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Editors

Transparent Conductive Zinc Oxide

Basics and Applications in Thin Film Solar Cells

With 270 Figures, 5 in color and 50 Tables

Springer

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Preface

Zinc oxide is a widely applied material in industry. It is produced in hundreds of thousands of tons for paints (chinese white), additive for rubber and plastics, catalysts, pharmaceuticals and cosmetics (sun creams), or as coating material for paper. In electronics industry ZnO is used in nickel- or manganese–zinc ferrites, as ingredient of phosphors, in surface-acoustic wave filters and as a transparent electrode. Zinc oxide is a wide bandgap compound semiconductor ($E_g = 3.2\,\mathrm{eV}$) which has been investigated as an electronic material for many decades, starting in the 1930s. It belongs to the class of transparent conducting oxides (TCO). The other important oxides are indium and tin oxide. Recently, fundamental and applied research on zinc oxide experienced a renaissance due to the prospective use of zinc oxide as an optoelectronic material for blue and UV lasers. Moreover, thin ZnO films are important components in most thin film solar cells. The cost-effective large-scale production of these films on the one hand and the development of ZnO films with improved properties on the other hand are key challenges in the field of production and R&D in photovoltaics.

Renewable energies are one or even the only answer to provide the world energy demand on the long term in a sustainable way. Moreover, the world is facing climate changes due to green house gas emissions, and the limitation of these emissions is one of the key challenges of the global society. Solar energy bears the largest potential of all renewable energy sources, however, it is still rather expensive for many large-scale applications today. The direct conversion of sunlight into electricity by photovoltaic (PV) solar modules has grown by 20–40% per annum during the last decade and has emerged to a billion Euro market. Significant cost reductions have been achieved and there is a huge potential to bring the costs down further. Currently, PV module production is dominated by crystalline silicon solar cells, which are based on Si wafers with a typical thickness of around 150–300 µm. However, the production of the comparatively thick silicon wafers involves high process temperatures and very pure silicon as an expensive feedstock material, partly limiting the potential for cost reductions. Thin-film solar cells require only a few micrometers of film thickness to absorb most of the sunlight and thus bear a great potential for significantly reducing the cost of photovoltaic energy conversion due to low material consumption, simple production techniques and high productivity by depositing on large areas. In addition, low-temperature processing and low material consumption save energy during production leading to short energy pay-back times.

Thin films of ZnO play an essential role in most thin film solar cells being produced today. ZnO films serve as transparent and conductive front contact, provide additional optical functions like light scattering and subsequent light trapping or enhance the reflection at the back contact. In heterojunction solar cells based on chalcopyrite absorber layers, ZnO is an inherent part of the p/n-junction. In general, ZnO films with improved optical, electronic or structural properties promise higher conversion efficiencies while the development of process technologies providing an optimum film quality on large areas at high growth rates are an essential prerequisite to meet the cost targets in production. Examples of long-term scientific challenges are the development of adapted nano-structured ZnO films, like e.g. ZnO nanorods, or p-type ZnO films which may both open up new possibilities for designing future thin film solar cells.

This book is devoted to the properties, preparation and applications of zinc oxide (ZnO) as an transparent electrode material. It focuses on ZnO for thin film solar cell applications and hopefully inspires also readers from related fields. The book is structured into three parts to serve both as an overview as well as a data collection for students, engineers and scientists. The first part, Chaps. 1–4, provide an overview of the application and fundamental material properties of ZnO films and their surface and interfaces properties. Chaps. 5–7 review thin film deposition techniques applied for ZnO preparation on lab scale but also for large area production. Finally, Chaps. 8 and 9 are devoted to applications of ZnO in silicon- and chalcopyrite-based thin film solar cells, respectively. One should note that the application of CVD grown ZnO in silicon thin film cells is discussed earlier in Chap. 6.

The idea to write this book evolved during a research project on zinc oxide in thin film solar cells, initiated by the German association "Forschungsverbund Sonnenenergie" and financed by the German Ministry of Education and Research which are gratefully acknowledged. Last, but not least, we thank all our colleagues who contributed with questions, discussions and data to this book.

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Contents

1 ZnO and Its Applications
K. Ellmer and A. Klein 1
1.1 Introduction 1
1.2 Zinc Oxide 2
1.3 Properties of ZnO 4
1.4 Material Preparation 9
1.4.1 Growth of ZnO Single Crystals 9
1.4.2 Deposition of ZnO Thin Films 9
1.4.3 Preparation of ZnO Nanostructures 11
1.5 Electronic Structure of ZnO 12
1.6 Intrinsic Defects in ZnO 14
1.6.1 Thermodynamic Properties 14
1.6.2 Self-Diffusion in ZnO 19
1.7 Applications of ZnO 21
1.7.1 Transparent Electrodes 24
1.7.2 Varistors 25
1.7.3 Piezoelectric Devices 26
1.7.4 Phosphors 26
1.7.5 Transparent Oxide Thin Film Transistors 26
1.7.6 Spintronics 27
References 27

2 Electrical Properties
K. Ellmer 35
2.1 Electrical Properties of ZnO Single Crystals 36
2.1.1 Dopants in ZnO Single Crystals 38
2.1.2 Electrical Transport in ZnO Single Crystals 41
2.2 Electrical Transport in Polycrystalline ZnO 53
2.2.1 ZnO Varistors 53
2.2.2 Thin ZnO Films 56
2.2.3 Transport Processes in Polycrystalline Films 57
2.2.4 Experimental Mobility Data of Polycrystalline ZnO 61
2.3 Outlook: Higher Electron Mobilities in Zinc Oxide 67
2.4 Transparent Field Effect Transistors with ZnO 70

2.5 Search for p-Type Conductivity in ZnO 71
References 72

3 Optical Properties of ZnO and Related Compounds
C. Bundesmann, R. Schmidt-Grund, and M. Schubert 79
3.1 Introduction 79
3.2 Basic Concepts and Properties 81
3.2.1 Structural Properties 81
3.2.2 Vibrational Properties 83
3.2.3 Infrared Model Dielectric Function: Phonons and Plasmons .. 85
3.2.4 Visible-to-Vacuum-Ultraviolet Model Dielectric Function: Band-to-Band Transitions and their Critical-Point Structures 86
3.2.5 Spectroscopic Ellipsometry 88
3.3 Dielectric Constants and Dielectric Functions 90
3.4 Phonons 92
3.4.1 Undoped ZnO 92
3.4.2 Doped ZnO 98
3.4.3 $Mg_xZn_{1-x}O$ 99
3.4.4 Phonon Mode Broadening Parameters 100
3.5 Plasmons 102
3.6 Below-Band-Gap Index of Refraction 105
3.6.1 ZnO 105
3.6.2 $Mg_xZn_{1-x}O$ 106
3.7 Band-to-Band Transitions and Excitonic Properties 108
3.7.1 ZnO 108
3.7.2 $Mg_xZn_{1-x}O$ 116
References 118

4 Surfaces and Interfaces of Sputter-Deposited ZnO Films
A. Klein and F. Säuberlich 125
4.1 Introduction 126
4.1.1 Semiconductor Interfaces 126
4.1.2 ZnO in Thin-Film Solar Cells 127
4.1.3 Photoelectron Spectroscopy (PES) 128
4.2 Surface Properties of ZnO 131
4.2.1 Crystallographic Structure of ZnO Surfaces 131
4.2.2 Chemical Surface Composition of Sputtered ZnO Films 133
4.2.3 Electronic Structure of ZnO Surfaces 139
4.3 The CdS/ZnO Interface 149
4.3.1 Band Alignment of II–VI Semiconductors 149
4.3.2 Sputter Deposition of ZnO onto CdS 151
4.3.3 Dependence on Preparation Condition 156
4.3.4 Summary of CdS/ZnO Interface Properties 162
4.4 The $Cu(In,Ga)Se_2$/ZnO Interface 164

4.4.1 Chemical Properties 165
4.4.2 Electronic Properties 169
4.5 The In_2S_3/ZnO Interface 172
4.5.1 Cu(In,Ga)Se_2 Solar Cells with In_2S_3 Buffer Layers 172
4.5.2 Chemical Properties 173
4.5.3 Electronic Properties 176
References 180

5 Magnetron Sputtering of ZnO Films
B. Szyszka 187
5.1 Introduction 187
5.2 History of ZnO Sputtering 188
5.3 Magnetron Sputtering 189
5.3.1 Glow Discharge Characteristics 190
5.3.2 Processes at the Target Surface 190
5.3.3 Magnetron Operation 192
5.3.4 Magnetron Sputtering of ZnO 194
5.3.5 Ceramic Target Magnetron Sputtering 215
5.3.6 Other Technologies for Sputter Deposition of ZnO 217
5.4 Manufacturing Technology 218
5.4.1 In-Line Coating 218
5.4.2 Rotatable Target Magnetron Sputtering 225
5.5 Emerging Developments 227
5.5.1 Ionized PVD Techniques 227
5.5.2 Hollow Cathode Sputtering 227
5.5.3 Model-Based Process Development 228
References 229

6 Zinc Oxide Grown by CVD Process as Transparent Contact for Thin Film Solar Cell Applications
S. Faÿ and A. Shah 235
6.1 Introduction 235
6.1.1 History of ZnO Growth by CVD Process 235
6.1.2 Extrinsic Doping of CVD ZnO 236
6.2 Development of Doped CVD ZnO Films 238
6.2.1 Influence of Deposition Pressure 238
6.2.2 Growth Mechanisms for CVD ZnO 241
6.2.3 Influence of Substrate Temperature 252
6.2.4 Influence of Precursor Flux 261
6.2.5 Doping of CVD ZnO Films 266
6.2.6 The Effect of Grain Size on Electrical and Optical Properties of CVD ZnO Layers 277
6.2.7 Alternative CVD Methods for Deposition of Thin ZnO Films 279

6.3 CVD ZnO as Transparent Electrode for Thin Film Solar Cells ... 280
6.3.1 Characteristics Required for CVD ZnO Layers Incorporated within Thin Film Solar Cells ... 280
6.3.2 Experimental Results ... 289
6.4 Conclusions ... 298
References ... 299

7 Pulsed Laser Deposition of ZnO-Based Thin Films
M. Lorenz ... 303
7.1 Brief History and Basics ... 303
7.2 Fundamental Processes and Plasma Diagnostics ... 305
7.3 PLD Instrumentation and Parameters for ZnO ... 309
7.4 Results on Epitaxial PLD ZnO Thin Films ... 313
7.4.1 Structure of Nominally Undoped PLD ZnO Thin Films ... 314
7.4.2 Surface Morphology of PLD ZnO Thin Films ... 319
7.4.3 Electrical Properties of PLD ZnO Thin Films: Effect of Buffer Layers ... 322
7.4.4 Luminescence of PLD ZnO Thin Films on Sapphire ... 327
7.4.5 Chemical Composition of Doped PLD ZnO Films and Doping Effects ... 331
7.5 Demonstrator Devices with PLD ZnO Thin Films ... 336
7.5.1 Large-area ZnO Scintillator Films ... 338
7.5.2 Bragg Reflector Mirrors and ZnO Quantum Well Structures ... 340
7.5.3 Schottky Diodes to ZnO Thin Films ... 341
7.5.4 PLD of ZnO pn-Junctions, First LEDs, and Other Highlights ... 344
7.6 Advanced PLD Techniques ... 346
7.6.1 Advances in PLD of Thin Films ... 346
7.6.2 High-Pressure PLD of ZnO-Based Nanostructures ... 348
7.7 Summary ... 349
References ... 350

8 Texture Etched ZnO:Al for Silicon Thin Film Solar Cells
J. Hüpkes, J. Müller, and B. Rech ... 359
8.1 Introduction ... 359
8.2 Silicon Thin Film Solar Cells ... 361
8.2.1 Principle of Operation ... 361
8.2.2 Amorphous and Microcrystalline Silicon ... 363
8.2.3 Design Aspects of Silicon Thin Film Solar Cells ... 365
8.2.4 Requirements for TCO Contacts ... 368
8.2.5 Solar Module Aspects ... 373
8.2.6 Approaches for Light Trapping Optimization ... 375
8.3 Sputter Deposition and Etching of ZnO:Al ... 377
8.3.1 Properties of Sputter Deposited ZnO:Al ... 378

8.3.2 Etching Behavior of Zinc Oxide 379
8.3.3 Practical Aspects for Etching of Sputtered ZnO:Al 392
8.4 High Efficiency Silicon Thin Film Solar Cells 393
8.4.1 Optimization of Solar Cells 393
8.4.2 Highly Transparent ZnO:Al Front Contacts 401
8.4.3 Application of Texture Etched ZnO:Al Films in High Efficiency Solar Cells and Modules 403
8.5 Summary 404
References 406

9 Chalcopyrite Solar Cells and Modules
R. Klenk 415
9.1 Heterojunction Formation 415
9.1.1 Why Use an Undoped ZnO Layer? 418
9.2 Transparent Front Contact 419
9.2.1 Monolithic Integration 420
9.2.2 Optical Losses 423
9.3 Manufacturing 423
9.3.1 Chemical Vapour Deposition 425
9.3.2 Sputtering 425
9.4 Stability 427
9.4.1 Module Degradation 428
9.5 Nonconventional and Novel Applications 431
9.5.1 Direct ZnO/Chalcopyrite Junctions 431
9.5.2 Superstrates 432
9.5.3 Transparent Back Contact 432
References 434

Index 439