

Contents

1 Microcharacterisation of Materials

| | |
|--------------------------|---|
| F. Ernst, W. Sigle | 1 |
| References | 8 |

2 Electron Scattering

| | |
|--|----|
| H. Müller, H. Rose | 9 |
| 2.1 Introduction | 9 |
| 2.2 The Schrödinger Equation | 10 |
| 2.3 The Scattering Amplitude | 16 |
| 2.4 The Born Approximation | 21 |
| 2.5 The Mutual Dynamic Object Spectrum | 30 |
| 2.6 Mixed Dynamic Form-Factor | 39 |
| 2.7 Coherence Function Approach | 44 |
| 2.8 Generalized Multislice Method | 53 |
| References | 66 |

3 Structure Determination

by Quantitative High-Resolution Electron Microscopy (Q-HRTEM)

| | |
|---|----|
| G. Möbus | 69 |
| 3.1 Introduction | 69 |
| 3.2 Strategies of Structure Retrieval | 71 |
| 3.2.1 Simulation of Image Formation in HRTEM | 71 |
| 3.2.2 Object Classes and Object-Image Relations in HRTEM .. | 73 |
| 3.3 Strain and Pattern Mapping | 78 |
| 3.3.1 Displacement Errors | 79 |
| 3.3.2 Classification of Strain Mapping Techniques | 81 |
| 3.3.3 Local Peak Detection | 81 |
| 3.3.4 Integral Peak Detection | 82 |
| 3.3.5 Geometric Phase Mapping | 84 |
| 3.3.6 Comparison of Techniques and Postprocessing Steps | 86 |
| 3.3.7 Pattern Mapping | 87 |
| 3.3.8 Noise Filters with Structure-Determination Strategies ... | 88 |
| 3.4 Iterative Digital Image Matching (IDIM) | 90 |
| 3.4.1 Algorithms and Modules of Iterative Refinement | 92 |

VIII Contents

| | | |
|-------|---|-----|
| 3.4.2 | Applications in Interface and Dislocation Science | 97 |
| 3.4.3 | Probability Calculus and Precision Estimation | 103 |
| 3.5 | HRTEM-Based Structure Determination Techniques | 107 |
| 3.5.1 | Classification of Techniques | 107 |
| 3.5.2 | List of Techniques Not Covered in This Book | 108 |
| 3.5.3 | A Practical Guide | 111 |
| 3.6 | Conclusions and Outlook | 112 |
| | References | 114 |

4 Quantitative Analytical Transmission Electron Microscopy

| | | |
|-------|---|-----|
| | P. Kohler-Redlich, J. Mayer | 119 |
| 4.1 | Introduction | 119 |
| 4.2 | Basics of Electron Energy-Loss Spectroscopy (EELS) | 121 |
| 4.2.1 | Inelastic Scattering Processes | 121 |
| 4.2.2 | Instrumentation: Dedicated Scanning and Energy-Filtering TEM | 124 |
| 4.3 | Investigation of Interfaces and Grain Boundaries | 127 |
| 4.3.1 | Experimental Techniques | 127 |
| 4.3.2 | Segregation at Grain Boundaries in Copper | 135 |
| 4.3.3 | Bonding at Metal-Ceramic Interfaces | 139 |
| 4.4 | Energy-Filtering Transmission Electron Microscopy | 147 |
| 4.4.1 | Basic Equations for Quantification | 148 |
| 4.4.2 | Elemental Distribution Images | 149 |
| 4.4.3 | Noise Statistics | 150 |
| 4.4.4 | Detection Limits | 151 |
| 4.4.5 | Resolution Limits | 154 |
| 4.4.6 | Preservation of Elastic Scattering Contrast | 160 |
| 4.4.7 | Relativistic Intensity Distribution | 162 |
| 4.4.8 | Quantitative Analysis of ESI Series | 164 |
| 4.4.9 | Analysis of Near-Edge Fine Structure | 168 |
| 4.5 | Quantitative Convergent Beam Electron Diffraction | 171 |
| 4.5.1 | Basic Principles of CBED | 172 |
| 4.5.2 | Determination of Bonding Charge Densities | 173 |
| 4.5.3 | Bonding Charge Density of NiAl | 176 |
| | References | 180 |

5 Advances in Electron Optics

| | | |
|-------|---|-----|
| | H. Rose | 189 |
| 5.1 | Fundamentals of Image Formation | 189 |
| 5.1.1 | Lippmann-Schwinger Equation | 196 |
| 5.1.2 | Kinematic Approximation | 199 |
| 5.1.3 | Phase Contrast | 204 |
| 5.1.4 | Diffraction Patterns | 210 |

| | | |
|--|---|-----|
| 5.2 | Properties of Aplanatic Electron Lenses | 212 |
| 5.2.1 | Sine Condition | 213 |
| 5.2.2 | Axial Aberrations | 215 |
| 5.2.3 | Generalized Coma | 217 |
| 5.3 | Perturbation Formalism | 219 |
| 5.3.1 | Gaussian Optics | 221 |
| 5.3.2 | Path and Momentum Deviations | 223 |
| 5.3.3 | Iteration Algorithm | 228 |
| 5.3.4 | Symplectic Representation | 231 |
| 5.3.5 | Canonical Boundary Conditions | 235 |
| 5.3.6 | Systems with Special Symmetry | 237 |
| 5.4 | Systems with Threefold Symmetry | 239 |
| 5.4.1 | Paraxial Trajectories | 240 |
| 5.4.2 | Second-Order Path Deviation | 241 |
| 5.4.3 | Third-Order Aberrations | 245 |
| 5.4.4 | Outline of a Fifth-Order Double Anastigmat | 251 |
| 5.5 | W-Filter | 253 |
| 5.5.1 | Geometry of the W-Filter | 254 |
| 5.5.2 | Paraxial Trajectories | 255 |
| 5.5.3 | SCOFF Design | 257 |
| 5.5.4 | Second-Rank Aberrations | 264 |
| 5.6 | Conclusion | 267 |
| | References | 269 |
| 6 Tomography by Atom Probe Field Ion Microscopy | | |
| | T. Al-Kassab, H. Wollenberger, G. Schmitz, R. Kirchheim | 271 |
| 6.1 | Introduction | 271 |
| 6.2 | Experimental Technique | 271 |
| 6.2.1 | The Field Ion Microscope (FIM) | 272 |
| 6.2.2 | The Atom Probe (APFIM) | 275 |
| 6.2.3 | The Position-Sensitive Detectors (PSD) | 277 |
| 6.3 | Tomography | 286 |
| 6.3.1 | The Ion Trajectories | 286 |
| 6.3.2 | Image Projections | 288 |
| 6.3.3 | Tomographic Reconstruction | 290 |
| 6.3.4 | Data Analysis | 293 |
| 6.3.5 | Artefacts of the Reconstruction | 294 |
| 6.4 | Atom Probe Tomography in Materials Studies | 298 |
| 6.4.1 | Distribution of Solutes | 298 |
| 6.4.2 | Early Stages of Phase Formation | 300 |
| 6.4.3 | Segregation Phenomena | 311 |
| | References | 316 |
| | List of Standard Abbreviations | 319 |
| | List of Standard Abbreviations | 320 |

| | |
|--|---|
| 7 Scanning Tunneling Microscopy (STM) | |
| and Spectroscopy (STS), Atomic Force Microscopy (AFM) | |
| H. Neddermeyer, M. Hanbücken | 321 |
| 7.1 | Introduction |
| 7.2 | Scanning Tunneling Microscopy (STM) |
| 7.3 | Scanning Tunneling Spectroscopy (STS) |
| 7.4 | Atomic Force Microscopy (AFM) |
| 7.5 | Special Techniques |
| 7.5.1 | Generalities |
| 7.5.2 | STM in Electrochemistry |
| 7.6 | Combination of STM with Other Techniques |
| 7.6.1 | STM and Low-Energy Electron Diffraction |
| 7.6.2 | STM and Surface X-ray Diffraction |
| 7.7 | In situ Studies of Adsorption, Reaction and Growth |
| 7.7.1 | Vicinal Surfaces of Silicon |
| 7.7.2 | Silicon Surfaces at High Temperatures |
| 7.7.3 | Initial Stages of Oxygen Interaction and Oxidation of Silicon Surfaces |
| 7.7.4 | Growth of Silicon by Chemical Vapour Deposition |
| 7.7.5 | Lithography: Fabrication of Nanostructures |
| 7.7.6 | Biological Material and Polymers |
| 7.8 | Prospects for the Future |
| | References |
| 8 Multi-Method High-Resolution Surface Analysis | |
| with Slow Electrons | |
| E. Bauer, T. Schmidt | 363 |
| 8.1 | Introduction |
| 8.2 | Interaction of Slow Electrons with Condensed Matter |
| 8.3 | Electron-Optical Considerations |
| 8.4 | Analytic Methods in the SPELEEM |
| 8.4.1 | SPELEEM |
| 8.4.2 | LEEM |
| 8.4.3 | Comparison of AEEM and XPEEM |
| 8.4.4 | XPEEM with the SPELEEM |
| 8.5 | Some Applications of SPELEEM |
| 8.6 | Concluding Remarks and Outlook |
| | References |
| 9 From Microcharacterization to Macroscopic Property: | |
| A Pathway Discussed on Metal/Ceramic Composites | |
| J. Rödel | 391 |
| 9.1 | Introduction |
| 9.2 | Interfacial Decohesion |

| | | |
|--|---|-----|
| 9.3 | Metal/Ceramic Interfaces | 396 |
| 9.3.1 | Background | 396 |
| 9.3.2 | Materials and Mechanical Testing | 397 |
| 9.3.3 | Characterisation of Microstructures and Interfaces | 399 |
| 9.3.4 | Mechanical Properties | 400 |
| 9.4 | Metal/Ceramic Composites with Interpenetrating Networks | 401 |
| 9.4.1 | Materials | 402 |
| 9.4.2 | Characterisation of Microstructures and Interfaces | 403 |
| 9.4.3 | Residual Stresses | 407 |
| 9.4.4 | Thermomechanical Behavior | 408 |
| 9.4.5 | Mechanical Properties | 410 |
| 9.5 | Outlook: Future Requirements and Developments | 415 |
| | References | 416 |
| 10 Microstructural Characterization of Materials: An Assessment | | |
| | R.W. Cahn, G. Ertl, J. Heydenreich | 419 |
| 10.1 | Microcharacterization of Materials | 419 |
| | Contributing Institutions | 432 |
| | Index | 435 |

High-Resolution Imaging and Spectrometry of Materials

Ernst, F.; Rühle, M. (Eds.)

2003, XIV, 442 p., Hardcover

ISBN: 978-3-540-41818-4