

Index

a

ABSE 425
 absorbed dose *see* exposure dose
 absorber materials 16–19 (*see also*
 photoresist)
 – densities 17
 – effective absorption 16–18
 – electroplating 18, 19, 40–43
 – gold 17–19, 40–43
 – material selection 19
 – physical vapor deposition 19
 absorption contrast 26, 27
 acceleration sensor 148–150, 199
 achromatic confocal distance sensor
 216–218
 actuators *see* microactuators
 adhesive bonding 174–176
 alignment
 – design for assembly 170, 172–174
 – mask and substrate 23, 24, 31, 33, 35, 38,
 173
 – optical components 213, 218, 220
 alignment markers 23, 24, 31, 33, 35, 38,
 173
 alumina, thermal expansion coefficient
 155
 alumina powder fillers 422, 423, 430, 434,
 435
 AMANDA micropump 148
 ambient effects 180
 ANKA 108–110, 201
 annealing, stress relieving 30, 155
 ANSYS 76–78
 aspect ratios 82, 86, 168, 206
 – filled resist systems 419, 427
 – microactuators 299
 – piezoelectric composite materials 338,
 339
 – RF applications 257, 272, 273

 – TIEGA process 455
 – vertical wall structures 249, 257
 assembly
 – design rules 170–178
 – feeding process 170, 171
 – gripping process 171, 172
 – joining 174–178
 – main steps 169
 – positioning 172–174
 – rotary bond tool 385–388
 AURORA 109–111, 443
 AURORA-2S 443, 454
 Axsun Technologies 201

b

bandpass filters 209–211
 Beer-Lambert law 14
 beryllium
 – electroplating 22
 – mask substrates 21, 22, 44
 – – alignment markers 23
 – – effective transparency 25
 – – fabrication 35–37
 – – properties and thickness 26
 – – temperature rise 20
 – optical transmission characteristics 23
 – X-ray attenuation characteristics 15, 16
 bidirectional transceiver/receiver 215
 biodegradability 152
 biodegradables 152
 bi-stability principle 149, 150
 bi-stable membrane microvalve 149, 150
 bonding
 – adhesive 174–176
 – plastic microfluidic devices 331–333
 boron nitride, X-ray attenuation
 characteristics 15
 borosilicate glass, mask substrates 22, 37, 38

Bosch process 192
 bulk micromachining 190, 191
 – microfabrication costs 196, 197
 – throughput rates 197

c

C (alumina powder) 422, 423
 cantilever beams 41, 42, 254, 255, 258–260
 carbon, X-ray attenuation characteristics
 15
 cavity resonators 270–277
 Center for Advanced Microstructures and
 Devices (CAMD) 13
 ceramic precursors 424, 425
 Ceraset 425
 clamping elements 177, 178
 cleanrooms 200
 CMOS thin-film techniques 7, 190
 comb drive actuator 225, 226, 306–308
 commercial issues 6, 7 (*see also* costs;
 productivity)
 – commercial centres 193, 194
 – foundry operation 199–201
 computer software *see* software
 COMS (Commercialization of Micro and
 Nano Systems Conference) 9
 conduction paths, hot embossing 92, 93
 coplanar waveguides (CPW) 249–251, 254,
 263–270
 copper
 – densities and absorption characteristics
 17, 18
 – powder fillers 436
 – thermal expansion coefficient 155
 costs 6, 7, 44, 192–199
 – cost models 194–196
 – X-ray sources 193, 194
 counter meshing gears discriminator 316,
 317
 crack avoidance
 – deep X-ray lithography (DXRL) 154–160
 – molding 168
 crosslinking
 – polytetrafluoroethylene (PTFE) 458–460
 – preceramic polymers 424, 425
 CT3000SG 422, 423
 curing process
 – adhesive bonding 175, 176
 – ceramic composites 423–425, 434
 cyanide-based electroplating 40
 cycle times (*see also* throughput rates)
 – hot embossing 413
 – micromolding 288, 327, 330, 411
 cylinder lenses 171, 172, 207–209

d

deep reactive ion etching (DRIE) 191, 192
 – microfabrication costs 196–199
 – throughput rates 197
 deep X-ray lithography (DXRL) 5, 6, 51–67
 – 3D microstructures 52, 55–67
 – costs 192–198
 – design for manufacturing 154–167
 – – crack avoidance 154–160
 – – mechanical stabilization 160–163
 – development modelling 118–132
 – – photoresist damage theory 119–121
 – – photoresist dissolution rate 121, 122
 – – topology representation 123–132
 – development process 53, 54
 – – dissolution rate 55, 60, 61, 121, 122
 – exposure dose 53–55
 – – two-step dose distribution 60, 61
 – exposure modelling 104–118
 – – beamline data 109–111
 – – beam-line modeling and calculation
 105–118
 – – object-oriented data structures 113–118
 – – process parameters 105, 106
 – – software 105, 106, 109, 132–140
 – exposure techniques 52, 55–67
 – – double exposure 62, 63
 – – inclined exposure 57–59
 – – low contrast masks 61
 – – multi-step dose distribution 63–65
 – – non-planar resist substrates 55–57
 – – two-step dose distribution 60–63
 – masks *see* X-ray masks
 – photoresist *see* photoresist
 – scanning process 418, 419
 – substrates *see* photoresist, substrates
 – throughput rates 197
 deformation matching 147
 demolding
 – hot embossing 75–77, 79–82
 – injection molding 397
 densities, absorber materials 17
 design methodology
 – design for assembly 168–178
 – design for manufacturing 154–168
 – – design rules 157–160
 – design principles 146–150
 – design requirements 179
 – design sequence 145, 146
 – embodiment design 146, 147
 – functional design 178–187
 – general microsystems design rules
 150–153
 ‘die attach’ machines 385

differential expansion 151
 diffraction effects 325–327
 dimensional deviations 152, 153, 160–163
 Direct-LIGA 5, 6, 8
 – microgears fabrication 371–373
 distance sensors *see* micro-optical distance sensors
 division of tasks 147, 148
 dose *see* exposure dose
 DoseSim 132–134
 double exposure technique 62, 63
 DRIE *see* deep reactive ion etching (DRIE)
 DSAS (Stress Deposit Analyzer System) 42
 DXRL *see* deep X-ray lithography (DXRL)
 dynamic thermomechanical analysis (DMA) 77

e

e-beam lithography (EBL) 419
 – nanoparticle-filled resists 432, 433
 effective absorption 16, 18
 effective transparency 15, 16
 eikonal partial differential equation 129
 electrical contact probe *see* microcontact probe
 electroforming 303
 – nickel mold inserts 306, 307, 326, 327, 341
 – TIEGA process 458
 electromagnetic actuators 299–302, 308
 – variable reluctance 310–312
 electromagnetic microchopper 227, 228
 electron beam lithography 419
 – nanoparticle-filled resists 432, 433
 electro-optical systems 218–225
 electroplating 18, 19
 – beryllium 22
 – circles 166
 – cyanide-based 40
 – cylindrical holes 166, 167
 – deformations 163, 164
 – design rules 162–167
 – gold 40–42, 274, 275
 – – internal stress 41–43
 – graphite 22
 – internal stress 41–43
 – mechanical stabilization 160–163
 – microgear wheels 372
 – microstructured frames 163–165
 – nickel 70, 89, 256, 258–260, 266, 275
 – polishing 268
 – subdivision of structures 165, 166
 electrostatic microactuators 225, 226, 299, 300, 306

– micropositioning 315
 – rotary 308–310
 electrostatic motors 226, 227, 310–312
 electrostatic switching matrix 226, 227
 embodiment design 146, 147
 EPON SU-8 *see* SU-8
 EUV *see* extreme ultraviolet (EUV) lithography
 EVG 97, 98
 excimer laser ablation 191, 192
 – compared with SR etching 462, 463
 – microfabrication costs 196–198
 – throughput rates 197
 exposure dose 24, 53–55
 – dissolution rate function 55, 121
 – distribution
 – – filled resists 425, 426
 – – multi-step or arbitrary 63–65
 – – simulation 104–106, 118
 – – two-step 60–63
 – dose ratio 25
 – relation to pattern depth 53, 325
 exposure techniques 52–67
 – 3D resist substrates 55–57
 – absorber thickness distribution 64
 – inclined exposure 57–59
 – multi-step or arbitrary dose distribution 63
 – planar movement of mask or resist substrate 64, 65
 – two-step dose distribution 60–63
 – UV lithography 417, 418
 exposure times 193, 196, 457
 extreme ultraviolet (EUV) lithography 1, 2, 444

f

fabrication (*see also* manufacturing)
 – design issues 152–154
 – process sequence and variations 5
 – task subdivision 147, 148
 fast marching method 122–124
 – topology representation 125, 126, 128–130
 fault-free design 150, 184–186
 FELIG 8, 201
 fiber optics
 – intensity coupling element 212, 213
 – multifiber connector 213, 214
 – switch 308, 316
 filler-polymer matrix composites 420–437
 – alumina powder fillers 422, 423, 430, 434, 435
 – curing depth 423, 424

- filled SU-8 428–432
- metal powder fillers 436
- nanoparticle-filled resists 432, 433
- polyimide–silica composites 437, 438
- preceramic polymers 424–428
- silica fillers 430, 432, 433
- finite element modelling (FEM) 76
- fluidic devices *see* microfluidic devices
- fluorescence radiation 15, 119
- fluorinated polyimide–silica composites 437
- force transmission 147, 149
- Forschungszentrum Karlsruhe (FZK) 2, 8, 96, 97
 - ANKA 108–110, 201
- foundry operation 199–201
- Fourier transform infrared (FTIR) spectrometer 82, 83, 86, 177, 229, 230, 316
- friction, design for 151
- front normal 128
- functional design 178–187
- functional division 147, 148

- g**
- gears *see* microgears
- G-G developer 54, 55, 121
- glass
 - lenses 176
 - mask substrates 37, 38
 - – properties and thickness 26
 - optical transmission characteristics 23
 - X-ray attenuation characteristics 15, 16
- glassy carbon *see* vitreous carbon
- gold
 - absorber layer fabrication 19
 - absorber materials 17–19, 40–43
 - densities and absorption characteristics 17, 18
 - electroplating 40–42, 274, 275
 - – internal stress 41–43
- graphite
 - electroplating 22
 - mask substrates 44
 - – fabrication 33–35
 - – properties and thickness 26
 - optical transmission characteristics 23
 - X-ray attenuation characteristics 16
- grippers 171, 172, 174

- h**
- Halback arrays 312
- hard disk drives 315
- hard tool–soft countertool combination 91, 92
- harmonic drive gear 352–393
 - advantages 369–371
 - applications 384–393
 - – microassembly 385–388
 - – microrobots 390–393
 - – nanostage 388–390
 - fabrication 371–373
 - flexible properties 361, 362
 - gear profiles 373–382
 - hollow shaft 366, 367, 383, 385
 - operating principle 358–361
 - properties 366–369
 - simulation 363–365
- HARMST (High Aspect Ratio Micro-Structure Technology) workshop 9
- heap data structure 130
- HELIOS 13, 443
- heterodyne receiver 215–217
- HEX03 96–98
- hole making 90–92
- hollow-cavity waveguide 288
- hook joint 177, 178
- hot embossing
 - applications
 - – high aspect ratio replication 86, 87
 - – large area replication 86, 87
 - – optical microstructures 83–86, 212
 - basic principle 72–74
 - compared with injection molding 73
 - composite foils 90
 - conduction paths 92, 93
 - cooling time 95
 - cycle times 413
 - damage structures 77
 - deformations 82
 - demolding 75
 - – simulation 76, 77, 79–82
 - design rules 167, 168
 - diced microstructures 90
 - facilities 96–98
 - heating and cooling blocks 95, 96
 - mold filling
 - – pressure distribution 79
 - – simulation 77, 79
 - multilayer replication 91–93
 - polymer mold inserts 93, 94
 - process optimization 82, 83
 - process simulation 76–83
 - – in practice 82, 83
 - – material properties basis 76, 77
 - replication on a substrate 88, 89
 - residual layer 88, 90

- through-holes 90–92
- tools 94–96
- hot punching 90, 91
- hydraulic actuators 314
- hydrogen bubbles, photoresist 155, 156, 166, 167
- hysteresis motor 313, 314

i

- IMTEK, X3D 109
- inclined exposure 57–59
- inclined sidewalls 57–59, 325
 - freely shaped 52, 60–67
- industrial production *see* manufacturing
- infrared spectrometer *see* Fourier transform
 - infrared (FTIR) spectrometer
- injection compression process 413, 414
- injection molding 70, 71
 - applications
 - – microfluidic devices 327–330
 - – microspectrometers 287, 288
 - – permanent magnets 304, 305
 - clamping unit 396–398, 403
 - compared with hot embossing 73
 - components and design concepts 396–407
 - cycle times 288, 327, 330, 411
 - design rules 167, 168
 - driers 404
 - ejection from mold 397
 - electric drive 403, 404
 - flow control 398, 399, 406, 409, 410
 - history 395, 396
 - hydraulic drive 403, 404
 - injection unit 398, 399, 408–410
 - materials
 - – lead zirconate titanate (PZT) 341
 - – liquid crystal polymer (LCP) 400
 - – polyacetal (POM) 400
 - – polycarbonate (PC) 400, 404
 - – poly(ether ether ketone) (PEEK) 400
 - – poly(methyl methacrylate) (PMMA) 70, 71, 329, 330, 400
 - – polypropylene (PP) 400–402
 - – polystyrene 332, 333
 - melt film 401
 - melt pressure transducer 405
 - melt temperature sensors 405, 406
 - microinjection molding machines 287, 288, 407–414
 - mold inserts *see* mold inserts
 - multi-cavity molds 412
 - non-return valves 402, 403
 - parallel processing 410, 411

- physical process 412, 413
- piston injection 414
- plastification unit 399–402, 407, 408
- processing temperatures 400
- quality assurance 406, 407, 411
- temperature control 404–406
- variotherm process 405
- venting 404
- INNOLIGA 8
- inspection devices, piezoelectric composites 337–344
- integrated circuit testing, microcontact probe 344–349
- intensity coupling element 212, 213

j

- Jenoptik Mikrotechnik 96–98
- joining (*see also* bonding)
 - design for 174–178

k

- kinoform lens 238

l

- laser micromachining 191, 192
 - compared with SR etching 462, 463
 - microfabrication costs 196–198
 - throughput rates 197
- lateral comb structures 253, 254
- lead, properties 17, 18
- lead zirconate titanate (PZT)
 - impedance curve 342
 - injection molding 341
 - piezoelectric composites 337–340
 - resist filler 434
- lead–tin alloy, absorber materials 19
- lenses *see* microlenses; X-ray lenses
- level sets 123–125
 - topology representation 126–132
- LEX-D 133
- liquid crystal polymer (LCP), injection molding 400
- Lito 2 108
- loads, fabrication 153 (*see also* thermal stress)

m

- M2DXL *see* moving mask deep X-ray lithography (M2DXL)
- ‘magic rings’ 312
- malfunction prevention 148
- manufacturing 7, 8
 - commercial centres 193, 194
 - commercial issues 6, 7 (*see also* costs)

- design methodology 154–168
- – design rules 157–160
- foundry operation 199–201
- masks *see* X-ray masks
- materials matching 147
- mechanical microclamping 176–178
- MEMSCOST 194
- mesh-free topology representation 124, 125
- metal powder fillers 436, 437
- μFEMOS 180
- micro harmonic drive gears *see* harmonic drive gear
- microactuators 297–317 (*see also* microgears; micromotors)
 - applications 314–317
 - backlash-free 383, 384
 - electrostatic 225, 226, 299, 300, 306
 - – micropositioning 315
 - – rotary 308–310
 - materials 303–305
 - scaling 298–302
 - types 306–314
- microassembly, rotary bond tool 385–388
- microchopper 227, 228
- microclamping 176–178
- microcontact probe 344–349
 - design of tip shape 346–349
 - materials 345, 346
 - production process 345
- microcracking 154–160
- microdrive systems 384–393 (*see also* harmonic drive gear; microactuators)
- microfabrication 152
- microfluidic devices 323–334
 - actuators 317
 - bonding 331–333
 - injection molding 327–330
 - microflow paths 331–333
 - nickel tool part 324–327
 - polystyrene 332, 333
- microgears 6, 90, 151, 434, 460 (*see also* harmonic drive gear)
- microlenses 84, 85 (*see also* X-ray lenses)
 - cylinder lenses 171, 172, 207–209
- micromotors 301, 309, 310, 312–314, 317, 318
 - electrostatic 226, 227, 310–312
 - pancake 383
- micro-optical benches (MOB) 84, 88, 170, 174, 181, 211–218
- micro-optical bypass switch 225, 226
- micro-optical components 205–230
 - electro-optical systems 218–225
 - materials 207–209
 - optical benches 211–218
 - optical components 208–211
 - optical MEMS 225–230
- micro-optical distance sensors 151, 173, 216–218
 - modeling and simulation 180–187
 - triangulation 219–222
- micro-optical switches 160–162
- micropositioning (*see also* microgears)
 - electrostatic microactuators 315
 - nanostage 388–390
- microprisms 208, 209
- micropumps 148
- microresonators 308
- microrobots 390–393
- microscopes 316
 - X-ray 233, 240, 241
- microspectrometers 85, 86, 90, 221–225, 281–296 (*see also* Fourier transform infrared (FTIR) spectrometer)
 - assembly 289
 - characteristics 285–287
 - fabrication 287–289
 - marketing and sales 295, 296
 - products and applications 290–295
- microstereolithography 419, 420
 - exposure techniques 55–66
 - filled resists 433–436
- microvalves 149, 150
- mikroFEMOS 96
- MIRRORCLE 444–451
- MOB *see* micro-optical benches (MOB)
- modeling 179–187 (*see also* simulation)
- mold inserts (*see also* hot embossing; injection molding)
 - electroforming 306, 307, 326, 327, 341
 - high aspect ratio 86
 - large area replication 87, 88
 - loads and stresses 153
 - multi-cavity molds 412
 - nickel 306, 307, 326, 327, 339–341
 - optical component fabrication 83, 84, 211–214
 - polymer 93, 94
- MOLDFLOW 76, 78
- molecular imprint 97
- mosaic lens 238
- moving mask deep X-ray lithography (M2DXL) 63, 64, 111, 112
- multifiber connectors 213, 214
- multi-mode fibers 212, 213
- multi-step dose distribution 63–65

n

nanoparticle-filled resists 432, 433
 nanoscopes 240, 241
 nanostage 388–390
 Nanotek 422, 423
 NCP-200 425
 negative resist 119
 NEUTRONEX 309 40, 43
 nickel
 – densities and absorption characteristics 17, 18
 – electroplating 70, 89, 256, 258–260, 266, 275
 – mold inserts 339, 340
 – – electroforming 306, 307, 326, 327, 341
 – thermal expansion coefficient 151
 – varactors 256–263
 – X-ray lenses 237
 nickel–iron electrolyte 372
 Ni–Mn alloy, microspring 346, 347
 non-planar resist substrates 55–57
 non-return valves, injection molding 402, 403

o

Obducat 97
 object-oriented data structures 113–118
 optical components *see* micro-optical components
 optical coupling elements 83
 optical fibers
 – intensity coupling element 212, 213
 – multifiber connector 213, 214
 – switch 308, 316
 optical lenses *see* microlenses
 optical lithography 2
 optical MEMS 225–230
 optical switch matrix 160–162
 ORMOCERs 438
 overload protection 149

p

parallel-plate variable capacitor 248, 249
 Parvus 390–393
 PEEK 84, 90, 93, 94
 – injection molding 400
 permanent magnets 312–314
 – injection molding 304, 305
 photoresist
 – bonding 155
 – casting 430
 – corners 159, 160
 – cracking 154–160
 – damage theory 119–121

– degradation mechanism 120
 – development of irradiated resist 53–55, 120, 121
 – – dissolution rate 55, 121–125
 – – simulation 133–139
 – exposure dose *see* exposure dose
 – exposure techniques *see* exposure techniques
 – exposure times *see* exposure times
 – flow properties 421–423
 – hydrogen bubbles 155, 156, 166, 167
 – mechanical stabilization 160–162
 – optical properties 423, 424
 – spin coating 421
 – subdivision 157
 – substrates
 – – 3D 55–57
 – – clearance 111, 211
 – – planar movement 63–65, 112
 – – thermal expansion 155
 – swelling 160–163
 – tapered structures 159
 – tension stress 155
 – thermal expansion 155, 160–163
 – viscosity 421–423
 – water uptake and swelling 160–162
 – X-ray absorption 418, 419
 photoresist materials
 – compared 457, 458
 – filler–polymer matrix composites 420–437
 – – filled SU-8 428–432
 – – metal powder fillers 436, 437
 – – nanoparticle-filled resists 432, 433
 – – polyimide–silica composites 437, 438
 – – preceramic polymers 424–428
 – – properties 420–424
 – – silica fillers 430, 432, 433
 – PMMA *see* poly(methyl methacrylate) (PMMA)
 – polytetrafluoroethylene *see* polytetrafluoroethylene (PTFE)
 – sol–gel-based composites 438
 – SU-8 *see* SU-8
 – types 119, 416, 417
 – water-based fillers 437, 438
 physical vapor deposition (PVD) 19, 22, 288, 289
 – titanium nitride 400
 piezoelectric composites 337–344
 – characteristics 342–344
 – impedance curve 342
 – production process 339–341
 platinum, properties 17, 18

- PMMA *see* poly(methyl methacrylate) (PMMA)
- polishing, electroplated nickel 268
- polyacetal (POM), injection molding 400
- polycarbonate (PC), injection molding 400, 404
- polydimethylsiloxane (PDMS) devices 323
- poly(ether ether ketone) (PEEK) 84, 90, 93, 94
- injection molding 400
- polyimide
- flexible mask substrates 38, 39
 - optical transmission characteristics 23
 - X-ray attenuation characteristics 15
- polyimide–silica composites 437
- polymer mold inserts
- fabrication loads and stresses 153
 - hot embossing 93, 94
- polymer-based masks 44
- polymers
- optical components 207–209, 211, 212
 - plastification 399–402
- poly(methyl methacrylate) (PMMA) 5, 53
- characteristics 119
 - copolymer 340
 - degradation mechanism 120
 - development of irradiated resist 55, 120, 121, 326
 - – dissolution rate 55, 121–125
 - exposure dose 53–55
 - exposure times 193, 196
 - hot embossing 76, 77
 - hydrogen bubbles 155, 156
 - injection molding 70, 71, 329, 330, 400
 - microfabrication costs 195–197
 - swelling 258
 - tension stress 155
 - thermal expansion 258
 - – coefficient 155
 - throughput rates 197
 - Young's modulus 77, 78
- polyoxymethylene (POM) 90
- polystyrene, microfluidic devices 332, 333
- polytetrafluoroethylene (PTFE)
- crosslinking 458–460
 - direct etching 453–467
 - exposure times 457
- POM (polyacetal), injection molding 400
- positioning *see* alignment; micropositioning
- positive resist 119
- PP (polypropylene), injection molding 400–402
- preceramic polymers 424–428
- precision (*see also* tolerance)
- dimensional deviations 152, 153, 160–163
 - X-ray mask pattern 345
- pre-polymerization, substrate 155
- press fits 176, 177
- pressure sensors 298
- process sequence and variations 5
- process simulation *see* simulation
- production *see* manufacturing
- productivity 7
- throughput rates 193, 197
- prototyping 7 (*see also* rapid prototyping)
- proximity exposure 417
- PTFE *see* polytetrafluoroethylene (PTFE)
- PVD *see* physical vapor deposition (PVD)
- pyrolytic graphite, substrate materials 22
- q**
- quality management 8
- r**
- radio frequency applications *see* RF applications
- rapid prototyping 38, 44, 419
- RCHP 422, 423
- reactive ion etching (RIE) 19 (*see also* deep reactive ion etching (DRIE))
- recycling, design for 152
- refractive index, X-ray 234
- residual stress, photoresist 155
- resist *see* photoresist
- resonant actuators 308, 316
- resonant filters 209–211
- resonant gratings 209, 316
- resonant microbeams 298
- RF applications 243–277
- cavity resonators 270–277
 - coplanar waveguide couplers 263–270
 - design approach 248–251
 - reactive elements 245
 - ‘software’ radios 247
 - substrates 248, 251
 - switches 245
 - variable capacitor (varactor) 252–263
 - vertical wall structures 249–251
 - wireless transceiver 246, 247
- RIE (reactive ion etching) 19 (*see also* deep reactive ion etching (DRIE))
- Ritsumeikan University (Japan)
- AURORA 109–111, 443
 - AURORA-2S 443, 454
 - X3D 109, 133–139
- rotary bond tool 385–388

- roughness, sidewalls 34, 38, 44, 206
- Rowland arrangement 223
- RX-PTFE 459–462
- S**
- SCARA robots 390–393
- self-compensation 148
- self-enforcement 148
- self-help principle 148
- self-protection 149
- sensors 297, 298
 - acceleration 148–150, 199
 - distance
 - – micro-optical 151, 173, 180–187, 216–222
 - pressure 298
 - servo actuators *see* actuators
- Shadow (program) 105
- shadow exposure 417
- sidewalls (*see also* aspect ratios)
 - inclined 57–60, 325
 - inclined and freely shaped 52, 60–67
 - roughness 34, 38, 44, 206
- silica composite fillers 430, 432–434, 437, 438
- silicon
 - mask substrates 39
 - microfabrication technologies 248, 249
 - thermal expansion coefficient 155
- silicon carbide, optical properties 23
- silicon carbonitride 424
- silicon nitride
 - mask substrates 22, 44
 - – fabrication 31–33
 - – properties and thickness 26
 - optical transmission characteristics 23
 - X-ray attenuation characteristics 15, 16
- simulation 179–187
 - development of irradiated resist 133–139
 - exposure dose distribution 104–106, 118
 - harmonic drive gear 363–365
 - hot embossing 76–83
 - micro-optical distance sensor 180–187
 - software 76, 78, 105, 132–139
- SLM465012VP 425
- soft X-ray lithography 20, 28
- soft X-ray sources 13, 444–451
- software
 - cost modeling 194
 - simulation 105
 - – development of irradiated resist 132–139
 - – hot embossing 76, 78
- spatial structure encoding and tracking 123–132
- spectrometers *see* microspectrometers
- spin coating 421
- sputter deposition, titanium membranes 22
- SR *see* synchrotron radiation sources
- stability, design for 149
- stereolithography 419, 420
- Stoney's equation 41
- stop faces 173
- Stress Deposit Analyzer System (DSAS) 42
- stress measurement 41, 42
- stresses (*see also* thermal stress)
 - demolding 79–82
 - fabrication 153
- string methods 123
- structure inversion 152
- SU-8 7, 8, 34, 37, 119
 - exposure time 193, 195
 - filled resists 428–432
 - flexible mask substrates 38
 - gold coating 275
 - microfabrication costs 195–198
 - throughput rates 197
 - UV LIGA 192
 - X-ray lenses 237
- SU-8TM 52
- subfunctions 147, 148
- substrate materials
 - beryllium 35–37, 44
 - effective transparency 15, 16
 - glass 37, 38
 - graphite 33–35, 44
 - material selection 21, 22
 - polymer-based 44
 - properties and thickness 25, 26
 - silicon 39
 - silicon nitride 44
 - thermal expansion coefficients 155
 - titanium 29–31, 44, 274
 - vitreous carbon 44
 - X-ray transmission characteristics 14–16
- sulfite-based electroplating 40–42
- surface curvature measure 128
- surface microengineering 192
 - microfabrication costs 196–198
 - throughput rates 197
- switching matrixes 226, 227
- synchrotron radiation sources 4, 12–13
 - ANKA 109, 110
 - AURORA 109–111
 - commercial centres 193, 194
 - commercial issues 200

- compact 193, 443–451
- costs 193
- MIRRORCLE-type 444–451
- power spectra 13
- radiation spectrum 15
- spectral distribution 17

t

- tantalum, properties 17, 18
- tape casting 426, 429
- task subdivision 147, 148
- TECHNI-GOLD 25 (TG 25) 40
- Teflon-included etched (TIE) process 454–467
- tension stress, photoresist 155
- thermal expansion
 - design for 151
 - photoresist substrates 155
- thermal stress
 - analysis 186, 187
 - fabrication 153
 - photoresist 155, 156
- thermo-elastic properties, mask substrates 19–21
- thermopneumatic micropump 148
- three-dimensional (3D) microfabrication 52, 55–67
- three-dimensional (3D) resist substrates 55–57
- through-holes 90–92
- throughput rates 193, 197 (*see also* cycle times)
- TIEGA 454–467
- tin, properties 17, 18
- titanium
 - mask substrates 22, 44, 256, 257, 274
 - – alignment markers 23
 - – fabrication 29–31
 - – properties and thickness 26
 - – temperature rise 20
 - optical transmission characteristics 23
 - X-ray attenuation characteristics 15, 16
- titanium nitride, physical vapor deposition 400
- TM DAR 422, 423
- tolerance 180, 184–186, 201, 249 (*see also* precision)
 - dimensional deviations 152, 153, 160–163
- topology representation 123–132
- transition radiation (TR) 444–446, 449–451
- transmission contrast 26
- Transmit (program) 105
- triangulation distance sensor 219–222

- tunable capacitors 252, 253, 315
- tungsten, properties 17, 18
- two-step dose distribution 60–63

u

- ultrasonic diagnosis 337–344
- uranium separation nozzles 2, 3
- UV LIGA 5, 190, 192
 - microfabrication costs 196–198
 - throughput rates 197
 - X-ray sources 444–451
- UV lithography 52, 416, 417
 - extreme ultraviolet (EUV) 1, 2, 444
- UV–VIS microspectrometer 85, 86, 287, 289

v

- valves *see* microvalves
- variable capacitors (varactors) 252–263
- vertical wall structures
 - RF applications 249–251
 - vertical wall varactors 254–263
- vitreous carbon
 - mask substrates 22, 44
 - optical transmission characteristics 23
 - properties and thickness 26
 - X-ray attenuation characteristics 16
- VL20 425

w

- wafer bonding 192
 - microfabrication costs 196–198
 - throughput rates 197
- water-based fillers 437, 438
- waveguides *see* coplanar waveguides (CPW)
- wear, design for 151

x

- X3D 109, 133–139
- XOP 105
- X-Ray (program) 105
- X-ray attenuation characteristics
 - absorber materials 16, 17
 - resist materials 419
 - substrate materials 14–16
- X-ray lenses 6, 233–241
 - characteristics 239, 240
 - geometry 235–239
 - materials 237
 - PTFE 463–467
- X-ray masks 11–44
 - absorbers
 - – materials *see* absorber materials
 - – thickness 26, 27

- absorption contrast 26, 27
 - alignment markers 35
 - architecture 24
 - costs 193
 - critical dimension (CD) 27–29
 - fabrication 27–42
 - alternative approaches 38, 39
 - beryllium masks 35–37
 - borosilicate glass masks 37, 38
 - commercial issues 200
 - gold electroplating 39–43
 - graphite masks 33–35
 - loads and stresses 153
 - silicon nitride masks 31–33
 - titanium membrane masks 29–31
 - intermediate 28–30
 - low contrast 61, 62
 - metal mesh 38
 - metal stencil 38
 - multi-step absorber thickness 63
 - planar movement technique 63, 64, 112
 - resolution 28, 29
 - silicon nitride masks, fabrication 31–33
 - substrates (*see also* substrate materials)
 - alignment markers 23, 24
 - dose ratio 25
 - effective transparency 25
 - flexible 38
 - membrane expansion 21
 - membrane-type 25
 - optical transmission 22–24
 - surface quality 21, 22
 - therm-elastic properties 19–21
 - thickness 16, 25, 26
 - temperature rise 19, 20
 - transmission contrast 26
 - working masks 28–31
 - X-ray microscopes 233, 240, 241
 - X-ray sources 12 (*see also* synchrotron radiation sources)
 - X-ray transmission characteristics
 - absorber materials 16–18
 - substrate materials 14–16
- Z**
- ZEP520 432, 433

