



High-rate growth of hydrogenated amorphous and microcrystalline silicon for thin-film silicon solar cells using dynamic very-high frequency plasma-enhanced chemical vapor deposition

Thomas Zimmermann

Forschungszentrum Jülich GmbH
Institute of Energy- and Climate Research (IEK)
Photovoltaics (IEK-5)

High-rate growth of hydrogenated amorphous and microcrystalline silicon for thin-film silicon solar cells using dynamic very-high frequency plasma-enhanced chemical vapor deposition

Thomas Zimmermann

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 183

ISSN 1866-1793

ISBN 978-3-89336-892-1

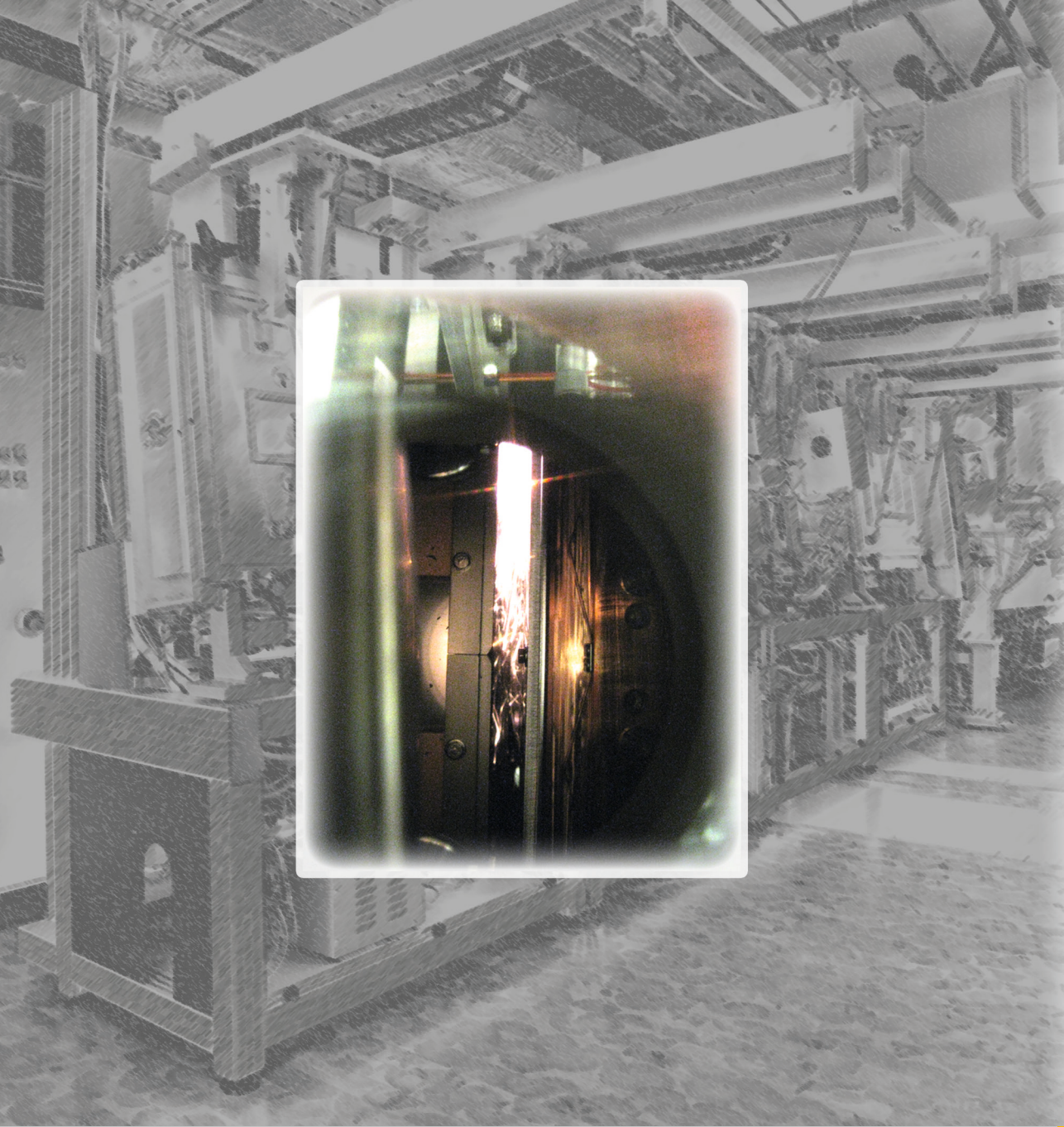
Contents

Abstract	iii
1 Introduction	1
2 Fundamentals	5
2.1 Thin-film silicon tandem solar cell	5
2.2 Preparation of a-Si:H and μ c-Si:H	7
2.2.1 Plasma Enhanced Chemical Vapor Deposition	7
2.2.2 Process parameters	8
2.2.3 Large-area deposition system (LADA)	9
2.3 Growth of a-Si:H and μ c-Si:H	11
2.3.1 Surface diffusion model	12
2.3.2 Etching model	13
2.3.3 Chemical annealing model	13
2.4 Material properties	14
2.4.1 Optical properties	14
2.4.2 Dangling bonds and hydrogen incorporation	15
2.4.3 Staebler-Wronski effect	15
2.5 Characterization methods	16
2.5.1 Conductivity measurement	16
2.5.2 Photothermal deflection spectroscopy	17
2.5.3 Raman spectroscopy	18
2.5.4 Fourier transform infrared spectroscopy	19
2.5.5 Current-voltage measurement	21
2.5.6 Differential spectral response	23

3	Development of a dynamic deposition technique for thin-film silicon	25
3.1	Large area deposition using very-high frequencies	25
3.1.1	State-of-the-art VHF-PECVD systems	26
3.1.2	Concept of dynamic deposition using linear plasma sources	28
3.2	Prerequisites for a uniform dynamic deposition process	29
3.3	Experimental realization of a dynamic deposition process	30
3.3.1	Development of a stable carrier grounding	30
3.3.2	Design of the transport system	32
3.3.3	Temperature control during dynamic deposition processes	33
3.3.4	Linear gas distribution system	35
3.4	Process sequence for thin-film silicon solar cells	36
3.5	Conclusions	38
4	Dynamic deposition of $\mu\text{c-Si:H}$ solar cells	39
4.1	Baseline static radio-frequency deposition process	39
4.1.1	Influence of the crystallinity on the solar cell performance	40
4.1.2	Correlation between growth rate and crystallinity	42
4.1.3	Summary	43
4.2	Implications of a linear gas distribution system	44
4.2.1	Homogeneity of solar cell performance	44
4.2.2	Local growth rate and crystallinity	46
4.2.3	Summary	48
4.3	Comparison of $\mu\text{c-Si:H}$ solar cells deposited by static RF- and VHF-PECVD processes	48
4.3.1	Influence of the crystallinity on the solar cell performance	48
4.3.2	Correlation between growth rate and crystallinity	51
4.3.3	Summary	52
4.4	Reduced deposition times for $\mu\text{c-Si:H}$ absorber layers	53
4.4.1	Correlation between growth rate and solar cell efficiency	54
4.4.2	Influence of i-layer thickness on solar cell efficiency	55
4.4.3	Summary	56
4.5	Dynamic deposition of $\mu\text{c-Si:H}$ absorber layers	57
4.5.1	Influence of the dynamic deposition process on the solar cell performance	57

4.5.2	Sources of reduced layer quality in dynamic deposition processes .	60
4.5.3	Influence of the dynamic deposition processes on the transition from microcrystalline to amorphous layer growth	62
4.5.4	Homogeneity of dynamic deposition process	63
4.5.5	Summary	64
4.6	Effects of changing silane concentrations during i-layer growth on $\mu\text{c-Si:H}$ solar cells	64
4.6.1	Variation in growth conditions due to dynamic deposition processes	65
4.6.2	Influence of the gas utilization on $\mu\text{c-Si:H}$ solar cells	67
4.6.3	Influence of the thickness per period on $\mu\text{c-Si:H}$ solar cells	69
4.6.4	Summary	71
4.7	Conclusions	71
5	Dynamic deposition of a-Si:H solar cells	73
5.1	Influence of the deposition rate on the i-layer properties	73
5.1.1	Hydrogen incorporation	74
5.1.2	Electrical properties	76
5.1.3	Optical properties	77
5.1.4	Summary	79
5.2	Influence of the deposition rate on the solar cell performance	79
5.2.1	Initial and stabilized solar cell performance as a function of the deposition rate	80
5.2.2	Influence of the process parameters on the stabilized open-circuit voltage and short-circuit current density	82
5.2.3	Origin of reduced short-circuit current density at high growth rates	84
5.2.4	Summary	85
5.3	Influence of the process parameter on the degradation loss	86
5.4	Interdependency of process parameters	88
5.5	Reduced deposition times for thin-film silicon tandem solar cells	90
5.5.1	Simplified tandem solar cell model	91
5.5.2	Correlation between growth rate and solar cell performance	92
5.5.3	Discussion of the model validity	94
5.5.4	Summary	95
5.6	Conclusions	95

6 Summary and Outlook	97
Appendix A Material properties of doped layers	103
Appendix B Deposition regimes for intrinsic μc-Si:H	104
Appendix C Deposition regimes for intrinsic a-Si:H	106
Bibliography	107
Acknowledgements	121
List of Publications	123
Curriculum Vitae	126



Energie & Umwelt / Energy & Environment
Band / Volume 183
ISBN 978-3-89336-892-1