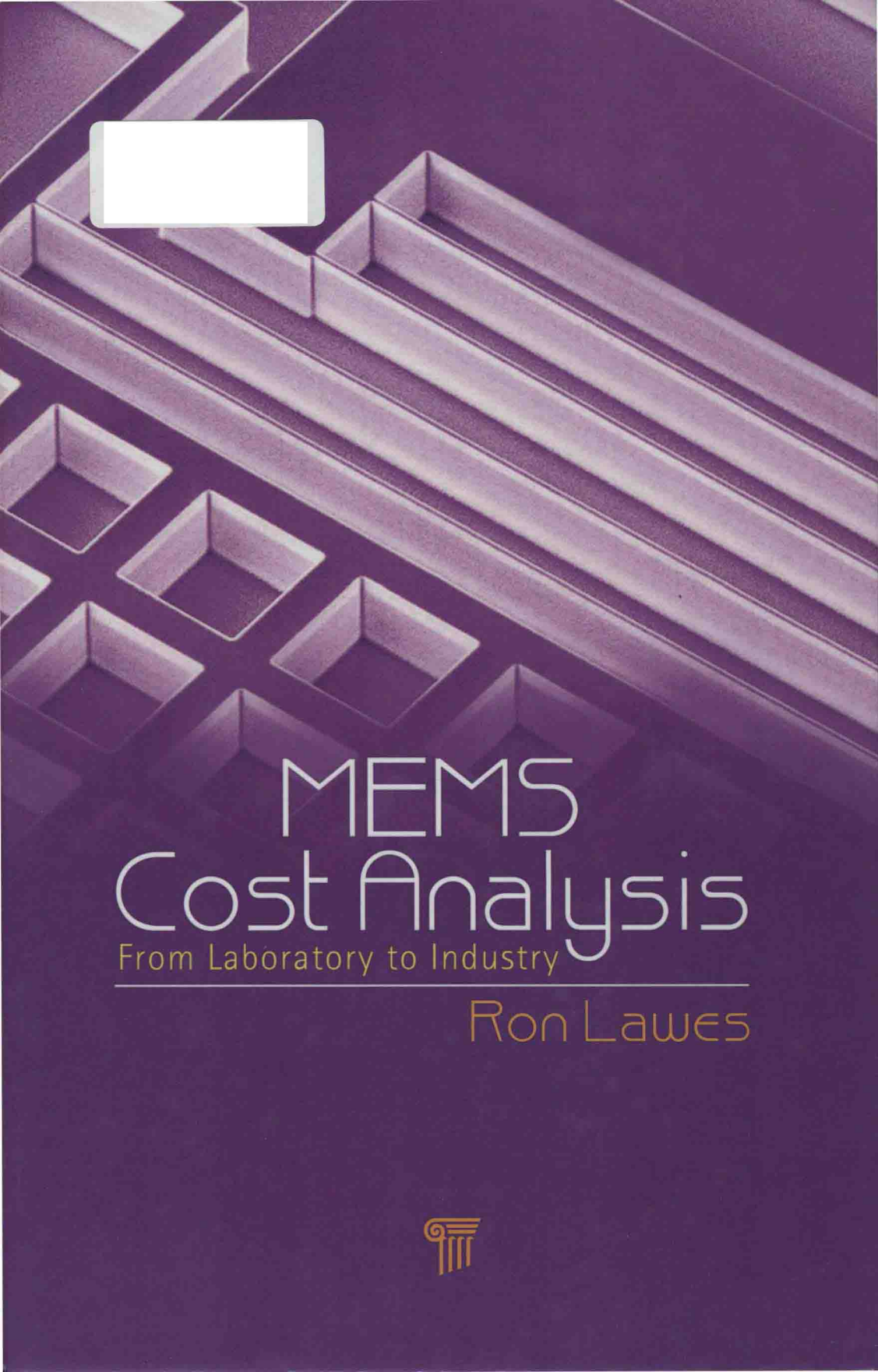

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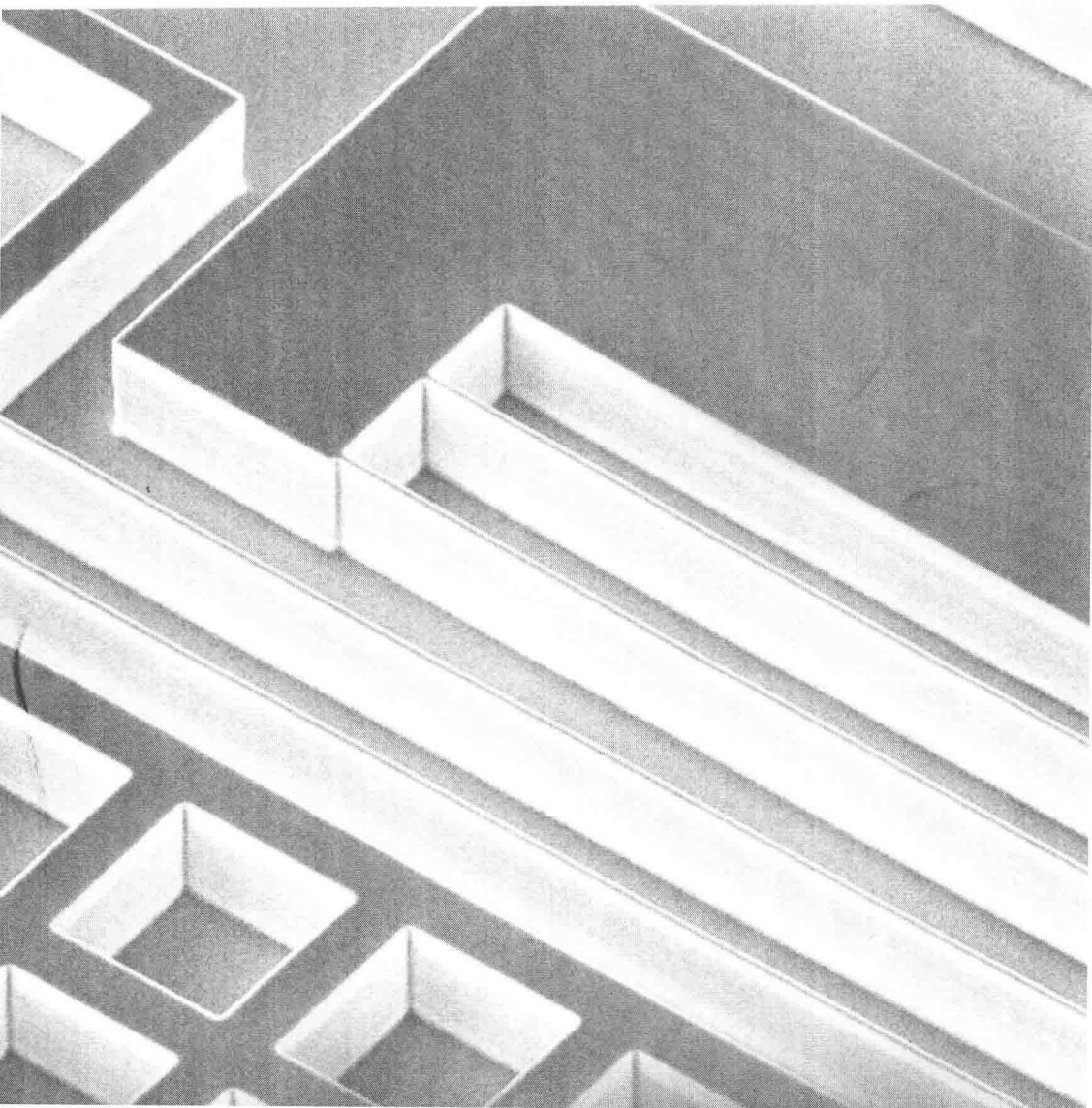

To my wife, Jean, who has listened for 54 years (and counting) to my obsession with technology. It would not have been possible to write this book if she had not fed me, watered me and corrected some of the text, but mainly had she not patiently waited several years for me to address numerous household jobs.

Preface

Manufacture of microelectromechanical systems (MEMS) is a major industry providing products to the consumer, automotive, medical and defence sectors. The products are small, often occupying an area less than 1 mm^2, have a high degree of functionality and are relatively cheap to manufacture (less than $1 per device).

Only 20 years ago, MEMS was mainly an academic activity, with many of the fabrication techniques and devices themselves in research or, at best, development. There seemed to be as many different methods of manufacture as there were devices. Nowadays there has been much standardisation in both fabrication, with silicon MEMS becoming mainstream, and packaging, where much has been adapted from the semiconductor industry. The cost of manufacture, including fabrication, testing and packaging, has become a major issue.

This volume seeks to show how cost analysis can be applied to MEMS, taking into account the wide range of processes and equipment, the major differences with the established semiconductor industry and the presence of both large-scale, product-orientated manufacturers and small- and medium-scale foundries. It examines the processes and equipment sufficiently for the reader to appreciate how costs arise. Appropriate publications are referenced so that technical details may be examined, outside the confines of cost analysis. Representative costs for equipment, processes and some products are examined in sufficient depth to show how financial models can be introduced to estimate the cost and price for a MEMS product.

Chapter 1 provides the historical background to the growth of the MEMS industry from its origins in the more mature semiconductor industry. Some of the key milestones over the last 50 years are

noted. Chapter 2 introduces basic fabrication processes that are fundamental to MEMS, notably material deposition, patterning and etching.

Chapter 3 introduces the equipment typical of surface micro-engineering of a few microns' depth, while Chapter 4 looks at high-aspect-ratio techniques where the microengineering can be several hundred microns in depth.

Chapter 5 examines the basis for testing MEMS devices, noting that this is a technology requiring equipment development. Chapter 6 discusses techniques to package the MEMS and signal-processing requirements, many of which come from the semiconductor industry.

MEMS manufacture must be carried out in ultra-clean rooms, where the particulate count in the air must be low and the size of particles sub-micron. The clean rooms, the manufacturing equipment and the plant to supply consumables must be installed in a building shell. This requires considerable investment that ultimately must be added to any cost estimate for a product. These issues are covered in Chapter 7.

Chapter 8 shows the structure of one version of a cost spreadsheet (MEMSCOST, written by the author) that brings together the technical details of MEMS fabrication, testing and packaging, with financial parameters, sufficient to cost any MEMS product.

Some examples of commercially successful MEMS products are examined in detail. Chapter 9 examines the cost of fabricating, testing and packaging three-axis accelerometers over a period of years, as predicted by MEMSCOST and compared with publically available market data. Chapter 10 repeats the process for the examination of MEMS microphones.

Commercial foundries have become an important source of manufacturing technology for the industry. Chapter 11 investigates the operation of foundries, contrasting multi-use foundries with single-product integrated device manufacturers (IDMs), some of which offer a job-shop capability and others (e.g., Sandia, MEMSCAP) a fixed process technology for a fixed price.

The purpose of MEMSCOST is to understand and calculate the cost of producing MEMS devices, to enable better investment and

to make pricing decisions. Chapter 12 looks at the overall financial analysis.

The methodology outlined has its origins as early as the 1990s, when the author was the founding director, Central Microstructure Facility, Rutherford and Appleton Laboratories, UK, from 1977 to 2003. In recent years this methodology has been further developed by the author to include a wider range of applications and more developed accounting procedures.

Professor Ron Lawes
Fellow, Royal Academy of Engineering
June 2012

Acknowledgements

I am indebted to many colleagues from the industry and academia for discussing MEMS technology and costs with me over the years and who have helped me to arrive at an understanding of industrial costs.

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Professors Anthony Walton and Tom Stevenson from the Scottish Microfabrication Centre at the University of Edinburgh and Professor Michael Kraft and Dr Iain Anteney from the Southampton Nanofabrication Centre at the University of Southampton provided excellent photographs of their clean-room facilities and equipment. Dr Mike Ward of Birmingham University provided an excellent photograph of an etched microstructure.

Professor Rob Santilli (AML) introduced me to wafer-bonding technology and showed me the cost structure of a typical small- and medium-sized company. Clive Bond at Loadpoint pointed out some of the finer points of wafer dicing and provided photographs of their equipment.

Dr Erol Harvey and Michael Wilkinson at MiniFAB, Australia, brought me into an industrial environment from a career in a government research laboratory and thus provided the industrial background that went into much of this book. MiniFAB also supplied data and pictures. Dr Matteo Altissimo from Monash University, Australia, supplied me with a picture of their electron beam machine.

Professor Volker Saile at Karlsruhe gave me the opportunity to study the potential for LIGA technology and provided a photograph of the synchrotron experimental area. The Diamond Light Source, UK, supplied an aerial view of the Diamond Synchrotron.

I am indebted to 'Sinjin' St John Dixon-Warren from Chipworks for the magnificent pictures of accelerometers and microphones shown in Chapters 9 and 10, respectively.

I also wish to acknowledge the roll of my former employer, the Science and Technology Facilities Council at the Rutherford Appleton Laboratory, for encouraging me to spend 42 years of research enjoying my passionate interest in technology.

A key analysis tool has been my MEMSCOST spreadsheet, which was developed to include details of MEMS processes and equipment and has enabled cost and other financial analysis. My daughter, Catherine, provided guidance on aspects of financial accounting and proofread every chapter.

However, any errors of fact or computation are mine and mine alone.

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