

Contents

List of Symbols	XIII
Key to the different layers in integrated circuits	XVIII
1 Introduction	1
2 Basic principles of integrated circuits technology	3
3 Film technology	13
3.1 Film production processes	13
3.1.1 The CVD process	13
3.1.2 Thermal oxidation	20
3.1.3 Vapour phase deposition	27
3.1.4 Sputtering	29
3.1.5 Spin coating	33
3.1.6 Film production by ion implantation	34
3.1.7 Film production using wafer-bonding and back-etching	34
3.1.8 Annealing techniques	35
3.2 The monocrystalline silicon wafer	38
3.2.1 Geometry and crystallography of silicon wafers	38
3.2.2 Doping of silicon wafers	39
3.2.3 Monocrystalline silicon growing techniques	39
3.3 Epitaxial layers	41
3.3.1 Uses for epitaxial layers	41
3.3.2 Diffusion of doping atoms from the substrate into the epitaxial layer	43
3.4 Thermal SiO ₂ layers	46
3.4.1 Uses of thermal SiO ₂ layers	46
3.4.2 The LOCOS technique	47
3.4.3 Properties of thin thermal SiO ₂ films	53
3.5 Deposited SiO ₂ films	59
3.5.1 Creating deposited SiO ₂ films	59
3.5.2 Applications of deposited SiO ₂ films	60
3.5.3 Spacer technology	60
3.5.4 Trench isolation	62
3.5.5 SiO ₂ isolation films for multi-level metallization	62
3.6 Phosphorus glass films	63
3.6.1 Producing phosphorus glass films	64

3.6.2	Flow-glass	66
3.6.3	Thermal phosphorus glass	67
3.7	Silicon nitride films	67
3.7.1	Producing silicon nitride films	68
3.7.2	Nitride films as an oxidation barrier	68
3.7.3	Nitride films as a capacitor dielectric	69
3.7.4	Using nitride films for passivation	70
3.8	Polysilicon films	70
3.8.1	Producing polysilicon films	70
3.8.2	Grain structure of polysilicon films	71
3.8.3	Conductivity of polysilicon films	72
3.8.4	Uses of polysilicon films	74
3.9	Silicide films	78
3.9.1	Producing silicide Films	79
3.9.2	Polycide films	81
3.9.3	Silication of source/drain regions	83
3.10	Refractory metal films	83
3.11	Aluminium films	85
3.11.1	Producing aluminium films	85
3.11.2	Crystal structure of aluminium films	86
3.11.3	Electromigration in aluminium interconnections	87
3.11.4	Aluminium-silicon contacts	88
3.11.5	Aluminium-aluminium contacts	90
3.12	Organic films	91
3.12.1	Spin-on glass films	91
3.12.2	Polyimide films	92
4	Lithography	95
4.1	Linewidth dimension, placement errors and defects	96
4.2	Photolithography	98
4.2.1	Photoresist films	98
4.2.2	Formation of photoresist patterns	102
4.2.3	Light intensity variation in the photoresist	105
4.2.4	Special photoresist techniques	110
4.2.5	Optical exposure techniques	116
4.2.6	Resolution capability of optical exposure techniques .	119
4.2.7	Alignment accuracy of optical exposure equipment ..	130
4.2.8	Defects occurring in optical lithography	133
4.3	X-ray lithography	134
4.3.1	Wavelength region for X-ray lithography	135
4.3.2	X-ray resists	136
4.3.3	X-ray sources	137
4.3.4	X-ray masks	142
4.3.5	Alignment procedure for X-ray lithography	144

4.3.6	Radiation damage in X-ray lithography	144
4.3.7	Opportunities for Y-ray lithography	144
4.4	Electron lithography	145
4.4.1	Electron resists	145
4.4.2	Resolution capability of electron lithography	146
4.4.3	Electron beam pattern generators	148
4.4.4	Electron projection equipment	153
4.4.5	Alignment techniques in electron lithography	154
4.4.6	Radiation damage in electron lithography	154
4.5	Ion lithography	156
4.5.1	Ion resists	156
4.5.2	Ion beam writing	158
4.5.3	Ion beam projection	160
4.5.4	Resolution capability of ion lithography	162
4.6	Pattern generation without using lithography	166
5	Etching technology	169
5.1	Wet etching	170
5.1.1	Wet chemical etching	170
5.1.2	Chemical-mechanical polishing	171
5.2	Dry etching	174
5.2.1	Physical dry etching	174
5.2.2	Chemical dry etching	176
5.2.3	Physical-chemical dry etching	178
5.2.4	Chemical etching reactions	186
5.2.5	Etching gases	188
5.2.6	Process optimization	188
5.2.7	Endpoint detection	193
5.3	Dry etch processes	196
5.3.1	Dry etching of silicon nitride	197
5.3.2	Dry etching of polysilicon	197
5.3.3	Dry etching of monocrystalline silicon	199
5.3.4	Dry etching of metal silicides and refractory metals ..	200
5.3.5	Dry etching of silicon dioxide	201
5.3.6	Dry etching of aluminium	203
5.3.7	Dry etching of polymers	205
6	Doping technology	207
6.1	Thermal doping	208
6.2	Doping by ion implantation	209
6.2.1	Ion implantation machines	209
6.2.2	Implanted doping profiles	211
6.3	Activation and diffusion of dopant atoms	219
6.3.1	Activating implanted dopant atoms	219

6.3.2	Intrinsic diffusion of dopant atoms	220
6.3.3	Diffusion for high concentrations of dopant atoms ...	223
6.3.4	Oxidation enhanced diffusion	224
6.3.5	Diffusion of dopant atoms at interfaces	225
6.3.6	Diffusion of dopant atoms in films	227
6.3.7	Sheet resistance of doped layers	229
6.3.8	Diffusion at the edge of doped regions	230
6.4	Diffusion of non-doping materials	231
7	Cleaning technology	235
7.1	Contaminants and their effect	235
7.2	Clean rooms, clean materials and clean processes	239
7.2.1	Clean rooms	239
7.2.2	Clean materials	242
7.2.3	Clean processing	244
7.3	Wafer cleaning	244
8	Process integration	249
8.1	The various MOS and bipolar technologies	249
8.1.1	Active components in integrated circuits	249
8.1.2	Comparison of MOS and bipolar technologies	249
8.1.3	Passive components in integrated circuits	252
8.2	Technology architecture	252
8.2.1	Architecture of MOS technology	252
8.2.2	Architecture of bipolar and BICMOS technologies ...	254
8.3	Transistors in integrated circuits	256
8.3.1	Design of MOS transistors and their isolation	256
8.3.2	Design of DMOS transistors	262
8.3.3	Design of bipolar transistors and their isolation	264
8.4	Memory cells	267
8.4.1	Design of static memory cells	267
8.4.2	Design of dynamic memory cells	269
8.4.3	Design of non-volatile memory cells	272
8.5	Multilayer metallization	276
8.5.1	Planarization of surfaces in integrated circuits	277
8.5.2	Contacts in integrated circuits	281
8.5.3	Metallization in integrated circuits	284
8.5.4	Passivation of integrated circuits	285
8.6	Detailed process sequence of selected technologies	286
8.6.1	Digital CMOS process	286
8.6.2	BICMOS process	286
8.6.3	Microwave bipolar process	286
8.6.4	DRAM process	295
	References	323
	Subject Index	329