

Contents

1	Introduction	9
1.1	Previous work and knowledge	11
1.2	The subject of hardware security	13
1.3	Motivation and overview	17
2	Background	21
2.1	Security evolution in silicon chips	23
2.1.1	Memory types	31
2.1.2	Types of security protection	43
2.2	Developers and attackers	47
2.3	Failure analysis techniques	49
3	Attack Technologies	52
3.1	Introduction	52
3.1.1	Protection levels	53
3.1.2	Attack categories	56
3.1.3	Attack scenarios	57
3.2	Non-invasive attacks	58
3.3	Invasive attacks	59
3.4	Semi-invasive attacks	62
4	Non-Invasive Attacks	64
4.1	Obscurity vs security	65
4.2	Timing attacks	66
4.3	Brute force attacks	67
4.4	Power analysis	69
4.5	Glitch attacks	73
4.5.1	Clock glitches	73

4.5.2	Power glitches	75
4.6	Data remanence	76
4.6.1	Low temperature data remanence in SRAM	77
4.6.2	Data remanence in non-volatile memories	81
4.6.3	Requirements for reliable data deleting from memory	88
5	Invasive Attacks	90
5.1	Sample preparation	90
5.1.1	Decapsulation	91
5.1.2	Deprocessing	95
5.2	Reverse engineering	98
5.2.1	Optical imaging for layout reconstruction	98
5.2.2	Memory extraction	100
5.3	Microprobing	102
5.3.1	Laser cutter	104
5.3.2	FIB workstation	106
5.4	Chip modification	107
6	Semi-Invasive Attacks	109
6.1	UV attacks	110
6.1.1	Locating the security fuses	110
6.1.2	Toothpick attack	111
6.1.3	EEPROM and Flash issues	113
6.2	Backside imaging techniques	114
6.3	Active photon probing	117
6.3.1	Laser scanning techniques	119
6.3.2	Reading the logic state of CMOS transistors	120
6.4	Fault injection attacks	122
6.4.1	Changing SRAM contents	122
6.4.2	Non-volatile memory contents modification	127
6.5	Modelling the attacks	129
6.5.1	Modelling the logic state reading	129
6.5.2	Modelling the fault injection attack	131

7	Hardware Security Analysis	134
7.1	Evolution against UV attacks134
7.2	Semi-invasive analysis of different security implementations136
7.2.1	Using laser scanning technique for analysis137
7.2.2	Using fault injection technique for analysis138
8	Defence Technologies	140
8.1	Unmarking, remarking and repackaging141
8.2	Multilevel and multipoint protection143
8.3	Burning access circuit and destroying test interface145
8.4	Smartcards and tamper protection147
8.5	Asynchronous logic148
9	Conclusion and Further Work	150
	Appendix. Overview of different microcontrollers and smartcards	155
	Glossary	157
	Bibliography	161