

# FUNDAMENTALS OF MICROSYSTEMS PACKAGING

Rao R. Tummala  
*Georgia Institute of Technology*  
Editor

Angie Hughes  
Nancy Trent  
Mahesh Varadarajan  
Managing Staff

Olatunji Cunningham  
Travis Gary  
Maurice Novembre  
Alyssa Poole  
Salley Theodore  
Illustrators

Kristy D'Arcy  
Melissa Sherrer  
Administrative Assistance

**McGRAW-HILL**

New York Chicago San Francisco Lisbon London  
Madrid Mexico City Milan New Delhi San Juan  
Seoul Singapore Sydney Toronto

# C O N T E N T S

## 1 INTRODUCTION TO MICROSYSTEMS PACKAGING 2

- 1.1 What Are Microsystems? 4
- 1.2 Microsystem Technologies 5
- 1.3 What Is Microsystems Packaging (MSP)? 12
- 1.4 Why Is Microsystems Packaging Important? 20
- 1.5 System-Level Microsystems Technologies 21
- 1.6 What is Expected of You as a Microsystems Engineer? 24
- 1.7 Summary and Future Trends 24
- 1.8 Who Invented Microsystems and Packaging Technologies? 26
- 1.9 Homework Problems 41
- 1.10 Suggested Reading 41

## 2 THE ROLE OF PACKAGING IN MICROELECTRONICS 44

- 2.1 What Is Microelectronics? 46
- 2.2 Characteristics of Semiconductors 47
- 2.3 Microelectronic Devices 53
- 2.4 Integrated Circuits 59
- 2.5 IC Packaging 65
- 2.6 Semiconductor Roadmap 68
- 2.7 IC Packaging Challenges 73
- 2.8 Summary and Future Trends 74
- 2.9 Homework Problems 77
- 2.10 Suggested Reading 79

## 3 THE ROLE OF PACKAGING IN MICROSYSTEMS 80

- 3.1 What Is an Electronic Product? 82
- 3.2 Anatomy of a Microsystem 82
- 3.3 Computers and the Internet 84
- 3.4 What Is the Role of Packaging in the Computer Industry? 89
- 3.5 What Is the Role of Packaging in the Telecommunication Industry 95
- 3.6 What Is the Role of Packaging in Automotive Systems 101
- 3.7 What Is the Role of Packaging in Medical Electronics 109
- 3.8 What Is the Role of Packaging in Consumer Electronics 111
- 3.9 What Is the Role of Packaging in Micro-Electro-Mechanical Systems (MEMS) Products 113
- 3.10 Summary and Future Trends 116
- 3.11 Homework Problems 118
- 3.12 Suggested Reading 119

## 4 FUNDAMENTALS OF ELECTRICAL PACKAGE DESIGN 120

- 4.1 What Is Electrical Package Design? 122
- 4.2 Fundamentals of Electrical Package Design 124
- 4.3 Electrical Anatomy of Systems Packaging 127
- 4.4 Signal Distribution 131
- 4.5 Power Distribution 156
- 4.6 Electromagnetic Interference 172
- 4.7 Design Process 176
- 4.8 Summary and Future Trends 179
- 4.9 Homework Problems 180
- 4.10 Suggested Reading 182

## 5 FUNDAMENTALS OF DESIGN FOR RELIABILITY 184

- 5.1 What Is Design for Reliability? 186
- 5.2 Microsystems Failures and Failure Mechanisms 186
- 5.3 Fundamentals of Design for Reliability 187
- 5.4 Thermomechanically-Induced Failures 188
- 5.5 Electrically-Induced Failures 203
- 5.6 Chemically-Induced Failures 206
- 5.7 Summary and Future Trends 208
- 5.8 Homework Problems 209
- 5.9 Suggested Reading 210

## 6 FUNDAMENTALS OF THERMAL MANAGEMENT 212

- 6.1 What Is Thermal Management? 214
- 6.2 Why Thermal Management? 214
- 6.3 Cooling Requirements for Microsystems 217
- 6.4 Thermal Management Fundamentals 220
- 6.5 Thermal Management of IC and PWB Packages 239
- 6.6 Electronic Cooling Methods 246
- 6.7 Summary and Future Trends 261
- 6.8 Homework Problems 262
- 6.9 Suggested Reading 262

## 7 FUNDAMENTALS OF SINGLE CHIP PACKAGING 264

- 7.1 What Is a Single Chip Package? 266
- 7.2 Functions of Single Chip Packages 267
- 7.3 Types of Single Chip Packages 268
- 7.4 Fundamentals of Single Chip Packaging 271
- 7.5 Materials, Processes, and Properties 284
- 7.6 Characteristics of Single Chip Packages 287
- 7.7 Summary and Future Trends 291
- 7.8 Homework Problems 292

7.9	Suggested Reading	293	11.9	Homework Problems	464
<b>8</b>	<b>FUNDAMENTALS OF MULTICHIP PACKAGING</b>	<b>296</b>	11.10	Suggested Reading	464
8.1	What Are Multichip Modules?	298	<b>12</b>	<b>FUNDAMENTALS OF OPTOELECTRONICS</b>	<b>466</b>
8.2	Multichip Module Functionality	299	12.1	What Is Optoelectronics Packaging?	468
8.3	Multichip Module Advantages	300	12.2	Why Is Optoelectronics Important?	468
8.4	Multichip Modules at the System Level	307	12.3	Optoelectronics Market	470
8.5	Types of Multichip Module Substrates	315	12.4	Anatomy of an Optoelectronic System	470
8.6	Multichip Module Design	329	12.5	Fundamentals of Optoelectronics	471
8.7	Multichip Module Technology Comparisons	333	12.6	Optical Interconnection System Configurations	489
8.8	Alternatives to Multichip Modules	335	12.7	Summary and Future Trends	494
8.9	Summary and Future Trends	336	12.8	Homework Problems	496
8.10	Homework Problems	338	12.9	Suggested Reading	498
8.11	Suggested Reading	338	<b>13</b>	<b>FUNDAMENTALS OF RF PACKAGING</b>	<b>500</b>
<b>9</b>	<b>FUNDAMENTALS OF IC ASSEMBLY</b>	<b>342</b>	13.1	What Is RF?	502
9.1	What Is IC Assembly?	344	13.2	RF Applications and Markets	503
9.2	Purpose of IC Assembly	345	13.3	Anatomy of RF Systems	504
9.3	Requirements for IC Assembly	345	13.4	Fundamentals of RF	513
9.4	IC Assembly Technologies	346	13.5	RF Packaging	534
9.5	Wirebonding	346	13.6	RF Measurement Techniques	537
9.6	Tape Automated Bonding	353	13.7	Summary and Future Trends	538
9.7	Flip Chip	361	13.8	Homework Problems	540
9.8	Summary and Future Trends	391	13.9	Suggested Reading	540
9.9	Homework Problems	392	<b>14</b>	<b>FUNDAMENTALS OF MICROELECTROMECHANICAL SYSTEMS</b>	<b>542</b>
9.10	Suggested Reading	397	14.1	What Are MEMS?	544
<b>10</b>	<b>FUNDAMENTALS OF WAFER-LEVEL PACKAGING</b>	<b>398</b>	14.2	What Are MEMS Applications?	544
10.1	What Is Wafer-level Packaging?	400	14.3	Fundamentals of MEMS Devices	547
10.2	Why Wafer-level Packaging?	401	14.4	Types of MEMS Packaging Solutions	560
10.3	WLP Technologies	405	14.5	Typical MEMS Devices	561
10.4	WLP Reliability	412	14.6	Key Failure Mechanisms of MEMS	565
10.5	Wafer-level Burn-in and Test	415	14.7	MEMS Inertial Sensors: A Case Study	566
10.6	Summary and Future Trends	417	14.8	Summary and Future Trends	576
10.7	Homework Problems	417	14.9	Homework Problems	576
10.8	Suggested Reading	417	14.10	Suggested Reading	578
<b>11</b>	<b>FUNDAMENTALS OF PASSIVES: DISCRETE, INTEGRATED, AND EMBEDDED</b>	<b>420</b>	<b>15</b>	<b>FUNDAMENTALS OF SEALING AND ENCAPSULATION</b>	<b>580</b>
11.1	What Are Passive Components?	422	15.1	What Is Encapsulation? What Is Sealing?	582
11.2	Role of Passive Components in Electronic Products	422	15.2	Why Is Encapsulation Necessary?	582
11.3	Fundamentals of Passive Components	426	15.3	Fundamentals of Encapsulation and Sealing	585
11.4	Physical Representations of Passive Components	437	15.4	Encapsulation Requirements	589
11.5	Discrete Passives	440	15.5	Encapsulant Materials	593
11.6	Integrated Passives	452	15.6	Encapsulation Processes	599
11.7	Embedded (Integral) Passives	454	15.7	Hermetic Sealing	603
11.8	Summary and Future Trends	463	15.8	Summary and Future Trends	607
			15.9	Homework Problems	608

15.10	Suggested Reading	609	19.9	Homework Problems	777
<b>16</b>	<b>FUNDAMENTALS OF SYSTEM-LEVEL PWB TECHNOLOGIES</b>	<b>612</b>	19.10	Suggested Reading	778
16.1	What Is a System-Level Printed Wiring Board?	614	<b>20</b>	<b>FUNDAMENTALS OF PACKAGE MANUFACTURING</b>	<b>780</b>
16.2	Types of Printed Wiring Boards	615	20.1	What Is Manufacturing?	782
16.3	Anatomy of a Printed Wiring Board	616	20.2	Goals of Manufacturing	782
16.4	Fundamentals of Printed Wiring Boards	618	20.3	Fundamentals of Manufacturing	783
16.5	CAD Tools for Printed Wiring Board Design	623	20.4	Statistical Fundamentals	785
16.6	Printed Wiring Board Materials	628	20.5	Process Control	803
16.7	Standard Printed Wiring Board Fabrication	635	20.6	Statistical Experimental Design	814
16.8	Limitations in Standard Printed Wiring Board Process	644	20.7	Process Modeling	825
16.9	Microvia Boards	650	20.8	Yield Modeling	831
16.10	Printed Wiring Board Market	653	20.9	CIM Systems	839
16.11	Summary and Future Trends	655	20.10	Summary and Future Trends	840
16.12	Homework Problems	655	20.11	Homework Problems	841
16.13	Suggested Reading	656	20.12	Suggested Reading	844
<b>17</b>	<b>FUNDAMENTALS OF BOARD ASSEMBLY</b>	<b>658</b>	<b>21</b>	<b>FUNDAMENTALS OF MICROSYSTEMS DESIGN FOR ENVIRONMENT</b>	<b>846</b>
17.1	What Is a Printed Wiring Board Assembly?	660	21.1	What Are the Environmental Concerns of Microsystems?	848
17.2	Surface Mount Technology	660	21.2	How Electronics Production Influences the Environment	851
17.3	Through-Hole Assembly	683	21.3	Life-Cycle Assessment	868
17.4	Generic Assembly Issues	688	21.4	Summary and Future Trends	874
17.5	Process Control	691	21.5	Homework Problems	876
17.6	Design Challenges	691	21.6	Suggested Reading	876
17.7	Summary and Future Trends	692	<b>22</b>	<b>FUNDAMENTALS OF MICROSYSTEMS RELIABILITY</b>	<b>878</b>
17.8	Homework Problems	693	22.1	What Is Thermomechanical Reliability?	880
17.9	Suggested Reading	693	22.2	Fundamentals of Thermomechanical Reliability	880
<b>18</b>	<b>FUNDAMENTALS OF PACKAGING MATERIALS AND PROCESSES</b>	<b>694</b>	22.3	Why Is Reliability Important?	883
18.1	The Role of Materials in Microsystems Packaging	696	22.4	Reliability Metrology	885
18.2	Packaging Materials and Properties	700	22.5	Failure Modes and Mechanisms	889
18.3	Materials Processes	717	22.6	Reliability Qualifications	896
18.4	Summary and Future Trends	735	22.7	Thermomechanical Failure Analysis	897
18.5	Homework Problems	744	22.8	Experimental Methods and Tools for Reliability Analysis	902
18.6	Suggested Reading	746	22.9	Integrated Virtual Reliability Prediction	918
<b>19</b>	<b>FUNDAMENTALS OF ELECTRICAL TESTING</b>	<b>748</b>	22.10	Summary and Future Trends	919
19.1	What Is Electrical Testing?	750	22.11	Homework Problems	921
19.2	Why Is Electrical Testing Necessary?	750	22.12	Suggested Reading	923
19.3	Anatomy of System-Level Electrical Testing	751	<b>GLOSSARY</b>	<b>924</b>	
19.4	Fundamentals of Electrical Tests	753	<b>APPENDICES</b>	<b>945</b>	
19.5	Interconnection Tests	759	<b>INDEX</b>	<b>955</b>	
19.6	Active Circuit Testing	765			
19.7	Design for Testability	769			
19.8	Summary and Future Trends	774			