
***Micro- and Opto-Electronic Materials and Structures:
Physics, Mechanics, Design, Reliability, Packaging***

***Volume I
Materials Physics—Materials Mechanics***

***Micro- and Opto-Electronic Materials and Structures:
Physics, Mechanics, Design, Reliability, Packaging***

***Volume I
Materials Physics—Materials Mechanics***

Edited by:

E. Suhir

*University of California, Santa Cruz
Santa Cruz, California, USA*

*University of Maryland
College Park, Maryland, USA*

Y.C. Lee

*University of Colorado
Boulder, Colorado, USA*

C.P. Wong

*Georgia Tech
Atlanta, Georgia, USA*



Springer

E. Suhir
University of California, Santa Cruz
Santa Cruz, California
and
University of Maryland
College Park, Maryland

Y.C. Lee
University of Colorado
Boulder, Colorado

C.P. Wong
Georgia Institute of Technology
Atlanta, Georgia

Micro- and Opto-Electronic Materials and Structures:
Physics, Mechanics, Design, Reliability, Packaging

Library of Congress Control Number: 2006922729

ISBN 0-387-27974-1 e-ISBN 0-387-32989-7
ISBN 978-0-387-27974-9

Printed on acid-free paper.

© 2007 Springer Science+Business Media, Inc.

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher (Springer Science + Business Media, Inc., 233 Spring Street, New York, NY 10013, USA), except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden.

The use in this publication of trade names, trademarks, service marks and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

Printed in the United States of America.

9 8 7 6 5 4 3 2 1 SPIN 11055464

springer.com

Contents

Volume I

<i>List of Contributors</i>	xxvii
-----------------------------	-------

<i>Preface</i>	xxxix
----------------	-------

Materials Physics

Chapter 1

Polymer Materials Characterization, Modeling and Application

L.J. Ernst, K.M.B. Jansen, D.G. Yang, C. van 't Hof, H.J.L. Bressers, J.H.J. Janssen and G.Q. Zhang

	3
1.1. Introduction	3
1.2. Polymers in Microelectronics	4
1.3. Basics of Visco-Elastic Modeling	6
1.3.1. Preliminary: State Dependent Viscoelasticity	6
1.3.2. Incremental Relationship	10
1.3.3. Linear State Dependent Viscoelasticity	13
1.3.4. Isotropic Material Behavior	14
1.3.5. Interrelations between Property Functions	15
1.3.6. Elastic Approximations	17
1.4. Linear Visco-Elastic Modeling (Fully Cured Polymers)	18
1.4.1. Introduction	18
1.4.2. Static Testing of Relaxation Moduli	18
1.4.3. Time-Temperature Superposition Principle	23
1.4.4. Static Testing of Creep Compliances	24
1.4.5. Dynamic Testing	27
1.5. Modeling of Curing Polymers	34
1.5.1. "Partly State Dependent" Modeling (Curing Polymers)	35
1.5.2. "Fully State Dependent" Modeling (Curing Polymers)	49
1.6. Parameterized Polymer Modeling (PPM)	53
1.6.1. PPM Hypotheses	54
1.6.2. Experimental Characterizations	55
1.6.3. PPM Modeling in Virtual Prototyping	62
Acknowledgments	62
References	62

Chapter 2

Thermo-Optic Effects in Polymer Bragg Gratings

Avram Bar-Cohen, Bongtae Han and Kyoung Joon Kim 65

2.1. Introduction 65

2.2. Fundamentals of Bragg Gratings 67

2.2.1. Physical Descriptions 67

2.2.2. Basic Optical Principles 68

2.3. Thermo-Optical Modeling of Polymer Fiber Bragg Grating 70

2.3.1. Heat Generation by Intrinsic Absorption 70

2.3.2. Analytical Thermal Model of PFBG 78

2.3.3. FEA Thermal Model of PFBG 80

2.3.4. Thermo-Optical Model of PFBG 80

2.4. Thermo-Optical Behavior of PMMA-Based PFBG 84

2.4.1. Description of a PMMA-Based PFBG and Light Sources 85

2.4.2. Power Variation Along the PFBG 86

2.4.3. Thermo-Optical Behavior of the PFBG–LED Illumination 87

2.4.4. Thermo-Optical Behavior of the PFBG–SM LD Illumination 92

2.4.5. Thermo-Optical Behavior of the PFBG Associated with Other Light Sources 101

2.5. Concluding Remarks 102

References 102

Appendix 2.A: Solution Procedure to Obtain the Optical Power Along the PFBG 104

Appendix 2.B: Solution Procedure to Determine the Temperature Profile Along the PFBG 106

2.B.1. Solution Procedure of the Temperature Profile Along the PFBG with the LED 106

2.B.2. Solution Procedure of the Temperature Profile Along the PFBG with the SM LD 106

Chapter 3

Photorefractive Materials and Devices for Passive Components in WDM Systems

Claire Gu, Yisi Liu, Yuan Xu, J.J. Pan, Fengqing Zhou, Liang Dong and Henry He 111

3.1. Introduction 111

3.2. Tunable Flat-Topped Filter 114

3.2.1. Principle of Operation 114

3.2.2. Device Simulation 116

3.2.3. Design for Implementation 117

3.3. Wavelength Selective 2×2 Switch 117

3.3.1. Principle of Operation 118

3.3.2. Experimental Demonstration 119

3.3.3. Theoretical Analysis 121

3.3.4. Optimized Switch Design 123

3.3.5. Discussion 125

3.4. High Performance Dispersion Compensators 126

3.4.1. Multi-Channel Dispersion-Slope Compensator 126

3.4.2. High Precision FBG Fabrication Method and Dispersion Management Filters 129

3.5. Conclusions 133

References 133

Chapter 4

Thin Films for Microelectronics and Photonics: Physics, Mechanics, Characterization, and Reliability

<i>David T. Read and Alex A. Volinsky</i>	135
4.1. Terminology and Scope	135
4.1.1. Thin Films	135
4.1.2. Motivation	136
4.1.3. Chapter Outline	136
4.2. Thin Film Structures and Materials	137
4.2.1. Substrates	137
4.2.2. Epitaxial Films	137
4.2.3. Dielectric Films	140
4.2.4. Metal Films	141
4.2.5. Organic and Polymer Films	142
4.2.6. MEMS Structures	142
4.2.7. Intermediate Layers: Adhesion, Barrier, Buffer, and Seed Layers	142
4.3. Manufacturability/Reliability Challenges	143
4.3.1. Film Deposition and Stress	144
4.3.2. Grain Structure and Texture	147
4.3.3. Impurities	151
4.3.4. Dislocations	152
4.3.5. Electromigration and Voiding	153
4.3.6. Structural Considerations	155
4.3.7. Need for Mechanical Characterization	155
4.3.8. Properties of Interest	156
4.4. Methods for mechanical characterization of thin films	157
4.4.1. Microtensile Testing	157
4.4.2. Instrumented Indentation	159
4.4.3. Other Techniques	164
4.4.4. Adhesion Tests	165
4.5. Materials and Properties	172
4.5.1. Grain Size and Structure Size Effects	172
4.6. Properties of Specific Materials	173
4.7. Future Research	175
4.7.1. Techniques	175
4.7.2. Properties	175
4.7.3. Length Scale	175
References	176

Chapter 5

Carbon Nanotube Based Interconnect Technology: Opportunities and Challenges

<i>Alan M. Cassell and Jun Li</i>	181
5.1. Introduction: Physical Characteristics of Carbon Nanotubes	181
5.1.1. Structural	181
5.1.2. Electrical	182
5.1.3. Mechanical	185
5.1.4. Thermal	186
5.2. CNT Fabrication Technologies	186

5.2.1. Chemical Vapor Deposition of Carbon Nanotubes	187
5.2.2. Process Integration and Development	189
5.3. Carbon Nanotubes as Interconnects	191
5.3.1. Limitations of the Current Technology	191
5.3.2. Architecture, Geometry and Performance Potential Using Carbon Nanotubes	191
5.4. Design, Manufacture and Reliability	194
5.4.1. Microstructural Attributes and Effects on Electrical Characteristics	194
5.4.2. Interfacial Contact Materials	196
5.4.3. End-contacted Metal–CNT Junction	198
5.4.4. Thermal Stress Characteristics	198
5.4.5. Reliability Test	199
5.5. Summary	200
References	200

Chapter 6

Virtual Thermo-Mechanical Prototyping of Microelectronics and Microsystems

A. Wymysłowski, G.Q. Zhang, W.D. van Driel and L.J. Ernst 205

6.1. Introduction	205
6.2. Physical Aspects for Numerical Simulations	206
6.2.1. Numerical Modeling	208
6.2.2. Material Properties and Models	211
6.2.3. Thermo-Mechanical Related Failures	215
6.2.4. Designing for Reliability	219
6.3. Mathematical Aspects of Optimization	225
6.3.1. Design of Experiments	226
6.3.2. Response Surface Modeling	236
6.3.3. Advanced Approach to Virtual Prototyping	242
6.3.4. Designing for Quality	249
6.4. Application Case	252
6.4.1. Problem Description	252
6.4.2. Numerical Approach to QFN Package Design	253
6.5. Conclusion and Challenges	259
6.6. List of Acronyms	264
Acknowledgments	264
References	264

Materials Mechanics

Chapter 7

Fiber Optics Structural Mechanics and Nano-Technology Based New Generation of Fiber Coatings: Review and Extension

E. Suhir 269

7.1. Introduction	269
7.2. Fiber Optics Structural Mechanics	270
7.2.1. Review	270
7.3. New Nano-Particle Material (NPM) for Micro- and Opto-Electronic Applications	273
7.3.1. New Nano-Particle Material (NPM)	273
7.3.2. NPM-Based Optical Silica Fibers	274

7.4. Conclusions	277
Acknowledgment	277
References	277

Chapter 8

Area Array Technology for High Reliability Applications

Reza Ghaffarian 283

8.1. Introduction	283
8.2. Area Array Packages (AAPs)	284
8.2.1. Advantages of Area Array Packages	285
8.2.2. Disadvantages of Area Arrays	285
8.2.3. Area Array Types	286
8.3. Chip Scale Packages (CSPs)	286
8.4. Plastic Packages	288
8.4.1. Background	288
8.4.2. Plastic Area Array Packages	288
8.4.3. Plastic Package Assembly Reliability	289
8.4.4. Reliability Data for BGA, Flip Chip BGA, and CSP	291
8.5. Ceramic Packages	293
8.5.1. Background	293
8.5.2. Ceramic Package Assembly Reliability	294
8.5.3. Literature Survey on CBGA/CCGA Assembly Reliability	295
8.5.4. CBGA Thermal Cycle Test	297
8.5.5. Comparison of 560 I/O PBGA and CCGA assembly reliability	302
8.5.6. Designed Experiment for Assembly	305
8.6. Summary	309
8.7. List of Acronyms and Symbols	310
Acknowledgments	311
References	311

Chapter 9

Metallurgical Factors Behind the Reliability of High-Density Lead-Free Interconnections

Toni T. Mattila, Tomi T. Laurila and Jorma K. Kivilahti 313

9.1. Introduction	313
9.2. Approaches and Methods	315
9.2.1. The Four Steps of The Iterative Approach	315
9.2.2. The Role of Different Simulation Tools in Reliability Engineering	321
9.3. Interconnection Microstructures and Their Evolution	324
9.3.1. Solidification	324
9.3.2. Solidification Structure and the Effect of Contact Metalization Dissolution	325
9.3.3. Interfacial Reactions Products	330
9.3.4. Deformation Structures (Due to Slip and Twinning)	333
9.3.5. Recovery, Recrystallization and Grain Growth	335
9.4. Two Case Studies on Reliability Testing	335
9.4.1. Case 1: Reliability of Lead-Free CSPs in Thermal cycling	337
9.4.2. Case 2: Reliability of Lead-Free CSPs in Drop Testing	341
9.5. Summary	347

Acknowledgments	348
References	348
Chapter 10	
Metallurgy, Processing and Reliability of Lead-Free Solder Joint Interconnections	
<i>Jin Liang, Nader Dariavach and Dongkai Shangguan</i>	351
10.1. Introduction	351
10.2. Physical Metallurgy of Lead-Free Solder Alloys	352
10.2.1. Tin-Lead Solders	352
10.2.2. Lead-Free Solder Alloys	353
10.2.3. Interfacial Reaction: Wetting and Spreading	357
10.2.4. Interfacial Intermetallic Formation and Growth at Liquid–Solid Interfaces	363
10.3. Lead-Free Soldering Processes and Compatibility	377
10.3.1. Lead-Free Soldering Materials	378
10.3.2. PCB Substrates and Metalization Finishes	380
10.3.3. Lead-Free Soldering Processes	381
10.3.4. Components for Lead-Free Soldering	384
10.3.5. Design, Equipment and Cost Considerations	387
10.4. Reliability of Pb-Free Solder Interconnects	388
10.4.1. Reliability and Failure Distribution of Pb-Free Solder Joints	388
10.4.2. Effects of Loading and Thermal Conditions on Reliability of Solder Interconnection	389
10.4.3. Reliability of Pb-Free Solder Joints in Comparison to Sn-Pb Eutectic Solder Joints	395
10.5. Guidelines for Pb-free Soldering and Improvement in Reliability	406
References	406
Chapter 11	
Fatigue Life Assessment for Lead-Free Solder Joints	
<i>Masaki Shiratori and Qiang Yu</i>	411
11.1. Introduction	411
11.2. The Intermetallic Compound Formed at the Interface of the Solder Joints and the Cu-pad	412
11.3. Mechanical Fatigue Testing Equipment and Load Condition in the Lead Free Solder	413
11.4. Results of Mechanical Fatigue Test	414
11.5. Critical Fatigue Stress Limit for the Intermetallic Compound Layer	417
11.6. Influence of the Plating Material on the Fatigue Life of Sn-Zn (Sn-9Zn and Sn-8Zn-3Bi) Solder Joints	424
11.7. Conclusion	426
References	426
Chapter 12	
Lead-Free Solder Materials: Design For Reliability	
<i>John H.L. Pang</i>	429
12.1. Introduction	429
12.2. Mechanics of Solder Materials	430
12.2.1. Fatigue Behavior of Solder Materials	431
12.3. Design For Reliability (DFR)	433

12.4. Constitutive Models For Lead Free Solders	435
12.4.1. Tensile Test Results	435
12.4.2. Creep Test Results	440
12.5. Low Cycle Fatigue Models	443
12.6. FEA Modeling and Simulation	448
12.7. Reliability Test and Analysis	454
12.8. Conclusions	456
Acknowledgments	456
References	456

Chapter 13

Application of Moire Interferometry to Strain Analysis of PCB Deformations at Low Temperatures

<i>Arkady Voloshin</i>	459
13.1. Introduction	459
13.2. Optical Method and Recording of Fringe Patterns	460
13.2.1. Fractional Fringe Approach	461
13.2.2. Grating Frequency Increase	461
13.2.3. Creation of a High-Frequency Master Grating	462
13.2.4. Combination of the High Grating Frequency and Fractional Fringe Approach	463
13.3. Data Processing	463
13.4. Test Boards and Specimen Grating	463
13.5. Elevated Temperature Test	465
13.6. Low Temperature Test	468
13.7. Conclusions	470
Acknowledgment	472
References	473

Chapter 14

Characterization of Stresses and Strains in Microelectronics and Photonics Devices Using Photomechanics Methods

<i>Bongtae Han</i>	475
14.1. Introduction	475
14.2. Stress/Strain analysis	476
14.2.1. Moiré Interferometry	476
14.2.2. Extension: Microscopic Moiré Interferometry	477
14.2.3. Specimen Gratings	479
14.2.4. Strain Analysis	480
14.2.5. Thermal Deformation Measured at Room Temperature	481
14.2.6. Deformation as a Function of Temperature	485
14.2.7. Hygroscopic Deformation	494
14.2.8. Micromechanics	501
14.3. Warpage Analysis	505
14.3.1. Twyman/Green Interferometry	505
14.3.2. Shadow Moiré	509
14.3.3. Far Infrared Fizeau Interferometry	514
Acknowledgment	520
References	520

Chapter 15

Analysis of Reliability of IC Packages Using the Fracture Mechanics Approach

Andrew A.O. Tay

15.1. Introduction	523
15.2. Heat Transfer and Moisture Diffusion in IC Packages	525
15.3. Fundamentals of Interfacial Fracture Mechanics	527
15.4. Criterion for Crack Propagation	529
15.5. Interface Fracture Toughness	529
15.6. Total Stress Intensity Factor	530
15.7. Calculation of SERR and Mode Mixity	531
15.7.1. Crack Surface Displacement Extrapolation Method	531
15.7.2. Modified J -integral Method	532
15.7.3. Modified Virtual Crack Closure Method	533
15.7.4. Variable Order Boundary Element Method	536
15.7.5. Interaction Integral Method	536
15.8. Experimental Verification	538
15.9. Case Studies	542
15.9.1. Delamination Along Pad-Encapsulant Interface	542
15.9.2. Delamination Along Die-Attach/Pad Interface	544
15.9.3. Analysis Using Variable Order Boundary Element Method	546
15.10. Discussion of the Various Numerical Methods for Calculating G and ψ	549
15.11. Conclusion	551
References	551

Chapter 16

Dynamic Response of Micro- and Opto-Electronic Systems to Shocks and Vibrations: Review and Extension

E. Suhir

16.1. Introduction	555
16.2. Review	556
16.3. Extension: Quality of Shock Protection with a Flexible Wire Elements	557
16.4. Analysis	558
16.4.1. Pre-Buckling Mode: Small Displacements	558
16.4.2. Post-Buckling Mode: Large Displacements	564
16.5. Conclusions	567
References	568

Chapter 17

Dynamic Physical Reliability in Application to Photonic Materials

Dov Ingman, Tatiana Mirer and Ephraim Suhir

17.1. Introduction: Dynamic Reliability Approach to the Evolution of Silica Fiber Performance	571
17.1.1. Dynamic Physical Model of Damage Accumulation	572
17.1.2. Impact of the Three-Dimensional Mechanical-Temperature-Humidity Load on the Optical Fiber Reliability	575
17.1.3. Effect of Bimodality and Its Explanation Based on the Suggested Model	576
17.2. Reliability Improvement through NPM-Based Fiber Structures	585

17.2.1. Environmental Protection by NPM-Based Coating and Overall Self-Curing Effect of NPM Layers	585
17.2.2. Improvement in the Reliability Characteristics by Employing NPM Structures in Optical Fibers	587
17.3. Conclusions	593
References	593
Chapter 18	
High-Speed Tensile Testing of Optical Fibers—New Understanding for Reliability Prediction	
<i>Sergey Semjonov and G. Scott Glaesemann</i>	595
18.1. INTRODUCTION	595
18.2. Theory	596
18.2.1. Single-Region Power-Law Model	596
18.2.2. Two-Region Power-Law Model	598
18.2.3. Universal Static and Dynamic Fatigue Curves	599
18.3. Experimental	602
18.3.1. Sample Preparation	602
18.3.2. Dynamic Fatigue Tests	604
18.3.3. Static Fatigue Tests	605
18.4. Results and Discussion	606
18.4.1. High-Speed Testing	606
18.4.2. Static Fatigue	610
18.4.3. Influence of Multiregion Model on Lifetime Prediction	613
18.5. Conclusion	613
References	614
Appendix 18.A: High Speed Axial Strength Testing: Measurement Limits	616
Appendix 18.B: Incorporating Static Fatigue Results into Dynamic Fatigue Curves	620
18.B.1. Static Fatigue Test	620
18.B.2. Dynamic Fatigue Test	621
18.B.3. Discussion	622
Chapter 19	
The Effect of Temperature on the Microstructure Nonlinear Dynamics Behavior	
<i>Xiaoling He</i>	627
19.1. Introduction	627
19.2. Theoretical Development	630
19.2.1. Background on Nonlinear Dynamics and Nonlinear Thermo-Elasticity Theories	630
19.2.2. Nonlinear Thermo-Elasticity Development for an Isotropic Laminate Subject to Thermal and Mechanical and Load	631
19.3. Thin Laminate Deflection Response Subject to Thermal Effect and Mechanical Load	633
19.3.1. Steady State Temperature Effect	633
19.3.2. Transient Thermal Field Effect	638
19.4. Stress Field in Nonlinear Dynamics Response	653
19.4.1. Stress Field Formulation	653
19.4.2. Stress Distribution	654
19.4.3. Failure Analysis	654

19.5. Discussions	660
19.6. Summary	661
Nomenclature	662
Acknowledgment	663
References	663
Chapter 20	
Effect of Material's Nonlinearity on the Mechanical Response of some Piezoelectric and Photonic Systems	
<i>Victor Birman and Ephraim Suhir</i>	667
20.1. Introduction	667
20.2. Effect of Physical Nonlinearity on Vibrations of Piezoelectric Rods Driven by Alternating Electric Field	668
20.2.1. Physically Nonlinear Constitutive Relationships for an Orthotropic Cylindrical Piezoelectric Rod Subject to an Electric Field in the Axial Direction	670
20.2.2. Analysis of Uncoupled Axial Vibrations	673
20.2.3. Solution for Coupled Axial-Radial Axisymmetric Vibrations by the Generalized Galerkin Procedure	677
20.2.4. Numerical Results and Discussion	678
20.3. The Effect of the Nonlinear Stress–Strain Relationship on the Response of Optical Fibers	683
20.3.1. Stability of Optical Fibers	684
20.3.2. Stresses and Strains in a Lightwave Coupler Subjected to Tension	686
20.3.3. Free Vibrations	690
20.3.4. Bending of an Optical Fiber	692
20.4. Conclusions	695
Acknowledgment	696
References	697
<i>Index</i>	701

Volume II

<i>List of Contributors</i>	xxvii
<i>Preface</i>	xxxix

Physical Design

Chapter 1	
Analytical Thermal Stress Modeling in Physical Design for Reliability of Micro- and Opto-Electronic Systems: Role, Attributes, Challenges, Results	
<i>E. Suhir</i>	3
1.1. Thermal Loading and Thermal Stress Failures	3
1.2. Thermal Stress Modeling	4
1.3. Bi-Metal Thermostats and other Bi-Material Assemblies	5
1.4. Finite-Element Analysis	5

1.5. Die-Substrate and other Bi-Material Assemblies	6
1.6. Solder Joints	8
1.7. Design Recommendations	9
1.8. “Global” and “Local” Mismatch and Assemblies Bonded at the Ends	10
1.9. Assemblies with Low Modulus Adhesive Layer at the Ends	11
1.10. thermally Matched Assemblies	11
1.11. Thin Films	12
1.12. Polymeric Materials And Plastic Packages	13
1.13. Thermal Stress Induced Bowing and Bow-Free Assemblies	14
1.14. Probabilistic Approach	15
1.15. Optical Fibers and other Photonic Structures	15
1.16. Conclusion	16
References	17

Chapter 2

Probabilistic Physical Design of Fiber-Optic Structures

Satish Radhakrishnan, Ganesh Subbarayan and Luu Nguyen

	23
2.1. Introduction	23
2.1.1. Demonstration Vehicle	24
2.2. Optical Model	25
2.2.1. Mode Field Diameter	26
2.2.2. Refraction and Reflection Losses	27
2.2.3. Calculations for Coupling Losses	27
2.2.4. Coupling Efficiency	28
2.3. Interactions in System and Identification of Critical Variables	30
2.3.1. Function Variable Incidence Matrix	30
2.3.2. Function Variable Incidence Matrix to Graph Conversion	31
2.3.3. Graph Partitioning Techniques	34
2.3.4. System Decomposition using Simulated Annealing	34
2.4. Deterministic Design Procedures	37
2.4.1. Optimal and Robust Design	40
2.4.2. A Brief Review of Multi-Objective Optimization	42
2.4.3. Implementation	43
2.4.4. Results	43
2.5. Stochastic Analysis	44
2.5.1. The First and Second Order Second Moment Methods	44
2.6. Probabilistic Design for Maximum Reliability	46
2.6.1. Results	49
2.7. Stochastic Characterization of Epoxy Behavior	51
2.7.1. Viscoelastic Models	52
2.7.2. Modeling the Creep Test	53
2.7.3. Dynamic Mechanical Analysis	54
2.7.4. Experimental Results	55
2.8. Analytical Model to Determine VCSEL Displacement	57
2.8.1. Results	63
2.9. Summary	67
References	67

Chapter 3

The Wirebonded Interconnect: A Mainstay for Electronics

<i>Harry K. Charles, Jr.</i>	71
3.1. Introduction	71
3.1.1. Integrated Circuit Revolution	71
3.1.2. Interconnection Types	72
3.1.3. Wirebond Importance	80
3.2. Wirebonding Basics	81
3.2.1. Thermocompression Bonding	81
3.2.2. Ultrasonic Bonding	83
3.2.3. Thermosonic Bonding	85
3.2.4. Wirebond Reliability	87
3.2.5. Wirebond Testing	89
3.2.6. Bonding Automation and Optimization	93
3.3. Materials	95
3.3.1. Bonding Wire	95
3.3.2. Bond Pad Metallurgy	100
3.3.3. Gold Plating	102
3.3.4. Pad Cleaning	104
3.4. Advanced Bonding Methods	105
3.4.1. Fine Pitch Bonding	105
3.4.2. Soft Substrates	108
3.4.3. Machine Improvements	110
3.4.4. Higher Frequency Wirebonding	110
3.4.5. Stud Bumping	115
3.5. Summary	116
Acknowledgments	116
References	116

Chapter 4

Metallurgical Interconnections for Extreme High and Low Temperature Environments

<i>George G. Harman</i>	121
4.1. Introduction	121
4.2. High Temperature Interconnections Requirements	122
4.2.1. Wire Bonding	122
4.2.2. The Use of Flip Chips in HTE	127
4.2.3. General Overview of Metallurgical Interfaces for Both HTE and LTE	129
4.3. Low Temperature Environment Interconnection Requirements	129
4.4. Corrosion and Other Problems in Both <i>HTE</i> , and <i>LTE</i>	130
4.5. The Potential Use of High Temperature Polymers in HTE	131
4.6. Conclusions	132
Acknowledgments	132
References	132

Chapter 5

Design, Process, and Reliability of Wafer Level Packaging

<i>Zhuqing Zhang and C.P. Wong</i>	135
5.1. Introduction	135

5.2. WLCSP	137
5.2.1. Thin Film Redistribution	137
5.2.2. Encapsulated Package	139
5.2.3. Compliant Interconnect	139
5.3. Wafer Level Underfill	141
5.3.1. Challenges of Wafer Level Underfill	142
5.3.2. Examples of Wafer Level Underfill Process	143
5.4. Comparison of Flip-Chip and WLCSP	145
5.5. Wafer Level Test and Burn-In	145
5.6. Summary	149
References	149

Chapter 6

Passive Alignment of Optical Fibers in V-grooves with Low Viscosity Epoxy Flow

<i>S.W. Ricky Lee and C.C. Lo</i>	151
6.1. Introduction	151
6.2. Design and Fabrication of Silicon Optical Bench with V-grooves	152
6.3. Issues of Conventional Passive Alignment Methods	158
6.3.1. V-grooves with Cover Plate	158
6.3.2. Edge Dispensing of Epoxy	161
6.4. Modified Passive Alignment Method	162
6.4.1. Working Principle	162
6.4.2. Alignment Mechanism	163
6.4.3. Design of Experiment	164
6.4.4. Experimental Procedures	164
6.4.5. Experimental Results	165
6.5. Effects of Epoxy Viscosity and Dispensing Volume	168
6.6. Application to Fiber Array Passive Alignment	170
6.7. Conclusions and Discussion	172
References	172

Reliability and Packaging

Chapter 7

Fundamentals of Reliability and Stress Testing

<i>H. Anthony Chan</i>	177
7.1. More Performance at Lower Cost in Shorter Time-to-market	178
7.1.1. Rapid Technological Developments	178
7.1.2. Integration of More Products into Human Life	178
7.1.3. Diverse Environmental Stresses	178
7.1.4. Competitive Market	179
7.1.5. Short Product Cycles	179
7.1.6. The Bottom Line	179
7.2. Measure of Reliability	180
7.2.1. Failure Rate	180
7.2.2. Systems with Multiple Independent Failure Modes	181
7.2.3. Failure Rate Distribution	182
7.3. Failure Mechanisms in Electronics and Packaging	184

7.3.1. Failure Mechanisms at Chip Level Include	184
7.3.2. Failure Mechanisms at Bonding Include	184
7.3.3. Failure Mechanisms in Device Packages Include	185
7.3.4. Failure Mechanisms in Epoxy Compounds Include	185
7.3.5. Failure Mechanisms at Shelf Level Include	185
7.3.6. Failure Mechanisms in Material Handling Include	185
7.3.7. Failure Mechanisms in Fiber Optics Include	185
7.3.8. Failure Mechanisms in Flat Panel Displays Include	186
7.4. Reliability Programs and Strategies	186
7.5. Product Weaknesses and Stress Testing	187
7.5.1. Why do Products Fail?	187
7.5.2. Stress Testing Principle	189
7.6. Stress Testing Formulation	191
7.6.1. Threshold and Cumulative Stress Failures	191
7.6.2. Stress Stimuli and Flaws	192
7.6.3. Modes of Stress Testing	193
7.6.4. Lifetime Failure Fraction	194
7.6.5. Robustness Against Maximum Service Life Stress	195
7.6.6. Stress–Strength Contour	197
7.6.7. Common Issues	198
7.7. Further Reading	201

Chapter 8

How to Make a Device into a Product: *Accelerated Life Testing (ALT), Its Role, Attributes, Challenges, Pitfalls, and Interaction with Qualification Tests* E. Suhir

8.1. Introduction	203
8.2. Some Major Definitions	204
8.3. Engineering Reliability	204
8.4. Field Failures	205
8.5. Reliability is a Complex Property	206
8.6. Three Major Classes of Engineering Products and Market Demands	206
8.7. Reliability, Cost and Time-to-Market	208
8.8. Reliability Costs Money	208
8.9. Reliability Should Be Taken Care of on a Permanent Basis	209
8.10. Ways to Prevent and Accommodate Failures	210
8.11. Redundancy	211
8.12. Maintenance and Warranty	211
8.13. Test Types	212
8.14. Accelerated Tests	212
8.15. Accelerated Test Levels	213
8.16. Qualification Standards	213
8.17. Accelerated Life Tests (ALTs)	214
8.18. Accelerated Test Conditions	215
8.19. Acceleration Factor	216
8.20. Accelerated Stress Categories	217
8.21. Accelerated Life Tests (ALTs) and Highly Accelerated Life Tests (HALTs)	218
8.22. Failure Mechanisms and Accelerated Stresses	219

8.23. ALTs: Pitfalls and Challenges	219
8.24. Burn-ins	220
8.25. Wear-Out Failures	221
8.26. Non-Destructive Evaluations (NDE's)	222
8.27. Predictive Modeling	222
8.28. Some Accelerated Life Test (ALT) Models	223
8.28.1. Power Law	224
8.28.2. Boltzmann-Arrhenius Equation	224
8.28.3. Coffin-Manson Equation (Inverse Power Law)	225
8.28.4. Paris-Erdogan Equation	226
8.28.5. Bueche-Zhurkov Equation	227
8.28.6. Eyring Equation	227
8.28.7. Peck and Black Equations	227
8.28.8. Fatigue Damage Model (Miner's Rule)	228
8.28.9. Creep Rate Equations	228
8.28.10. Weakest Link Models	228
8.28.11. Stress–Strength Models	229
8.29. Probability of Failure	229
8.30. Conclusions	230
References	230

Chapter 9

Micro-Deformation Analysis and Reliability Estimation of Micro-Components by Means of NanoDAC Technique

Bernd Michel and Jürgen Keller 233

9.1. Introduction	233
9.2. Basics of Digital Image Correlation	234
9.2.1. Cross Correlation Algorithms on Gray Scale Images	234
9.2.2. Subpixel Analysis for Enhanced Resolution	236
9.2.3. Results of Digital Image Correlation	238
9.3. Displacement and Strain Measurements on SFM Images	239
9.3.1. Digital Image Correlation under SPM Conditions	239
9.3.2. Technical Requirements for the Application of the Correlation Technique	241
9.4. Deformation Analysis on Thermally and Mechanically Loaded Objects under the SFM	241
9.4.1. Reliability Aspects of Sensors and Micro Electro-Mechanical Systems (MEMS)	241
9.4.2. Thermally Loaded Gas Sensor under SFM	242
9.4.3. Crack Detection and Evaluation by SFM	243
9.5. Conclusion and Outlook	250
References	250

Chapter 10

Interconnect Reliability Considerations in Portable Consumer Electronic Products

Sridhar Canumalla and Puligandla Viswanadham 253

10.1. Introduction	253
10.2. Reliability—Thermal, Mechanical and Electrochemical	255
10.2.1. Accelerated Life Testing	255
10.2.2. Thermal Environment	257

10.2.3. Mechanical Environment	257
10.2.4. Electrochemical Environment	264
10.2.5. Tin Whiskers	267
10.3. Reliability Comparisons in Literature	267
10.3.1. Thermomechanical Reliability	268
10.3.2. Mechanical Reliability	270
10.4. Influence of Material Properties on Reliability	271
10.4.1. Printed Wiring Board	271
10.4.2. Package	272
10.4.3. Surface Finish	272
10.5. Failure Mechanisms	273
10.5.1. Thermal Environment	273
10.5.2. Mechanical Environment	276
10.5.3. Electrochemical Environment	286
10.6. reliability test Practices	291
10.7. Summary	294
Acknowledgments	295
References	295
 Chapter 11	
MEMS Packaging and Reliability	
<i>Y.C. Lee</i>	299
11.1. Introduction	299
11.2. Flip-Chip Assembly for Hybrid Integration	304
11.3. Soldered Assembly for Three-Dimensional MEMS	309
11.4. Flexible Circuit Boards for MEMS	313
11.5. Atomic Layer Deposition for Reliable MEMS	316
11.6. Conclusions	320
Acknowledgments	320
References	320
 Chapter 12	
Advances in Optoelectronic Methodology for MOEMS Testing	
<i>Ryszard J. Pryputniewicz</i>	323
12.1. Introduction	323
12.2. MOEMS Samples	324
12.3. Analysis	328
12.4. Optoelectronic Methodology	330
12.5. Representative Applications	334
12.6. Conclusions and Recommendations	338
Acknowledgments	339
References	339
 Chapter 13	
Durability of Optical Nanostructures: Laser Diode Structures and Packages, A Case Study	
<i>Ajay P. Malshe and Jay Narayan</i>	341

13.1. High Efficiency Quantum Confined (Nanostructured) III-Nitride Based Light Emitting Diodes And Lasers	342
13.1.1. Introduction	342
13.2. Investigation of Reliability Issues in High Power Laser Diode Bar Packages	348
13.2.1. Introduction	348
13.2.2. Preparation of Packaged Samples for Reliability Testing	349
13.2.3. Finding and Model of Reliability Results	350
13.3. Conclusions	357
Acknowledgments	358
References	358

Chapter 14

Review of the Technology and Reliability Issues Arising as Optical Interconnects Migrate onto the Circuit Board

P. Misselbrook, D. Gwyer, C. Bailey, D. Gwyer, C. Bailey, P.P. Conway and K. Williams 361

14.1. Background to Optical Interconnects	362
14.2. Transmission Equipment for Optical Interconnects	362
14.3. Very Short Reach Optical Interconnects	365
14.4. Free Space USR Optical Interconnects	366
14.5. Guided Wave USR Interconnects	367
14.6. Component Assembly of OECS's	370
14.7. Computational Modeling of Optical Interconnects	373
14.8. Conclusions	380
Acknowledgments	380
References	381

Chapter 15

Adhesives for Micro- and Opto-Electronics Application: Chemistry, Reliability and Mechanics

D.W. Dahringer 383

15.1. Introduction	383
15.1.1. Use of Adhesives in Micro and Opto-Electronic Assemblies	383
15.1.2. Specific Applications	384
15.2. Adhesive Characteristics	385
15.2.1. General Properties of Adhesives	385
15.2.2. Adhesive Chemistry	390
15.3. Design Objective	393
15.3.1. Adhesive Joint Design	393
15.3.2. Manufacturing Issues	397
15.4. Failure Mechanism	401
15.4.1. General	401
15.4.2. Adhesive Changes	401
15.4.3. Interfacial Changes	401
15.4.4. Interfacial Stress	401
15.4.5. External Stress	402
References	402

Chapter 16

Multi-Stage Peel Tests and Evaluation of Interfacial Adhesion Strength for Micro- and Opto-Electronic Materials

Masaki Omiya, Kikuo Kishimoto and Wei Yang 403

16.1. Introduction 403

16.2. Multi-Stage Peel Test (MPT) 407

16.2.1. Testing Setup 407

16.2.2. Multi-Stage Peel Test 408

16.2.3. Energy Variation in Steady State Peeling 409

16.3. Interfacial Adhesion Strength of Copper Thin Film 413

16.3.1. Preparation of Specimen 413

16.3.2. Measurement of Adhesion Strength by the MPT 414

16.3.3. Discussions 415

16.4. UV-Irradiation Effect on Ceramic/Polymer Interfacial Strength 419

16.4.1. Preparation of PET/ITO Specimen 419

16.4.2. Measurement of Interfacial Strength by MPT 422

16.4.3. Surface Crack Formation on ITO Layer under Tensile Loading 424

16.5. Concluding Remarks 426

Acknowledgment 427

References 427

Chapter 17

The Effect of Moisture on the Adhesion and Fracture of Interfaces in Microelectronic Packaging

Timothy P. Ferguson and Jianmin Qu 431

17.1. Introduction 432

17.2. Moisture Transport Behavior 433

17.2.1. Background 433

17.2.2. Diffusion Theory 434

17.2.3. Underfill Moisture Absorption Characteristics 435

17.2.4. Moisture Absorption Modeling 438

17.3. Elastic Modulus Variation Due to Moisture Absorption 442

17.3.1. Background 442

17.3.2. Effect of Moisture Preconditioning 444

17.3.3. Elastic Modulus Recovery from Moisture Uptake 447

17.4. Effect of Moisture on Interfacial Adhesion 449

17.4.1. Background 449

17.4.2. Interfacial Fracture Testing 451

17.4.3. Effect of Moisture Preconditioning on Adhesion 452

17.4.4. Interfacial Fracture Toughness Recovery from Moisture Uptake 461

17.4.5. Interfacial Fracture Toughness Moisture Degradation Model 462

References 469

Chapter 18

Highly Compliant Bonding Material for Micro- and Opto-Electronic Applications

E. Suhir and D. Ingman 473

18.1. Introduction 473

18.2. Effect of the Interfacial Compliance on the interfacial Shearing Stress	474
18.3. Internal Compressive Forces	476
18.4. Advanced Nano-Particle Material (NPM)	476
18.5. Highly-Compliant Nano-Systems	478
18.6. Conclusions	479
References	480
Appendix 18.A: Bimaterial Assembly Subjected to an External Shearing Load and Change in Temperature: Expected Stress Relief due to the Elevated Interfacial Compliance	480
Appendix 18.B: Cantilever Wire (“Beam”) Subjected at its Free End to a Lateral (Bending) and an Axial (Compressive) Force	483
Appendix 18.C: Compressive Forces in the NPM-Based Compound Structure	485
Chapter 19	
Adhesive Bonding of Passive Optical Components	
<i>Anne-Claire Pliska and Christian Bosshard</i>	487
19.1. Introduction	487
19.2. Optical Devices and Assemblies	489
19.2.1. Optical Components	489
19.2.2. Opto-electronics Assemblies: Specific Requirements	489
19.3. Adhesive Bonding in Optical Assemblies	503
19.3.1. Origin of Adhesion	503
19.3.2. Adhesive Selection and Dispensing	508
19.3.3. Dispensing Technologies	515
19.4. Some Applications	518
19.4.1. Laser to Fiber Assembly	518
19.4.2. Planar Lightwave Circuit (PLC) Pigtailling	520
19.5. Summary and Recommendations	522
Acknowledgments	523
References	523
Chapter 20	
Electrically Conductive Adhesives: A Research Status Review	
<i>James E. Morris and Johan Liu</i>	527
20.1. Introduction	527
20.1.1. Technology Drivers	527
20.1.2. Isotropic Conductive Adhesives (ICAs)	529
20.1.3. Anisotropic Conductive Adhesives (ACAs)	529
20.1.4. Non-Conductive Adhesive (NCA)	529
20.2. Structure	529
20.2.1. ICA	529
20.2.2. ACA	532
20.2.3. Modeling	534
20.3. Materials and Processing	534
20.3.1. Polymers	534
20.3.2. ICA Filler	536
20.3.3. ACA Processing	536
20.4. Electrical Properties	538

20.4.1. ICA	538
20.4.2. Electrical Measurements	544
20.4.3. ACA	544
20.5. Mechanical Properties	546
20.5.1. ICA	546
20.5.2. ACA	547
20.6. Thermal Properties	553
20.6.1. Thermal Characteristics	553
20.6.2. Maximum Current Carrying Capacity	553
20.7. Reliability	554
20.7.1. ICA	554
20.7.2. ACA	557
20.7.3. General Comments	565
20.8. Environmental Impact	565
20.9. Further Study	565
References	565

Chapter 21

Electrically Conductive Adhesives

Johann Nicolics and Martin Mündlein

571

21.1. Introduction and Historical Background	571
21.2. Contact Formation	574
21.2.1. Percolation and Critical Filler Content	574
21.2.2. ICA Contact Model	575
21.2.3. Results	578
21.3. Aging Behavior and Quality Assessment	595
21.3.1. Introduction	595
21.3.2. Material Selection and Experimental Parameters	595
21.3.3. Curing Parameters and Definition of Curing Time	597
21.3.4. Testing Conditions, Typical Results, and Conclusions	598
21.4. About Typical Applications	602
21.4.1. ICA for Attachment of Power Devices	602
21.4.2. ICA for Interconnecting Parts with Dissimilar Thermal Expansion Coefficient	604
21.4.3. ICA for Cost-Effective Assembling of Multichip Modules	606
21.5. Summary	607
Notations and Definitions	607
References	608

Chapter 22

Recent Advances of Conductive Adhesives: A Lead-Free Alternative in Electronic Packaging

Grace Y. Li and C.P. Wong

611

22.1. Introduction	611
22.2. Isotropic Conductive Adhesives (ICAs)	613
22.2.1. Improvement of Electrical Conductivity of ICAs	614
22.2.2. Stabilization of Contact Resistance on Non-Noble Metal Finishes	615
22.2.3. Silver Migration Control of ICA	618

22.2.4. Improvement of Reliability in Thermal Shock Environment	618
22.2.5. Improvement of Impact Performance of ICA	619
22.3. Anisotropic Conductive Adhesives (ACAs)/Anisotropic Conductive Film (ACF)	619
22.3.1. Materials	620
22.3.2. Application of ACA/ACF in Flip Chip	621
22.3.3. Improvement of Electrical Properties of ACAs	621
22.3.4. Thermal Conductivity of ACA	623
22.4. Future Advances of ECAs	623
22.4.1. Electrical Characteristics	623
22.4.2. High Frequency Compatibility	623
22.4.3. Reliability	623
22.4.4. ECAs with Nano-filler for Wafer Level Application	625
References	625

Chapter 23

Die Attach Quality Testing by Structure Function Evaluation

Márta Rencz, Vladimir Székely and Bernard Courtois 629

Nomenclature 629

Greek symbols 629

Subscripts 630

23.1. Introduction 630

23.2. Theoretical Background 630

23.3. Detecting Voids in the Die Attach of Single Die Packages 634

23.4. Simulation Experiments for Locating the Die Attach Failure on Stacked Die Packages 636

23.4.1. Simulation Tests Considering Stacked Dies of the Same Size 637

23.4.2. Simulation Experiments on a Pyramidal Structure 639

23.5. Verification of the Methodology by Measurements 642

23.5.1. Comparison of the Transient Behavior of Stacked Die Packages Containing Test Dies, Prior Subjected to Accelerated Moisture and Temperature Testing 642

23.5.2. Comparison of the Transient Behavior of Stacked Die Packages Containing Real Functional Dies, Subjected Prior to Accelerated Moisture and Temperature Testing 644

23.6. Conclusions 649

Acknowledgments 649

References 650

Chapter 24

Mechanical Behavior of Flip Chip Packages under Thermal Loading

Enboa Wu, Shoulung Chen, C.Z. Tsai and Nicholas Kao 651

24.1. Introduction 651

24.2. Flip Chip Packages 652

24.3. Measurement Methods 654

24.3.1. Phase Shifted Shadow Moiré Method 654

24.3.2. Electronic Speckle Pattern Interferometry (ESPI) Method 655

24.4. Substrate CTE Measurement 656

24.5. Behavior of Flip Chip Packages under Thermal Loading 661

24.5.1. Warpage at Room Temperature 661

24.5.2. Warpage at Elevated Temperatures	662
24.5.3. Effect of Underfill on Warpage	666
24.6. Finite Element Analysis of Flip Chip Packages under Thermal Loading	668
24.7. Parametric Study of Warpage for Flip Chip Packages	669
24.7.1. Change of the Chip Thickness	670
24.7.2. Change of the Substrate Thickness	670
24.7.3. Change of the Young's Modulus of the Underfill	671
24.7.4. Change of the CTE of the Underfill	672
24.7.5. Effect of the Geometry of the Underfill Fillet	672
24.8. Summary	674
References	674
Chapter 25	
Stress Analysis for Processed Silicon Wafers and Packaged Micro-devices	
<i>Li Li, Yifan Guo and Dawei Zheng</i>	677
25.1. Intrinsic Stress Due to Semiconductor Wafer Processing	677
25.1.1. Testing Device Structure	678
25.1.2. Membrane Deformations	679
25.1.3. Intrinsic Stress	681
25.1.4. Intrinsic Stress in Processed Wafer: Summary	683
25.2. Die Stress Result from Flip-chip Assembly	685
25.2.1. Consistent Composite Plate Model	685
25.2.2. Free Thermal Deformation	687
25.2.3. Bimaterial Plate (BMP) Case	688
25.2.4. Validation of the Bimaterial Model	691
25.2.5. Flip-Chip Package Design	695
25.2.6. Die Stress in Flip Chip Assembly: Summary	697
25.3. Thermal Stress Due to Temperature Cycling	698
25.3.1. Finite Element Analysis	698
25.3.2. Constitutive Equation for Solder	699
25.3.3. Time-Dependent Thermal Stresses of Solder Joint	700
25.3.4. Solder Joint Reliability Estimation	701
25.3.5. Thermal Stress Due to Temperature Cycling: Summary	703
25.4. Residual Stress in Polymer-based Low Dielectric Constant (low- k) Materials	703
References	708
<i>Index</i>	711

List of Contributors

VOLUME I

Avram Bar-Cohen

University of Maryland
College Park, Maryland, USA

Victor Birman

University of Missouri-Rolla
St. Louis, Missouri, USA

H.J.L. Bressers

Philips Semiconductors
Nijmegen, The Netherlands

Alan M. Cassell

NASA Ames Research Center
Moffett Field, California, USA

N. Dariavach

EMC Corp
Hopkinton, Massachusetts, USA

Liang Dong

Lightwaves 2020 Inc.
Milpitas, California, USA

L.J. Ernst

Delft University of Technology
Delft, The Netherlands

Reza Ghaffarian

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, USA

G. Scott Glaesemann

Corning Incorporated
Corning, New York, USA

Claire Gu

University of California, Santa Cruz
Santa Cruz, California, USA

Bongtae Han

University of Maryland
College Park, Maryland, USA

Henry He

Lightwaves 2020 Inc.
Milpitas, California, USA

Xiaoling He

University of Wisconsin
Milwaukee, Wisconsin, USA

Dov Ingman

Technion, Israel Institute of Technology
Haifa, Israel

K.M.B. Jansen

Delft University of Technology
Delft, The Netherlands

J.H.J. Janssen

Philips Semiconductors
Nijmegen, The Netherlands

Kyoung Joon Kim

University of Maryland
College Park, Maryland, USA

Jorma K. Kivilahti

Helsinki University of Technology
Helsinki, Finland

Tomi T. Laurila

Helsinki University of Technology
Helsinki, Finland

J. Liang

EMC Corp
Hopkinton, Massachusetts, USA

Yisi Liu

University of California, Santa Cruz
Santa Cruz, California, USA

Jun Li

NASA Ames Research Center
Moffett Field, California, USA

Toni T. Mattila

Helsinki University of Technology
Helsinki, Finland

Tatiana Mirer

Technion, Israel Institute of Technology
Haifa, Israel

J.J. Pan

Lightwaves 2020 Inc.
Milpitas, California, USA

John H.L. Pang

Nanyang Technological University
Nanyang, Singapore

David T. Read

National Institute of Standards and
Technology
Boulder, Colorado, USA

Sergey Semjonov

Fiber Optics Research Center
Moscow, Russia

D. Shangguan

FLEXTRONICS
San Jose, California, USA

Masaki Shiratori

Yokohama National University
Yokohama, Japan

Andrew A.O. Tay

National University of Singapore
Republic of Singapore

W.D. van Driel

Delft University of Technology
Delft, The Netherlands

C. van't Hof

Delft University of Technology
Delft, The Netherlands

Alex A. Volinsky

University of South Florida
Tampa, Florida, USA

Arkady Voloshin

Lehigh University
Bethlehem, Pennsylvania, USA

A. Wymyslawski

Wroclaw University of Technology
Wroclaw, Poland

Yuan Xu

University of California, Santa Cruz
Santa Cruz, California, USA

D.G. Yang

Delft University of Technology
Delft, The Netherlands

Qiang Yu

Yokohama National University
Yokohama, Japan

G.Q. Zhang

Delft University of Technology
Delft, The Netherlands and
Philips Semiconductors
Eindhoven, The Netherlands

Fengqing Zhou

Lightwaves 2020 Inc.
Milpitas, California, USA

VOLUME II

C. Bailey

University of Greenwich
London, United Kingdom

Christian Bosshard

CSEM SA, Untere Grundlistrasse 1
Alpnach Dorf, Switzerland

Sridhar Canumalla

Nokia
Irving, Texas, USA

H. Anthony Chan

University of Cape Town
Rondebosch, South Africa

Harry K. Charles, Jr.

The Johns Hopkins University
Laurel, Maryland, USA

Shoulung Chen

National Taiwan University
Taiwan

Bernard Courtois

TIMA-CMP
Grenoble Cedex, France

D.W. Dahringer

D.W. Dahringer Consultants
Glen Ridge, New Jersey, USA

Timothy P. Ferguson

Southern Research Institute
Birmingham, Alabama, USA

Yifan Guo

Skyworks Solutions, Inc.
Irvine, California, USA

D. Gwyer

University of Greenwich
London, United Kingdom

George G. Harman

National Institute of Standards and
Technology
Gaithersburg, Maryland, USA

D. Ingman

Technion, Israel Institute of Technology
Haifa, Israel

Nicholas Kao

National Taiwan University
Taiwan

J. Keller

Fraunhofer Institute for Reliability and
Micro Integration (IZM)
Berlin, Germany

Kikuo Kishimoto

Tokyo Institute of Technology
Tokyo, Japan

S.W.R. Lee

Hong Kong University of Science and
Technology
Clear Water Bay, Kowloon, Hong Kong

Grace Y. Li

Georgia Institute of Technology
Atlanta, Georgia, USA

Li Li

Cisco Systems, Inc.
San Jose, California, USA

Johan Liu

Chalmers University of Technology
Goteborg, Sweden

C.C. Lo

Hong Kong University of Science and
Technology
Clear Water Bay, Kowloon, Hong Kong

Ajay P. Malshe

University of Arkansas
Fayetteville, Arkansas, USA

Bernd Michel

Fraunhofer MicroMaterials Center
Berlin, Germany

P. Misselbrook

Celestica
Kidsgrove, Stoke-on-Trent, United
Kingdom
and
University of Greenwich
London, United Kingdom

James E. Morris

Portland State University
Portland, Oregon, USA

Martin Mündlein

Vienna Institute of Technology
Vienna, Austria

Jay Narayan

North Carolina State University
Raleigh, North Carolina, USA

Johann Nicolics

Vienna Institute of Technology
Vienna, Austria

Luu Nguyen

National Semiconductor Corporation
Santa Clara, California, USA

Masaki Omiya

Tokyo Institute of Technology
Tokyo, Japan

Anne-Claire Pliska

CSEM SA, Untere Grundlistrasse 1
Alpnach Dorf, Switzerland

Jianmin Qu

Georgia Institute of Technology
Atlanta, Georgia, USA

Satish Radhakrishanan

Purdue University
West Lafayette, Indiana, USA

Marta Rencz

MicReD Ltd.
Budapest, Hungary

Ganesh Subbarayan

Purdue University
West Lafayette, Indiana, USA

Vladimir Szekely

Budapest University of Technology and
Economics
Budapest, Hungary

C.Z. Tsai

National Taiwan University
Taiwan

Puligandla Viswanadham

Nokia Research Center
Irving, Texas, USA

K. Williams

Loughborough University
Loughborough, United Kingdom

Enboa Wu

National Taiwan University
Taipei, Taiwan

Wei Yang

Tsinghua University
Beijing, P.R. China

Z. Zhang

Georgia Institute of Technology
Atlanta, Georgia, USA

Dawei Zheng

Kotura, Inc.
Monterey Park, California, USA

Preface

This book encompasses a broad area of micro- and opto-electronic engineering materials: their physics, mechanics, reliability, and packaging, with an emphasis on physical design issues and problems. The editors tried to bring in the most eminent engineers and scientists as chapter authors and put together the most comprehensive book ever written on the subjects of materials, mechanics, physics, packaging, functional performance, mechanical reliability, environmental durability and other aspects of reliability of micro- and opto-electronic assemblies, components, devices, and systems. University professors and leading industrial engineers contributed to the book. The contents of the book reflect the state-of-the-art in the above listed fields of applied science and engineering.

The intended audience are all those who work in micro- and opto-electronics, and photonics; electronic and optical materials; applied and industrial physics; mechanical and reliability engineering; electron and optical devices and systems. The expected and targeted readers are practitioners and professionals, scientists and researchers, lecturers and continuing education course directors, graduate and undergraduate students, technical supervisors and entrepreneurs. The book can serve, to a great extent, as an encyclopedia in the field of physics and mechanics of micro- and opto-electronic materials and structures. In the editors' opinion, it can serve also as a textbook, as a reference book, and as a guidance for self- and continuing education, i.e., as a source of comprehensive and in-depth information in its areas. The book's chapters contain both the description of the state-of-the-art in a particular field, as well as new results obtained by the chapter authors and their colleagues.

We would like to point out that many methods and approaches addressed in this book extend far beyond microelectronics and photonics. Although these methods and approaches were developed, advanced and reported primarily in application to micro- and opto-electronic systems, they are applicable also in many related areas of engineering and physics.

The editors are proud of the broad scope of the book, and of the quality of the contributed chapters, and would like to take this opportunity to deeply acknowledge, with thanks, the conscientious effort of the numerous contributors.

February 2006

E. Suhir
C.-P. Wong
Y.-C. Lee