Table of Contents

Streszczenie 9

Abstract 10

List of Symbols 11

List of Acronyms 21

Acknowledgements 25

1. Introduction 27
1.1. Why Amorphous Silicon? 28
1.2. Ground Thin Film Silicon Electronics Structures 29
1.3. Instability of Amorphous Silicon Film Based Devices 32

2. Growth of Amorphous, Micro- and Poly- Silicon Material 34
2.1. Comparison of Deposition Methods 34
2.2. Plasma Enhanced Chemical Vapour Deposition (PECVD) 37
2.2.1. Example of Optimized Deposition Conditions and Apparatus Developed by the Author 40
2.3. Deposition Phase Diagrams Allow Controlling of the Technology 42
2.4. Reactive Magnetron Sputtering (RMS) 45
2.4.1. Experimental Details 47
2.5. Large Area Deposition and Production Systems 50
2.6. Conclusion 51

3. Basic Measurements and Properties of Thin Silicon Films 53
3.1. a-Si:H Films Studied by Schottky Barrier Method 55
3.1.1. An Example of Schottky Barrier Classical Studies 56
3.1.2. An Example of Analysis of Gap States by the Schottky Barrier 59
3.2. Photoconductivity 61

3.2.1. Sub-Bandgap Absorption 63
3.2.2. Hole Drift Mobility in a-Si:H 66
3.2.3. The Midgap Density of States Assisted Controlling of Deposition Process 71
3.3. Hydrogen Decides about a Set of Final Film Properties 72
3.3.1. Hydrogen Content 73
3.3.2. Study of a-Si:H Film Properties by IR Evolution Measurement 75
3.3.3. Optimization of Al/a-SiN_x/a-Si:H Structure 77
3.3.4 The Hydrogen Bonding in Microcrystalline Silicon 84
3.3.5. Hydrogen Effusion from Silicon Films 84
3.3.6. Analysis of NMR Measurements 86
3.4. Microcrystalline and Polycrystalline Silicon 88
3.4.1. Raman Spectroscopy 89
3.4.2. Orientation and Size of the Grains by X-ray Diffraction 91
3.4.3. Study of Al/n^+/i and TCO/p^+/i a-Si:H Structure by X-ray Small Angle Method 92
3.4.4. Studies of the Amorphous/Microcrystalline Structure by AFM Method 95
3.4.5. The Band Gap E_g, the Photo- and Dark Conductivity σ_{ph} and σ_d and the Activation Energy E_A 97
3.4.6. Experiments with Laser Crystallized Amorphous Film 100
3.5. Doped Materials 103
3.5.1. Doped Amorphous Silicon and Silicon Alloys 103
3.5.2. Conductivity of Doped a-Si:H Films 105
3.6. Electron Spin Resonance in the Analysis of Doped Silicon Films 107
3.6.1. Effectiveness of the p/i and i/n Junctions Applied in Optoelectronic Structures 111
3.6.2. Summary of Silicon Thin Film Parameters Allowing Inspection of the Deposition Process 113
3.7. Conclusion 116

4. Metastability, Thermal Equilibrium and Role of Hydrogen in a-Si:H 119
4.1. Introduction 119
4.2. Creation and Annealing of Defects 120
4.3. Examples of the Staebler–Wronski Effect (SWE) in a-Si:H 122
4.4. Nature of a-Si:H and Metastability 127
4.4.1. Hydrogen-Mediated Weak Bond/Dangling Bond Conversion and Distribution of Localized Defect States in a-Si:H 127
4.4.2. Simple Models Describing Electron States in a-Si:H and Energy Distribution of Hydrogen 129
4.4.3. H-bonding States in a-Si:H and Hydrogen Diffusion 131

4.5. New Experimental Data and Theories of Metastability 133
4.6. Methods of Reducing the SWE 137
4.7. Conclusions 139

5. Amorphous, Microcrystalline and Polycrystalline Si Thin Film Transistors and TFT Matrix 141
5.1. a-Si:H TFT Described Like MOSFET Transistors 143
5.1.1. TFT Characteristics Assisted Designing of Improved TFT Devices 147
5.1.2. Method of Measurement of TFTs Configured in Line Form 153
5.2. How to Avoid Threshold Voltage Shift 155
5.3. Influence of X-Radiation on a-Si:H TFT Threshold Voltage 160
5.4. Modelling of a-Si:H TFT Behaviour 165
5.5. Electrolyte Gate a-Si:H TFT (ISFET) 173
5.6. A Comparison of the Author's μc-Si:H TFT with the World Achievements 177
5.7. New Solutions for Reducing Instabilities 185
5.8. Conclusions and Requirements of a TFT 189

6. p-i-n Photodiode Sensor 192
6.1. The Sensor Photocurrent 193
6.1.1. Reverse Bias Dark and Light Current 193
6.2. Current Stability 199
6.2.1. Thick Photodiode Sensors 200
6.2.2. Reasons for the Image Lag 201
6.3. Application of Large Area Image Sensors-Medical X-ray Imaging 201
6.3.1. Introduction 201
6.3.2. Spatial Resolution, Frame Rate, Signal to Noise Ratio and Long Term Stability 203
6.3.3. X-ray Scintillators and Photoconductors 205
6.3.4. Example of a Test X-ray Matrix 208
6.3.5. Smart and Self-Correcting Pixel Sensors 212
6.3.6. The Author's Achievements and New Ideas for a TFT 214
6.4. Conclusion 215

7. Silicon Thin Film Solar Cells 217
7.1. Operation of a Silicon Thin Film Solar Cell 220
7.1.1. Analysis of a Standard a-Si:H Cell Operation 220
7.1.2. Instabilities and Improvements of Solar Cells 225
7.2. Electrical and Optical Device Modelling 227
7.2.1. Simulation Programs: AMPS and Simul-SC 228
7.2.2. Defect Pool Model and Recombination Statistic in Amorphous Silicon 230

7.2.3. Analysis of the Dark Forward Current 233
7.2.4. An Example of Solar Cell Modelling 237
7.2.5. Optical Properties and Modelling of the a-Si:H Solar Cell Layers 239
7.3. Optimalization of Solar Cell Construction 242
7.3.1. Front System with Substrate, Texturization, TCO and Antireflection Films of Single or Multijunction Solar Cells 243
7.3.2. An Example of the Improvment of the Efficiency of Solar Cells with Double Side Coatings 246
7.3.3. Single or Multijunction p-i-n Si:H System with p^+ Window in the Superstrate and Substrate Configuration of Solar Cells 248
7.3.4. Back Electrode Systems 250
7.4. a/μc-Si:H Based Solar Cell Technologies 254
7.4.1. Multijunction Solar Cell Structures Made by the Author 254
7.4.2. An Example of Tandem Solar Cell Optimalization 259
7.5. Analysis of I-V Characteristics of Thin Film Solar Cells 266
7.5.1. Light and Dark I-V Characteristics 268
7.5.2. I-V Curve with Varying Illumination 270
7.5.3. Extraction of the Solar Cell Parameters 275
7.6. Examples of the Best Thin Silicon Solar Cells in the World 279
7.6.1. Record Thin Silicon Solar Cells 279
7.6.2. Thin Silicon Modules 281
7.7. Manufacturing of Modules 283
7.7.1. BP Solarex on Glass Technology 283
7.7.2. United Solar Ovonic Corporation Superstrate Technology 285
7.8. Conclusions 286

8. Summary and Outlook 289

References 292