The background of the cover is a high-contrast, purple-tinted photograph of a microchip wafer. The wafer is divided into a grid of square dies. The perspective is from above, looking down at the wafer, which creates a sense of depth and geometric pattern. The lighting highlights the edges of the dies, giving them a three-dimensional appearance.

MEMS Cost Analysis

From Laboratory to Industry

Ron Lawes



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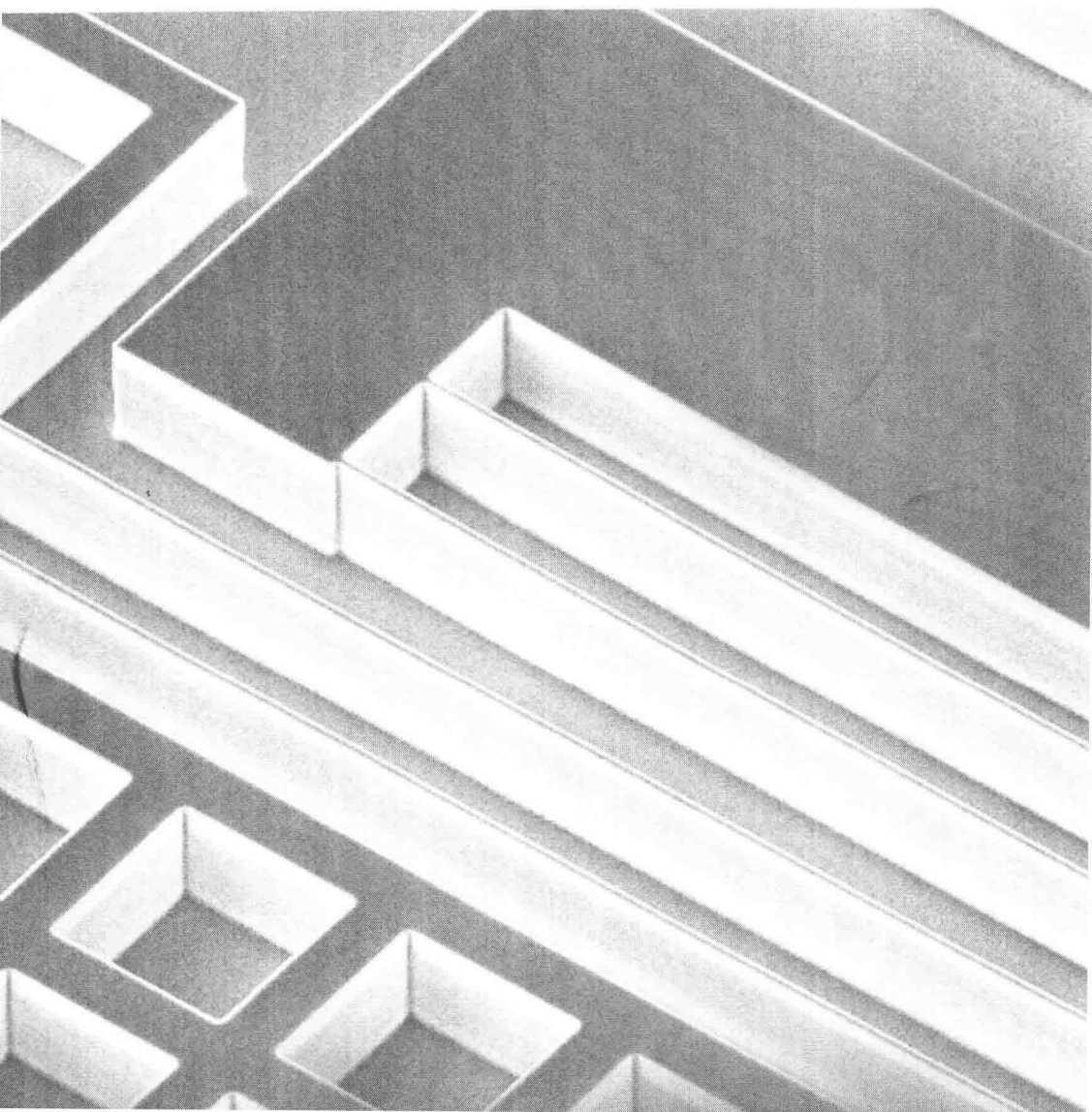
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MEMS Cost Analysis



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

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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.

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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.

Contents

<i>Preface</i>	xi
<i>Acknowledgements</i>	xv
1 The World of MEMS	1
1.1 Introduction	1
2 Basic Fabrication Processes	13
2.1 Introduction	13
2.2 Lithography, Masks and Reticles	15
2.3 Deposition and Etching	19
2.4 The Sacrificial Layer	20
2.5 Number of Dies per Wafer	23
2.6 Clean Rooms	29
3 Surface Micromachining	31
3.1 Introduction	31
3.2 Optical Mask Aligner	32
3.3 Optical Wafer Stepper	36
3.4 Low-Pressure Chemical Vapour Deposition	41
3.5 Plasma-Enhanced Chemical Vapour Deposition	44
3.6 Thermal Oxide Growth	46
3.7 DC and RF Sputter Deposition	51
3.8 Wet Etching	54
3.9 Reactive-Ion Etching	57
3.10 Chemical Mechanical Polishing	61
3.11 Electron-Beam Pattern Generation	63
3.12 Surface Microengineering Equipment Summary	69

4 High-Aspect-Ratio Micromachining	73
4.1 Introduction	73
4.2 Deep Reactive-Ion Etching	77
4.3 Excimer Laser Ablation	82
4.4 X-Ray LIGA	85
4.5 UV LIGA	91
4.6 Bulk Micromachining	94
4.7 Wafer Bonding	97
4.8 Electrodeposition	100
4.9 Critical-Point-Drying	104
4.10 Injection Moulding	107
4.11 High-Aspect-Ratio Equipment Summary	109
5 MEMS Testing	115
5.1 Introduction	115
5.2 Testing of Semiconductors	116
5.3 Testing of MEMS	120
6 MEMS Packaging	125
6.1 Introduction	125
6.2 Packages	127
6.3 Dicing	131
6.4 Die Attach	134
6.5 Wire Bonding	136
6.6 Lid Seal	140
6.7 Single- and Multi-Die Packaging	141
6.8 MEMS Packaging Summary	143
7 Clean Rooms, Buildings and Plant	147
7.1 Introduction	147
7.2 Clean Rooms and Buildings for Integrated Circuits	150
7.3 Clean Rooms and Buildings for a MEMS Foundry	156
8 The MEMSCOST Spreadsheet	165
8.1 Introduction	165
8.2 Basic Structure of the MEMSCOST Spreadsheet	166
8.3 Master Set-Up	167
8.4 Process Libraries	170

8.5	Fabrication Machine Simulators	173
8.6	Test and Packaging Machine Simulators	174
8.7	CMOS/BiCMOS Simulation	179
8.8	Financial Data	186
8.9	Wafer and Die Calculations	187
8.10	MEMSCOST Reports	188
8.11	Unit Costs	190
9	Product Costs: Accelerometers	197
9.1	Introduction	197
9.2	Costs for Die Fabrication	205
9.3	Revenue Estimates	209
9.4	Cost Comparison for Testing Regimes	215
9.5	Cost Comparison between Single- and Multi-Die Assemblies	218
9.6	Sensitivity of Costs to Manufacturing Parameters	221
10	Product Costs: Microphones	225
10.1	Introduction	225
10.2	Costs for Die Fabrication	231
10.3	Revenue Estimates	235
10.4	Cost Comparisons for Testing Regimes	240
10.5	Cost Comparison between Single- and Multi-Die Assembly	241
10.6	Sensitivity to Manufacturing Costs	243
11	MEMS Foundries	247
11.1	Introduction	247
11.2	MEMS Foundries	248
11.3	Multi-Product Use of Processes and Equipment	249
11.4	MEMS Foundry Lightly Loaded	250
11.5	Multi-Project Wafers	252
12	Financial Reporting and Analysis	263
12.1	Introduction	263
12.2	Key Financial Statements	263
12.3	Business Case	264
12.3.1	Product Specification	265

12.3.2	Investment	265
12.3.3	Capital Investment	266
12.3.4	Start-Up Expenses	266
12.3.5	Production	267
12.3.6	Cash Flow	269
12.4	Depreciation	271
12.5	Profit, Profit Margin and Markup	273
12.6	Total Cost of Ownership	273
12.7	Return on Investment	274
12.8	Earnings per Share	275
13	Conclusions	277
	<i>Index</i>	283