

Table of contents

1	Introduction	1
2	The concepts of crystalline silicon thin-film solar cells	5
2.1	Introduction.....	5
2.2	Advantages of crystalline silicon thin-film solar cells	5
2.3	Low-temperature approach	6
2.4	High-temperature approach	7
2.4.1	Epitaxial wafer-equivalents	8
2.4.2	Zone-melted crystalline films	10
2.4.3	Transfer techniques	10
2.5	Summary.....	11
3	Silicon deposition by Chemical Vapour Deposition (CVD)	13
3.1	Silicon deposition techniques	13
3.2	Principle of thermal atmospheric pressure CVD	14
3.2.1	Reaction kinetics for Trichlorosilane and Silicontetrachloride	15
3.2.2	Growth rate	16
3.2.3	Chemical yield	17
3.2.4	Dopant incorporation	17
3.3	Deposition concept and reactors at Fraunhofer ISE	23
3.3.1	Deposition principle.....	24
3.3.2	RTCVD100	25
3.3.3	RTCVD160	26
3.3.4	ConCVD	27
3.4	Process control	28
3.4.1	Process sequence.....	28
3.4.2	Doping.....	29
3.4.3	Layer thickness homogeneity	29
3.4.4	Epitaxial quality	30
3.5	Summary.....	31

4	Optimisation of crystalline silicon thin-film solar cells	33
4.1	Basic principles.....	33
4.1.1	Simulation tool.....	33
4.1.2	High-efficiency solar cell process.....	35
4.1.3	Screen-printing solar cell process.....	35
4.2	Optimisation of the substrates.....	36
4.2.1	Pre-deposition cleaning.....	36
4.2.2	Block position of off-spec cast mc.....	38
4.2.3	Gettering of off-spec cast mc substrates.....	40
4.3	Optimisation of the epitaxial layer.....	41
4.3.1	Epitaxial BSF.....	41
4.3.2	Base lifetime.....	43
4.3.3	Base thickness.....	45
4.3.4	Base doping level.....	46
4.3.5	Graded base profile.....	48
4.3.6	Precursor.....	51
4.4	Summary.....	54
5	Epitaxy of emitters	57
5.1	Introduction.....	57
5.1.1	Advantages of emitter deposition in photovoltaics.....	57
5.1.2	Limitations of the deposition process and reactor.....	58
5.2	p-type emitters on n-type wafers.....	60
5.2.1	Approach and solar cell process.....	60
5.2.2	First results.....	61
5.2.3	Two-layer emitters.....	64
5.2.4	Further improvements.....	66
5.3	n-type emitters on p-type wafers.....	67
5.3.1	Phosphine flow during cooling.....	68
5.3.2	Solar cells with texturing.....	69
5.4	n-type epitaxial emitters for cSiTF solar cells with evaporated contacts..	71
5.4.1	Emitter treatments after deposition.....	71
5.4.2	Improved two-layer emitters.....	74
5.4.3	Simulation of an optimised emitter.....	78
5.4.4	Recombination in epitaxial emitters.....	82

5.4.5 Implementation of texture.....	86
5.5 n-type epitaxial emitters for cSiTF solar cells with screen-printed contacts.....	88
5.5.1 Design of the doping profile	88
5.5.2 Contact formation	89
5.5.3 Solar cells.....	91
5.5.4 Alternative emitter structures.....	94
5.6 Summary.....	95
6 HCl gas etching of crystalline silicon	97
6.1 Etch mechanism	97
6.1.1 Surface kinetics	97
6.1.2 Etch rate	99
6.1.3 Surface morphology.....	100
6.2 Optical confinement by surface texturing.....	103
6.2.1 Optical properties.....	104
6.2.2 Electrical properties	108
6.3 Optical confinement by porous intermediate layers	110
6.3.1 Functional principle of porous silicon	110
6.3.2 Creation and reorganisation of pores	112
6.3.3 Epitaxial layer quality	114
6.3.4 Solar cells.....	116
6.4 Gettering effect of HCl etching	118
6.5 HCl gettering of multicrystalline wafers	120
6.5.1 Experimental method.....	120
6.5.2 Variation of temperature and HCl concentration.....	121
6.5.3 Dependence on time.....	124
6.6 HCl gettering and epitaxy on metallurgical silicon substrates	125
6.6.1 Impurity concentrations	126
6.6.2 Microscopic analysis of the substrate gettering.....	128
6.6.3 Epitaxial growth.....	130
6.6.4 Solar cells.....	132
6.7 Summary.....	134
7 Summary	137

8 Outlook	141
Deutsche Zusammenfassung	143
Appendix A Solar cell fundamentals	147
Appendix A.1 I-V characteristics	147
Appendix A.2 Recombination mechanisms	148
Appendix B Measurements methods	150
Appendix B.1 Spreading resistance profiling (SRP)	150
Appendix B.2 Secondary ion mass spectrometry (SIMS)	151
Appendix B.3 Glow discharge mass spectrometry (GDMS).....	151
Appendix B.4 Neutron activation analysis (NAA)	152
Nomenclatures List	153
References	159
Publications	177
Danksagung	179