, and display system.

Another aim of this volume is to introduce the reader to MEMS research and development in Japan. The Japanese industry possesses considerable MEMS device knowhow which has not yet been globally presented in appropriate detail. It is my hope that MEMS researchers and engineers in the world may profit and build upon these efforts and contributions.

Finally, I would like to thank all the contributors for their kind collaboration. They spent considerable time to write their chapters despite numerous other commitments and full schedules. In turn, I hope the readers may enjoy the book and gain further insights and understanding of MEMS reliability through this volume.

Toshiyuki Tsuchiya
Kyoto, June 2007

Foreword (by Series Editors)

We are proud to present the sixth volumes of *Advanced Micro & Nanosystems* (*AMN*), entitled "*Reliability of MEMS*".

In the past two decades, after the concept of MEMS was propounded, various kinds of micro-devices have been developed and commercialized. As symbolized by the term MEMS – the acronym of "Micro Electro Mechanical Systems" – the behavior of the mechanical structure plays an important role in the operation of these devices. A complete understanding of the relevant mechanical properties of thin films and the resultant mechanical behavior of microstructures is an utmost priority in progressing on the broader range of MEMS applications. This need has motivated research on methodologies to measure and evaluate the mechanical behavior and mechanical properties. Through these untiring efforts, many useful methodologies have been developed and relevant data has been accumulated. Reliability related material properties, such as strength and fatigue, have much more importance than ever before. The need for increased reliability studies is not only for the many MEMS products that are already commercialized but also for emerging MEMS applications operating in harsh environments such as high temperature, high pressure and high radiation. As one indication of this new research priority for reliability, in recent presentations at conferences in the MEMS field, reporting of device performance on long-term stability of behavior such as sensitivity, resonant frequency and noise figure is now much more prevalent than in the past. As represented by these facts, reliability of MEMS finally has become a performance property that should be assured through careful theoretical and experimental investigations.

However, there is still a long way to go to attain this goal. New findings, such as refined fatigue properties of single crystalline silicon, impose on the MEMS engineers to revise device design criteria. Though a large amount of data has been obtained from present devoted research efforts, comprehensive theory for describing the fatigue properties of MEMS devices and materials has not been established. The accumulated data and acquired knowledge should be shared by all the researches and engineers in MEMS to reach this goal.

In this volume, the mechanical reliability of MEMS, both from the material research and device development perspectives, is described to elucidate our knowledge about the reliability. The first part of this volume is devoted to material

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research on evaluation methods of mechanical properties and on the measured properties for MEMS devices. The second part describes recently developed MEMS devices and their reliability related properties. Through reading this volume, we hope all of you gain much more interest in the reliability of MEMS and share and extend the knowledge and help in the development of highly reliable MEMS devices. To accomplish such a goal, we are very glad to have the support of Prof. Dr. Toshiyuki Tsuchiya from Kyoto University, Japan, who is the editor of this volume.

Oliver Brand, Gary K. Fedder, Christofer Hierold, Jan G. Korvink, and Osamu Tabata
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Overview: Introduction to MEMS Reliability

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As the overview of the volume, "MEMS reliability", we describe the current understandings on mechanical reliabilities of microelectromechanical system (MEMS) to contribute the expansion of the device applications. "MEMS reliability" has wide meanings in exact sense, because MEMS is complex systems containing wide range of physical and chemical theories. Since the fabrication technologies in MEMS are mostly based on that in semiconductor devices, the electrical properties evaluation can be utilized, such as thermal cycle test and accelerated life time test in high temperature. However, in MEMS we should consider the mechanical properties. In their reliability properties, various mechanical tests need to be operated, such as shock survival and long term endurance in static and dynamic loadings. In addition, MEMS consists mainly of silicon that is a brittle material and has not been considered as a mechanical structural material. Engineers think MEMS requires subtle treatment in their operations. In this overview, we focused on the mechanical reliability in MEMS, especially in devices consisted of silicon structures.

Mechanical reliability in MEMS

Microelectromechanical Systems (MEMS) means an integrated device fabricated using (silicon) micromachining, which contains mechanical structures, transducers, and controlling and detecting circuit on single or multiple chips. The following definitions were provided by a research organization in the United States,

> "MEMS means batch-fabricated miniature devices that
> convert physical parameters to or from electrical signals
> and that depend on mechanical structures or parameters in
> important ways for their operation." [1]

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