

Preface

Throughout the relatively short history of microelectromechanical systems (MEMS), there have been numerous advances and inventions directly related to device fabrication. From humble beginnings using borrowed and modified IC fabrication techniques to current MEMS-specific tools such as deep reactive ion etching (DRIE) using inductively coupled plasma (ICP) sources, MEMS researchers have continually advanced and augmented the capabilities of wafer-based fabrication technologies. These advances have been instrumental in the demonstration of new devices and applications – Texas Instruments’ Digital Micromirror Device, the MIT microturbine, Analog Devices’ accelerometers – and even in the creation of new fields of research and development: bioMEMS, microfluidic devices, and optical MEMS.

To date, a number of books have been written about these new fabrication technologies and materials in general, but discussion of their relationship to MEMS design has been minimal. As a particularly diverse and multidisciplinary area of research, the field of MEMS offers a vastly different set of challenges relative to typical IC fabrication and design. Much effort is often focused on characterization runs and developing in-house recipes and specific processes to develop and manufacture MEMS structures, each time at the risk of wasting research efforts and “reinventing the wheel.” A wealth of knowledge exists in the MEMS community, but much of this expertise is most readily accessed by informal, nonmethodological means such as discussions with colleagues at conferences. The authors of this book have observed an unnecessarily steep learning curve for the development of common MEMS processes, and believe the time spent traversing this curve would be better spent brainstorming new ideas and uncovering new applications. This book was conceived and born of this belief.

A fundamental and comprehensive MEMS-focused reference book will be an important asset for current and future research scientists and engineers. It was decided early in the brainstorming sessions for this book to include *materials* as well as *processes* in the discussion, as MEMS utilizes a wide variety of each in common applications. We intend this book to provide the reader with the basics of MEMS materials and processes, but beyond this goal, we intend for it to give practical insight into the workings and standard procedures carried out in research labs

and production facilities on a daily basis. To this end, each chapter has an extended section with case studies, giving step-by-step examples and recipes prepared by experts in industry and academia. Particularly, the effect of processing conditions on material properties are covered where applicable, illustrating the interdependence and multidisciplinary nature of MEMS fabrication. The chapters are meant to be a springboard of sorts, providing basic information about each topic, with a large number of classic and contemporary literature references to provide in-depth knowledge. Ultimately, it is our goal to provide a useful design reference volume for the seasoned researcher and the MEMS newcomer alike. We hope this book consolidates important information for readers and thereby spurs the creation of many new devices and processes.

MEMS devices are essentially microsystems that have structures and empty space built together. The authors of this book view the materials and processes as the fundamental building blocks for making those structures and empty spaces. Keeping this in mind, the book is divided into two main sections: Chapters 2, 3, 4, 5, and 6 covering materials and Chapters 7, 8, 9, 10, 11, 12, and 13 covering fabrication techniques. These two general thrusts are bookended by Chapter 1, which discusses general MEMS design, and Chapter 14, which deals with MEMS process integration.

Chapter 1 provides a basic framework for the design of MEMS systems and processes, which we highly recommend reading before diving into the materials and process sections of the book. Chapter 2 presents an overview of the recipes and methods used in the deposition of semiconductor and dielectric thin-films, particularly those most commonly used in the fabrication of MEMS. The basics here include chemical vapor deposition, epitaxy, physical vapor deposition, atomic layer deposition, and spin-on techniques. Additive processes for depositing metal films are discussed in detail in Chapter 3, where particular attention is paid to thick metal deposition with significant coverage devoted to electrochemical and electroless plating processes that are often required for MEMS fabrication. The entirety of Chapter 4 is devoted to the use of polymeric materials for MEMS. Polymers, such as polydimethylsiloxane (PDMS), are important materials for a vast array of devices, as encapsulants for tactile sensors and as an integral enabling technology for the emerging field of bioMEMS. The piezoelectric films detailed in Chapter 5 are an important part of MEMS technology, serving as both sensor and actuator elements. The basic properties of these materials and the physics of operation are described in detail as well as practical deposition and fabrication methods. Chapter 6 focuses on the fabrication and integration of shape memory alloy (SMA) materials, which provide high-force and high-displacement actuator mechanisms for MEMS.

Chapter 7 begins the section on processing of materials for MEMS applications by covering the very important area of dry etching methods (including DRIE), particularly the influence of different parameters on the etch recipe development process. Complementing the coverage of dry etching, wet etching processes for MEMS micromachining are covered in Chapter 8 with a comprehensive recipe and reference list included in this chapter to aid in finding etch rates and etch selectivities for a wide range of materials from silicon to III–V compound semiconductors.

Chapter 9 describes the technology of lithography and related techniques, covering traditional contact lithography, projection and X-ray lithography, and more exotic direct-write and printing lithographic techniques. Doping processes typical in and for MEMS applications for electrical purposes and etching control are reviewed in Chapter 10, along with diagnostic techniques for these methods. Wafer bonding, a crucial fabrication technique for silicon MEMS encapsulation and structure fabrication, is covered in detail in Chapter 11 with emphasis placed on direct and intermediate layer bonding methods.

Chapter 12 discusses the still-evolving field of MEMS packaging, pointing out differences with current microcircuit packaging techniques; this chapter in particular highlights how MEMS devices present very unique challenges as compared to traditional microcircuits. Surface treatments for MEMS devices are discussed in Chapter 13, covering antistiction and planarization coatings, functionalization of surfaces for biological and optical applications, and chemical mechanical polishing (CMP). Chapter 14 concludes the book with a discussion of the integration of any number of the above processes and materials into a compatible and efficient process flow, referred to here as *process integration*. The final chapter also discusses economic and practical aspects of process integration, citing some commercially successful examples of MEMS devices.

This reference volume would not have been possible without the help of many of our colleagues in the MEMS fields, from both academia and industry. We would like to extend words of thanks and gratitude to Stephen (Steve) Senturia for providing the vision, support, and guidance to our team over the past five years in navigating the completion of the chapters and for reviewing them diligently, and to the Series Associate Editors Roger Howe and Antonio (Tony) Ricco for carefully reviewing the chapters, providing helpful comments, and for recommending prospective contributing authors. We thank Steven (Steve) Elliot, from Springer, for his patience in dealing with thirty-five unique and independent experts, and his persistence in contacting each of us in order to develop the logistics for the book publishing process. Last but not least, we acknowledge all thirty-five contributing authors, who selflessly gave time, expertise, effort, and creativity to make this book a one-of-a-kind contribution to the current and future MEMS community, including industry and government professionals, academic faculty and staff, and students.

The idea for this book was born at the *Transducers 2005 Conference* in Seoul, South Korea, and it was finalized and finished at *The Hilton Head 2010 Workshop* on Hilton Head Island, South Carolina. The five years of cooperative activity that culminated in this handbook prove that great ideas can become reality when colleagues work collaboratively to achieve a common goal. This message, which we have tried to convey by writing this book, is what the greater MEMS community is all about.

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