

Index

A

Acceptors, 8–9, 50, 224–25
Accumulation, 26, 207
Acronyms, 513–15
Adjusted transistors, 383–84
Advanced-technology bipolar transistors, 299–302
Aligners, 41–42
Alignment markers, 466–67
Alloy, 42, 67
Aluminum, deposition and removal of, 59–60
Aluminum fuses, 186
Analog BiCMOS, 48, 51, 71, 104–15
 bipolar transistors, 294–97
 devices available, 111–15
 diodes in, 356–58
 fabrication sequence, 106–11
 features of, 104–5
 guard rings in, 458–60
 parasitic channels and, 137–39
 polysilicon-gate CMOS versus, 110–11
 power transistor layout in, 317–18
Anisotropic dry etching, 45–46
Annealing, 54
Annular transistors, 391–93
Anode, 13, 16, 347
Antenna effect, 118, 122–24
Antimony, 7, 50–51
Antiparallel diode clamps, 480
Areal fluctuations, 217–19
Arrayed-emitter transistors, 290
Arsenic, 7, 9, 50–51
Ashing, 42
Asperities, 196
Assembly, 64–69
 mounting and bonding, 66–68
 packaging, 69
Assembly yield, 495
Asymmetric, 33, 402
Asymmetric extended-drain NMOS transistors, 404, 430
Asymmetric extended-drain PMOS transistors, 405
Asymmetric LDD transistors, 402
Asymmetric MOS transistors, 26, 28, 103
Avalanche breakdown, 18, 24, 99, 262–64
Avalanche diodes. *See* Zener diodes
Avalanche multiplication, 17, 291

B

Backgate contacts, 393–96
Backgate doping, 27, 92, 116, 368–69
Backgate effect, 30
Backgates, 25–26, 28, 31–32
Ball bonding, 67–68
Bamboo poly, 179
Bandgap energy, 4, 5
Base-emitter junction capacitors, 205–7

Base implants, 75, 107
Base-over-isolation (BOI), 75, 133, 139
Base pinch resistors, 162, 163, 165, 172–73
Base punchthrough, 24, 296
Base resistors, 81, 99, 115, 170–71
Base-side ballasting, 268
Bent-gate transistors, 417
Berkeley k, 367
Beta multiplication, 263
BiCMOS processes. *See* Analog BiCMOS
Bipolar-CMOS (BiCMOS) processes. *See* Analog BiCMOS
Bipolar electron guard rings, 456–57
Bipolar hole guard rings, 457–58
Bipolar junction transistors (BJTs), 20–24, 260–304
 alternative small-signal, 293–302
 avalanche breakdown and, 262–64
 beta, 22–23, 262
 I-V characteristics, 23–24
 secondary breakdown and, 264–66
 thermal runaway and, 264–66
 topics in, 260–74
Bipolar power switches, 409–10
Bipolar processes, 71, 72. *See also* Standard bipolar
Bipolar small-signal transistors, 274–93, 306
 construction of, 281–83
 high-voltage, 291–93
 standard bipolar lateral PNP, 283–90
 standard bipolar NPN, 72, 77–79, 274–79
 standard bipolar substrate PNP, 279–83
Bipolar transistors, 20–24, 29, 260–304. *See also* Bipolar junction transistors;
 Bipolar small-signal transistors; Power bipolar transistors
 advanced-technology, 299–302
 applications of, 305–42
 in CMOS processes, 297–99
 high-voltage, 291–93
 matching, 322–39
 emitter degeneration, 325–27
 NBL shadow, 327–28
 random variations, 323–25
 rules for, 334–39
 stress gradients, 332–34
 thermal gradients, 328–32
 parasitics of, 272–74
Bird's-beak, 48, 91
BJT transistors, 20–24, 260–304
 alternative small-signal, 293–302
 avalanche breakdown and, 262–64
 beta, 22–23, 262
 I-V characteristics, 23–24
 secondary breakdown and, 264–66
 thermal runaway and, 264–66
 topics in, 260–74
Black's Law, 506

Blocking voltage, 400
Body effect, 30, 132
Bonding, 2–4, 66–68
Bondpad circles, 470
Bondpads, 67, 186, 445, 464, 468–71
Boron, 8, 50–51
Boron suckup, 47
Borophosphosilicate glass (BPSG), 61, 124
Breakdown diodes, 346n
Breakdown mechanisms, 372–75
Breakdown voltage, 346
Buffered Zener clamps, 476–78
Built-in potential, 11–12, 13, 15, 201, 285, 297, 320, 409, 459–60
Buried channel, 384
Buried-channel lightly doped drain (BCLDD), 403
Buried layer, 55, 57. *See also* N-buried layer, P-buried layer
Buried Zeners, 131, 349–52

C

Cadmium sulfide, 9
Capacitance, 194–200
Capacitors, 48, 64, 194–213
 capacitance and, 194–200
 cell area estimation, 489
 comparison of available, 205–12
 matching of resistors and, 214–59
 rules for, 253–57
 parasitics, 203–5
 polysilicon-gate CMOS and, 100
 standard bipolar and, 83
 variability of, 200–203
Capillary, 67
Carbon, 3, 4
Carriers, 5–6, 7–8
 diffusion of, 9–10
 lifetime of, 6
Carrier saturation velocity, 265
Cathedral PNP, 282
Cathode, 13, 16, 347
CB-shortened diodes, 79
Cell area estimation, 489–91
Centroidal symmetry principle, 230
Centroids, 229–31, 433
 common layout, 231–35
Chamfers, 292, 417
Channel length modulation, 30, 33, 429
Channel routing, 501–3
Channels, 25, 55
Channel stop implants, 90–91, 108, 135, 137, 381–83
Channel stops, 135–39, 381–83. *See also* Guard rings
Charged device model (CDM), 119–20, 472
Charge spreading, 191–39, 174, 245–46
 effects of, 131–33
 preventative measures, 133–39

- CMOS and BiCMOS, 137–39
 - standard bipolar, 133–37
- Chemical bonding, 2–3
- Chirality, 436, 436*n*
- Choke points, 500
- Christmas-tree devices, 315–16
- Circular emitters, 323, 324
- Clad gates, 371
- Clad moats, 101, 359, 371, 472
- Clad poly, 62
- Cleavage planes, 38
- CMOS latchup, 89, 144–45, 375–76, 394
- CMOS processes, 48, 51, 53*n*, 59, 88, 104, 260, 363–64. *See also* Polysilicon-gate CMOS
 - bipolar transistors in, 297–99
 - diodes in, 356–58
 - guard rings in, 458–60
 - parasitic channels and, 137–39
- Coding layers, 378
- Collector, 20–21
- Collector-base-emitter (CBE), 276
- Collector-diffused isolation (CDI), 105, 380
- Collector efficiency, 270
- Collector-emitter-base (CEB), 276
- Collector-emitter voltage, 23–24
- Comb capacitors, 199
- Common-centroid layouts, 231–35, 330–31, 333, 435–39
- Common wells, 390, 453–54
- Complementary Metal-Oxide-Semiconductor. *See* CMOS processes
- Compound semiconductors, 9
- Conductivity, 4, 6–7, 157
- Conductivity modulation, 166, 174–75, 243–44
- Constant-field scaling, 386
- Constant-voltage scaling, 386
- Contact OR, 76, 111
- Contact potential, 15, 240. *See also* Built-in potential
- Contact resistance, 159, 161, 166–67
- Contacts over active gate, 431–32
- Contact spiking, 60
- Contamination, 124–28
 - dry corrosion, 124–25
 - mobile ion, 125–28
- Conventional MOS power transistors, 410–17
- Counterdoping, 8–9
- Covalent bonds, 3–6
- Cross-coupled pairs, 234, 438–39
- Cross-coupled quads, 330
- Crossing leads, 463–64
- Cross-injection, 151–53
- Crosstalk, 500
- Crossunders, 85, 171
- Cruciform-emitter transistors, 316–17
- Crystal
 - manufacturing of, 37–38
 - Miller indices of, 516–18
 - structure of, 38–39
- Current-controlled devices, 261
- Current crowding, 278–79
- Current gain, 22–23
 - forward active, 260
- Current hogging, 267, 267*n*
- Current matching, 440
- Current proportional to absolute temperature (IPTAT), 330
- Cutoff, 21, 32, 364
- Czochralski process, 37–38
- D**
- Darlington pair, 450–52, 453
- DDD transistors, 400–403
- Deep-N+ diffusions, 72, 74–75, 107. *See also* Sinks
- Deglazing, 51
- Depletion-mode NMOS transistors, 27–28
- Depletion-mode transistors, 367
- Depletion regions, 10–13, 12–13, 15–18, 30–31
- Deposition, 50
 - of aluminum, 59–60
- Device matching. *See* Matching
- Device noise, 504–6
- Device physics, 1–35
 - bipolar junction transistors (BJTs), 20–24
 - JFET transistors, 31–33
 - MOS transistors, 24–31
 - PN junctions, 10–20
 - semiconductors, 1–10
- Device transconductance, 365–67, 400, 408, 427, 433–35
- Diagonal MOS power devices, 413
- Diamond, 3–4
- Die area estimation, 491–94
- Die assembly, 488–512
 - floorplanning, 495–500
 - planning for, 488–95
 - top-level interconnection, 500–510
- Dielectric, 194–96
- Dielectric breakdown, 366, 374, 472
- Dielectric capacitance, 197
- Dielectric constant, 195
- Dielectric polarization, 126–27, 246–48
- Dielectric relaxation, 248–49
- Dielectric strength, 196
- Differential pairs, 328–29
- Differential trimming, 187–88
- Diffused resistors, 454
- Diffusion, 9–10, 49, 50–53
 - deep-N+, 72, 74–75, 107. *See also* Sinks
 - emitter, 75–76
 - etch effects and, 430–33
 - limitations of, 52–53
 - near the channel, 432
- Diffusion capacitors, 199
- Diffusion currents, 9–10
- Diffusion interactions, 224–25
- Diode clamps, antiparallel, 480
- Diode-connected transistors, 79, 343–46
- Diodes, 13–18, 343–62
 - in CMOS and BiCMOS processes, 356–58
 - matching, 359–62
 - schematic symbols for, 18
 - Schottky, 15–17, 18, 101, 269, 343, 352–56
 - matching, 361–62
 - standard bipolar and, 85–86
 - in standard bipolar, 343–56
- Zener, 17–18, 112, 131, 346–52, 454
 - buried, 131, 349–52
 - matching, 360–61
 - surface, 347–49
- Direct-bandgap semiconductors, 6
- Direct-step-on-wafer (DSW), 65–66
- Direct-write-on-wafer (DWW), 65*n*
- Distributed backgate contacts, 396
- Distributed capacitance, 167–68
- DMOS transistors, 105, 399, 403, 417–21
 - lateral, 418–20
 - NPN, 420–21
- Dogbone resistors, 160–61, 230
- Donors, 7, 8–9
- Dopant-enhanced oxidation, 47–48
- Doped semiconductors, 6–9
- Doping profile, 52–53
- Double-base transistors, 279
- Double-diffused drain (DDD) transistors, 400–403
- Double-diffused JFETs, 426
- Double-diffused MOS (DMOS) transistors. *See* DMOS transistors
- Double-level metal (DLM), 278
 - polysilicon-gate CMOS and, 100–101
 - standard bipolar and, 84–85
- Drain implants, analog BiCMOS and, 109–10
- Drains, 26
 - polysilicon-gate CMOS and, 93–94
- Drawing layers, 378
- Drawn length, 158–58, 160–61, 378
- Drawn width, 158–58, 160–61, 378
- Drift, 9–10
 - long-term, 247
- Drift currents, 10
- Drift region, 102, 275, 313*n*, 401–2, 417–19
- Drive, 50
- Dry corrosion contamination, 124–25
 - effects of, 124–25
 - preventative measures, 125
- Dry etching, 45–46
- Dry oxide, 43
- Dual-doped poly CMOS transistors, 385
- Dual-in-line packages (DIPs), 66–67
- Dumbbell resistors. *See* Dogbone resistors
- Dummy gate oxidation, 49, 91–92, 108
- Dummy resistors, 223–24
- Dynamic antisaturation circuits, 320–21
- E**
- Early effect, 24, 30, 78
- Ebers-Moll equations, 261*n*
- Effective gate voltage, 364–65
- Effective length, 378
- Effective width, 378–79
- Electrically programmable read-only memory (EEPROM), 186
- Electrical overstress (EOS), 118. *See also* Antenna effect; Electromigration; Electrostatic discharge
- Electrodes, 194–95
- Electromigration, 60, 118, 121–22, 506–8
 - effects of, 121–22
 - preventative measures, 122
- Electrons, 4
- Electron vacancy, 4–5
- Electrostatic discharge (ESD), 120. *See also* ESD structures
 - effects of, 120
 - preventative measures, 120–21

- Electrostatic interactions, thermoelectrics and, 242-49
- Electrostatic shielding, 244-45, 246, 253, 505
- Elongated-emitter lateral PNPs, 289
- Emitter ballasting, 308
- Emitter crowding, 278-79
- Emitter current focusing, 265
- Emitter debiasing, 307-9
- Emitter degeneration, 325-27
- Emitter diffusion, 75-76
- Emitter-in-iso Zeners, 349-50
- Emitter injection efficiency, 23
- Emitter oxides, 121, 121n
- Emitter pilot, 76
- Emitter punchthrough, 60, 61, 62, 300
- Emitter push, 53, 225
- Emitter resistors, 82, 171-72
- Emitters, 20-21
- Emitter saturation current, 261
- Enhancement-mode NMOS transistors, 27-28
- Epi-base transistors, 296-97
- Epi-FETs. *See* Epi pinch resistors
- Epi pinch resistors, 175-76, 423-25
- Epitaxy, 56-57
- analog BiCMOS and, 106
- polysilicon-gate CMOS and, 89
- standard bipolar and, 74
- ESD structures, 471-83
- selecting, 483-85
- Etch-and-regrowth, 406
- Etch effects, 430-33
- Etch guards, 223-24
- Evaporation, 59-60
- Excess minority carrier concentrations, 10-12
- Extended-base NPN transistors, 295-96
- Extended drain, 403
- Extended-drain, high-voltage transistors, 103-4
- Extended-drain NMOS transistors, 403-5, 430
- Extended-drain PMOS transistors, 405
- Extended-drain transistors, 403-5
- Extended-voltage transistors, 399-406, 400-402
- Extent into, 525-26
- Extrinsic collectors, 275
- Extrinsic drain, 401
- Extrinsic semiconductors, 6-9
- terminology used, 8
- F**
- Fabrication, 36-70
- analog BiCMOS, 106-11
- assembly, 64-69
- diffusion, 49-53
- ion implantation, 53-55
- metallization, 58-64
- oxide growth and removal, 42-49
- photolithography, 40-42
- polysilicon-gate CMOS, 89-95
- silicon deposition, 55-58
- silicon manufacture, 36-39
- standard bipolar, 73-77
- Failure mechanisms, 60, 118-55
- contamination, 124-28
- electrical overstress, 118-24
- NPN power transistors, 307-10
- parasitics, 139-53
- summary of, 154
- surface effects, 128-39
- Farad, 194, 194n
- Faraday shielding. *See* Electrostatic shielding
- Field-effect transistors (FETs), 24-25, 363, 399. *See also* JFET transistors
- Field oxides, 44, 48
- Field plates, 287, 421
- Field plating, 135-37
- Field regions, 90, 376
- Field relief guard rings, 354-55
- Field-relief structure, 403-4
- Fillets, 198, 292, 417
- Fingers, 279, 435, 439-40, 452-53
- Fixed oxide charge, 369
- Flanging, 135, 136, 137
- Flawed device mergers, 446-50
- Floorplans, 495-500
- Force leads, 504
- Forming gas, 284
- Forward active current gain, 260
- Forward-biased PN junctions, 13-14, 16
- Forward-bias safe operating area (FBSOA), 265
- Four-terminal NPNs, 272
- Fringing, 197
- Fuses, 185-89
- G**
- Galena crystal detector, 36, 343
- Gallium arsenide, 9
- Gallium phosphide, 9
- Gate area, 428
- Gate-coupled NMOS, 481-82
- Gate delay, 386-87
- Gate dielectrics, 25, 364
- Gate oxide capacitors, 197
- Gate oxide thickness, 428-29
- Gates, 25, 31-32
- Geometric effects, 427-30
- Germanium, 3, 4, 6-7, 8
- Gilbert multiplier, 342
- Gold preforms, 67, 227
- Gradients, 229-31, 433
- Grains, 121
- Gross profit margin (GPM), 494-95
- Group-III elements, 8
- Group-IV elements, 3-4. *See also specific elements*
- Group-V elements, 7
- Grown-junction transistors, 49
- Guard rings, 394, 445, 455-60. *See also* Channel stops
- bipolar electron, 456-57
- bipolar hole, 457-58
- in CMOS and BiCMOS designs, 458-60
- field relief, 354-55
- minority-carrier, 147-53, 375-76, 453-54
- Gummel number, 22
- H**
- Headers, 226, 227
- Heat sinks, 237-38
- Heavily doped substrates, 142
- H-emitter transistors, 317n
- High-level injection, 23
- High-sheet implants, 86, 173, 174-75
- High-sheet resistance (HSR), 86, 173
- High-sheet resistors, 86, 173-75
- High-voltage bipolar transistors, 291-93
- Hole-blocking guard rings, 457-58
- Hole-collecting guard rings, 457-58
- Hot carrier injection, 31, 128-31
- effects of, 128-30
- preventative measures, 130-31
- Hot carriers, 31, 128-29, 374-75
- Hot-dog transistors, 289-90
- Hot hole degradation, 97
- Hot spots, 264-65, 309-10
- Human body model (HBM), 119, 471-72
- Hydrofluoric acid (HF), 42, 45
- I**
- III-V compound semiconductors, 9
- II-VI compound semiconductors, 9
- Implant dose, 54
- Implant energy, 54-55
- Indirect-bandgap semiconductors, 6-7
- Indium, 8
- Indium antimonide, 9
- Ingots, 38
- Injection molding, 69
- Input ESD devices, 476
- Insulated-gate field effect transistors (IGFETs), 28n
- Integrated bipolar logic, 71
- Interdigitated arrays, 231-32
- Interdigitated backgate contacts, 395-96
- Interdigitated-emitter transistors, 311-13
- Interdigitation pattern, 231-32
- Interlevel nitride, 63-64
- Interlevel oxide (ILO), 63-64, 94, 101
- International System of Units (SI), 156-57, 156n, 194
- Intrafinger debiasing, 308-9
- Intrinsic collector current, 267
- Intrinsic saturation voltage, 409-10
- Intrinsic semiconductors, 6-7
- Inverse moat, 90, 108
- Inversion, 25
- Ionic bonding, 2-3
- Ion implantation, 49, 53-55
- Isobaric contour plots, 229
- Isobars, 229
- Isolation diffusion, standard bipolar and, 72, 74-75
- Isothermal contour plots, 238
- Isotherms, 238
- Isotropic wet etching, 45-46
- I-V characteristics
- bipolar junction transistors, 23-24
- MOS transistors, 29-31
- IV-IV compound semiconductors, 9
- J**
- JFET transistors, 31-33, 363, 399, 422-26
- layout of, 423-26
- modeling, 422-23
- Junction capacitors, 83, 197-203
- base-emitter, 205-7
- Junction field-effect transistors (JFETs). *See* JFET transistors
- Junction isolation (JI), 72-75

- Junction temperature, 237
 Junction-to-ambient thermal impedance, 237
 Junction-to-case thermal impedance, 237
- K**
 Kelvin connections, 177, 500, 503–4
 Kilby, J. S., 36
 Kooi effect, 48–49, 91–92
- L**
 Laser trims, 185, 190–91
 Latchup, 139–40, 145, 455–56
 CMOS, 89, 144–45, 375–76, 394
 Lateral autodoping, 57, 106
 Lateral DMOS transistors, 418–20
 Lateral PNP transistors, 80–81, 112–14, 283–84, 293, 325–27, 345–46, 454
 cell area estimation, 490
 construction of, 285–90
 rules for matching, 337–39
 saturation in, 270–71
 standard bipolar, 283–90
 Lateral resistance, 141, 141*n*
 Lawrence-Warner curves, 198
 Layout
 common-centroid, 231–35, 330–31, 333, 435–39
 editor software, 532
 mock, 461–62
 samples, 519–23
 syntax for, 523–26
 LDD transistors, 101–3, 130, 400–403
 Leadframes, 66–67
 Leakage. *See* Reverse conduction
 Least significant bit (LSB), 187
 Light-emitting diodes (LEDs), 6
 Lightly doped drain (LDD) transistors, 101–3, 130, 400–403
 Lightly doped substrates, with heavily doped isolation, 143
 Lightly doped substrates, with lightly doped isolation, 143
 Linear-mode applications, 311
 Linear region, 29, 32, 365
 Linear temperature coefficient of resistivity (TCR), 163
 Line regulation, 330
 Linewidth control, 162–63, 162*n*, 179
 Liquid-phase epitaxy, 56
 Lithium, 125*n*
 Load regulation, 330
 LOCOS processing, 48–49
 analog BiCMOS and, 108
 polysilicon-gate CMOS and, 91–92
 Logic gates, 387, 397
 Long-term drift, 247
 Look-ahead trimming, 188
 Low pressure chemical vapor deposited (LPCVD) epitaxy, 56–57
- M**
 Machine model (MM), 119, 471–72
 Majority-carrier devices, 16
 Majority carriers, 7–8
 Mask layers, 378
- Matching (matched devices), 214
 bipolar transistors, 322–39
 capacitors and resistors, 214–59
 rules for, 249–53
 diodes, 359–62
 minimal, 249, 334, 439
 moderate, 249, 334, 439
 MOS transistors, 426–42
 rules for, 439–42
 NPN transistors, 335–37
 precise, 249, 335, 439
 rules for, 249–57
 Mathematical derivations, 527–31
 Maze routing, 501
 Meander resistors. *See* Serpentine resistors
 Medium-risk merged devices, 453–54
 Merged devices, 445–55
 devising new, 455
 flawed, 446–50
 low-risk, 452–53
 successful, 450–52
 Merged devices medium-risk, 453–54
 Metallic bonding, 2
 Metallization, 58–64
 analog BiCMOS and, 110
 deposition and removal of aluminum, 59–60
 interlevel oxide, interlevel nitride, and protective overcoat, 63–64
 polysilicon-gate CMOS and, 94
 refractory barrier metal, 60–62
 silicidation, 62–63
 standard bipolar and, 76
 Metallization-induced stresses, 434
 Metallization resistance, 411, 412–14
 Metallurgical-grade polysilicon, 36
 Metallurgical junction, 224–25
 Metal-oxide-semiconductor field-effect transistors (MOSFETs), 25, 26, 363. *See also* MOS transistors
 Metal-oxide-semiconductor transistors. *See* MOS transistors
 Metal pitch, 502
 Metal resistors, 176–77
 Metals, 1–4
 Miller effect, 88
 Miller indices, 39, 516–18
 Minimal matching, 249, 334, 439
 Minority-carrier guard rings, 147–53, 375–76, 453–54. *See also* N-bars; P-bars
 Minority-carrier injection, 140, 143–53
 effects of, 143–46
 preventative measures, 146–53
 cross-injection, 151–53
 substrate injection, 146–50
 Minority carriers, 8
 Mismatches, 214–15
 causes of, 217–49
 measuring, 214–16
 random, 216, 217
 six-sigma, 216
 standard deviation of, 215–16
 systematic, 216
 three-sigma, 216
 Moat-2, 406
 Moat regions, 48, 90, 376
 Mobile ion contamination, 124, 125–28
 effects of, 125–26
 preventative measures, 126–28
- Mobile ions, 125, 246–47
 Mobile oxide charge, 369
 Mock layouts, 461–62
 Moderate matching, 249, 334, 439
 Molding process, 69
 Monocrystalline silicon, 38, 55
 MOS capacitors, 25–26, 196, 202, 203, 207–9
 MOS power switches, 409–10
 MOS transistors, 24–31, 202–3, 207–8, 363–98
 applications of, 399–444
 backgate contacts, 393–96
 cell area estimation, 490–91
 channel stops and, 381–83
 coding, 377–79
 common-centroid layout of, 435–39
 in common wells, 453–54
 I-V characteristics, 29–31
 matching, 426–42
 rules for, 439–42
 modeling, 364–70
 parasitics of, 370–76
 scaling, 386–88
 special symbols for, 27–28
 threshold adjust implants, 383–86
 threshold voltage of, 27–28, 87–88, 367–70
 topics in, 364–76
 variant structures, 388–93
 Most significant bit (MSB), 187
 Mounting, 66–68
 Mount pads, 66–67, 496–97
 Multilevel oxide (MLO), 63–64, 94
 Multiple gate oxides, 405–6
- N**
 NAND gates, 390
 Narrow-emitter transistors, 279
 Native transistors, 383–84
 Natural PMOS transistors, 97–98
 Natural transistors, 383–84
 N-bars, 152–53, 338, 448, 454
 NBL push, 53
 NBL shadow, 57, 73, 74, 220, 222, 253, 327–28, 336, 339, 442
 N-buried layer (NBL), 73–74, 106. *See also* NBL shadow
 N-channel JFETs, 31–33
 N-channel MOS (NMOS) transistors. *See* NMOS transistors
 Negative resists, 41
 Nichrome, 181, 190
 NMoat, 178, 180, 375, 376, 377–78, 381, 388, 458–59, 462, 474, 521–23
 NMOS parasitic channels, 131–39
 NMOS transistors, 26–28, 31, 207
 depletion-mode, 27–28
 enhancement-mode, 27–28
 extended-drain, 403–5
 gate-coupled, 481–82
 PMOS versus, 432–33
 polysilicon-gate CMOS and, 88, 89–90, 95–96, 97
 Noble silicides, 353
 Noisy signals, 504–6
 Nonlinearity, resistivity and, 163–66
 Nonmetals, 1–4

NPN transistors, 20–21, 22–23. *See also*

Power bipolar transistors
 analog BiCMOS and, 112
 DMOS, 420–21
 rules for matching, 335–37
 saturation in, 266–70
 standard bipolar, 72, 77–79, 274–79
 NSD implants, 93–94
 NSD resistors, 99, 180
 N-source/drain (NSD), 376
 N-type gate poly (NPoly), 385–86
 N-type silicon, 7–9, 10–11
 N-type V_i adjust (NVT), 385
 N-well, 379–80
 N-well CMOS processes, 89–90, 379–81
 N-well diffusion, 107
 N-well JFETs, 424–26
 N-well resistors, 180–81

O

Octagonal emitters, 323, 324
 Offset voltage, 322
 Ohmic contacts, 19–20, 60
 Ohmic debiasing, 448–49
 Ohms, 156–57
 Ohms per square, 81
 One-dimensional arrays, 234–35
 (111) planes, 39
 (100) planes, 39
 ONO capacitors, 196
 Optical generation, 5
 Optical shrinks, 387–88
 Outdiffusion, 52
 Output ESD devices, 476
 Overhang, 525
 Overlap, 524–25
 Oxidation furnaces, 43
 Oxide, 42–43
 growth and removal, 42–49
 Oxide capacitors, 196
 Oxide rupture. *See* Dielectric breakdown
 Oxide sidewall spacer, 102, 402
 Oxide steps, 46–47
 Oxide thickness gradients, 433
 Oxidization-enhanced diffusion, 53

P

Package shift, 226–36, 332–33
 Packaging, 69
 Packing factor, 493
 Pad oxide, 48, 89, 90
 Paddings, 466–85, 491–92
 Paper dolls, 462
 Parallel-plate capacitors, 194–95
 Parasitic channels, 131–39
 effects of, 131–33
 preventative measures, 133–39
 CMOS and BiCMOS, 137–39
 standard bipolar, 133–37
 Parasitic components, 139, 167
 Parasitic PNP, 267
 Parasitics, 139–53
 of bipolar transistors, 272–74
 of capacitors, 203–5
 minority-carrier injection, 143–53
 of MOS transistors, 370–76
 of resistors, 167–70
 substrate debiasing, 140–43
 Parasitic transistors, 381
 Pattern distortion, 73, 221
 Patterning, 42
 Pattern shift, 57, 220–22, 327
 Pattern washout, 221
 P-bars, 151–53, 338, 448, 452, 454
 P-buried layer (PBL), 84, 280
 P-channel JFETs, 33, 426
 P-channel MOS (PMOS) transistors. *See*
 PMOS transistors
 Pellicles, 42
 Perimeter utilization factor, 494
 Periodic table, 1–4
 Peripheral fluctuations, 217–19
 Permittivity of free space, 366
 Phosphors, 6
 Phosphorus, 7, 50–51
 Phosphorus-doped silicon, 7
 Phosphorus pileup, 47
 Phosphorus plow, 47
 Phosphosilicate-doped glass (PSG), 61, 77
 Photolithography, 40–42
 patterning, 42
 photomasks and reticles, 41–42
 photoresists, 40–41
 Photomasks, 41–42
 Photons, 5, 6
 Photoresists, 40–41
 Piezoresistivity, 226, 227–28
 Pilling-Bedworth ratio, 46*n*
 Pinched off, 29
 Pinch-off, 29
 Pinchoff voltage, 175–76, 422, 424–26
 Pinch resistors, 82–83
 Pinholes, 196
 Planar process, 49
 Plate capacitors, 199
 PMoat, 96, 152, 178, 375–78, 381, 388, 462,
 521–23
 PMOS parasitic channels, 131–39
 PMOS thick-field threshold, 131–32
 PMOS transistors, 26–28, 30, 73
 extended-drain, 405
 NMOS versus, 432–33
 polysilicon-gate CMOS and, 87–88, 90, 92,
 97–98
 PN junctions, 10–20
 depletion regions, 10–13
 diodes, 13–15, 16–17, 343
 matching, 359–60
 Ohmic contacts, 19–20
 Schottky diodes, 15–17
 Zener diodes, 17–18
 PNP transistors, 20–23
 analog BiCMOS and, 112–14
 standard bipolar, 72, 79–81, 279–90
 Polycrystalline silicon, 36, 37, 55
 Poly leads, 138–39
 Poly-poly capacitors, 196, 209–11, 224
 Polysilicon deposition and patterning, 58, 93,
 109
 Polysilicon emitter transistors, 300–301
 Polysilicon etch rate variations, 222–24,
 430–31
 Polysilicon fuses, 185–86, 188–89
 Polysilicon-gate CMOS, 71, 87–104. *See also*
 Self-aligned poly-gate CMOS
 transistors

analog BiCMOS versus, 110–11
 devices available, 95–100
 fabrication sequence, 89–95
 features of, 88
 process extensions, 100–104
 sample layout rules, 521–23
 Polysilicon (poly) resistors, 98–99, 101,
 164–65, 177–80
 variations in, 222–24
 Ports, 390
 Positive resists, 41
 Potassium, 125*n*
 Power bipolar transistors, 306–22
 in analog BiCMOS, 317–18
 failure mechanisms of, 307–10
 layout of, 311–19
 saturation detection and limiting, 319–22
 selecting a layout, 318–19
 Power-delay product, 387
 Power MOS transistors, 407–21
 conventional, 410–17
 DMOS transistors, 417–21
 Power transistors, 407
 Precise matching, 249, 335, 439
 Prels, 390
 Primary routing channels, 502–3
 Probe cards, 66, 67
 Probes, 66
 Probe yield, 495
 Process biases, 219–20
 Process control structures, 65
 Process extensions
 polysilicon-gate CMOS and, 100–104
 standard bipolar and, 84–87
 Process transconductance, 365–66
 Process variation
 capacitors and, 200–201
 resistors and, 162–63, 178–79
 Proportional base drive, 410
 Protective overcoat (PO), 59, 63–64, 110
 polysilicon-gate CMOS and, 94–95
 standard bipolar and, 77
 Proximity effect, 142, 456
 PSD implants, 87, 93–94
 PSD resistors, 99, 180
 P-source/drain (PSD), 377
 P-type gate poly (PPoly), 385–86
 P-type silicon, 8–9, 10–11
 P-type V_i adjust (PVT), 385
 Pulsed-mode transistors, 311
 Punchthrough, 373–74
 base, 24, 296
 emitter, 60, 61, 62, 300
 Punchthrough stops, 374
 P-well, 379–80
 P-well CMOS processes, 90, 379–81

Q

Quartz, 36
 Quasisaturation, 275, 295
 Quatrefoils, 360–61

R

Random mismatches, 216, 217
 Random statistical fluctuations, 217–19
 Rapid transient overload, 408–9
 Rate-triggered clamps, 481
 Ratioed pairs, 329

- Ratioed quads, 328, 330–32
 - Reactive ion etching (RIE), 45–46
 - Reactive ions, 45
 - Recombination, 4–6
 - Rectangular MOS power device, 411–13
 - Rectifiers, 13
 - Reflow, 61
 - Refractory barrier metal, 60–62
 - Refractory silicides, 353
 - Relative permittivity, 195
 - Remote sensing, 504
 - Representative processes, 71–117
 - analog BiCMOS, 104–15
 - polysilicon-gate CMOS, 87–104
 - standard bipolar, 72–87
 - Resistivity, sheet resistance and, 156–58
 - Resistors, 156–93
 - adjusting values, 182–91
 - analog BiCMOS and, 115
 - cell area estimation, 489
 - comparison of available, 170–82
 - layout of, 158–61
 - matching of capacitors and, 214–59
 - rules for, 249–53
 - parasitics of, 167–70
 - polysilicon-gate CMOS and, 98–99, 100
 - resistivity and sheet resistance, 156–58
 - standard bipolar and, 81–83
 - trimming, 182, 185–91
 - tweaking, 182–85
 - variability of, 162–67
 - RESURF (reduced surface field), 420*n*
 - Reticles, 41–42
 - Retrograde well, 374
 - Retrograde-well NPN transistors, 299
 - Reverse-biased PN junctions, 13–13, 16
 - Reverse breakdown, 17–18
 - Reverse conduction, 14–15
 - Reverse recovery time, 266
 - Ring collectors, 320
 - Routing factor, 493
 - Rule of coincidence, 233
 - Rule of compactness, 234
 - Rule of dispersion, 234
 - Rule of symmetry, 233–34
- S**
- Sacrificial gate oxide, 92
 - Sandwich capacitor, 208
 - Saturation, 29, 32, 266–71
 - detection and limiting, 319–22
 - Saturation current, 422–23
 - Saturation regions, 29, 365
 - Saturation voltage, 273, 313
 - Scaling laws, 386–88
 - Schottky barriers, 15–16, 19, 352
 - Schottky-clamped NPNs, 269
 - Schottky clamps, 453
 - Schottky diodes, 15–17, 18, 101, 269, 343, 352–56
 - matching, 361–62
 - standard bipolar and, 85–86
 - Scribe seals, 127–28, 466–67
 - Scribe streets, 466–67
 - SDD transistors, 102, 402–3
 - Secondary breakdown, 264–66, 309–10, 408
 - Secondary breakdown voltage, 310
 - Secondary collectors, 320–21
 - Seebeck coefficient, 240–
 - Seebeck effect, 240. *See also* Thermoelectric effect
 - Self-aligned poly-gate CMOS transistors, 376–96
 - backgate contacts, 393–96
 - channel stops, 381–83
 - coding the MOS transistor, 377–79
 - N-well and P-well processes, 379–81
 - scaling the transistor, 386–88
 - threshold adjust implants, 383–86
 - variant structures, 388–93
 - Semiconductors, 1–10
 - diffusion and drift, 9–10
 - extrinsic, 6–9
 - fabrication. *See* Fabrication
 - generation and recombination, 4–6
 - Semisimple figure, 286*n*
 - Sense leads, 504
 - Sensitive signals, 504–6
 - Serpentine resistors, 160, 161, 184, 241
 - Serpentine transistors, 391
 - Shadow effect, 146–47
 - Sheet resistance, 81
 - resistivity and, 156–58
 - Shells, 2–4
 - Shichman-Hodges equations, 365, 409, 427, 528, 530, 531
 - Sichrome, 181, 190
 - Silica. *See* Oxide; Silicon dioxide
 - Silicidation, 62–63, 85
 - polysilicon-gate CMOS and, 101
 - Silicide block mask, 101, 179, 180, 298
 - Silicides, 17
 - Silicon, 3–4, 6–9, 36–37
 - crystal structure of, 38–39
 - manufacturing, 36–39
 - crystal growth, 37–38
 - wafers, 38
 - Miller indices of cubic crystal, 516–18
 - Silicon-controlled rectifier (SCR), 145, 482–83
 - Silicon deposition, 55–58
 - epitaxy, 56–57
 - polysilicon deposition, 58
 - Silicon dioxide, 25, 28, 36, 42–43. *See also* Oxide
 - growth and removal, 42–49
 - Simple figure, 286*n*
 - Single-diffused drain (SDD) transistors, 102, 402–3
 - Single-level interconnection, 58–59, 460–66
 - crossing leads, techniques for, 463–64
 - mock layouts and stick diagrams, 461–62
 - tunnels and, 464–66
 - Single-level-metal (SLM), 58–59, 84–85
 - Single-well processes, 379–80
 - Sinkers, 72, 74–75, 105, 112, 148–49, 225, 245, 275, 277, 287, 295, 313, 318, 347–48
 - Sintering, 60
 - Six-sigma mismatch, 216
 - Sliding contacts, 183
 - Sliding heads, 183, 184
 - SLM interconnection system, 58–59
 - Small-signal transistors, 274. *See also* Bipolar small-signal transistors
 - Snapback, 263–64, 374, 478, 479, 481
 - Soakage, 211, 248–49
 - Sodium, 2–3, 125–26, 125*n*, 369*n*
 - Sodium thiodide, 3, 124–25
 - Sodium line, 77
 - Solid-state devices
 - defined, 1
 - manufacturing process of, 36–70
 - physics of, 1–33
 - Sources, 26, 93–94, 109–10
 - Space charge layers, 12
 - Spacing, 524
 - SPICE (Simulation Program with Integrated Circuit Emphasis), 156*n*
 - Spin-on glasses, 51
 - Split-collector lateral PNP transistors, 287, 454
 - Split field plates, 166, 247–48
 - Sputtering, 61–62
 - Square emitters, 323, 324
 - SSA transistors, 301–2
 - Stacked capacitor, 208
 - Staged oxidation, 406
 - Standard bipolar, 72–87
 - devices available, 77–83
 - diodes in, 343–56
 - extensions to, 293–94
 - fabrication sequence, 73–77
 - features of, 72–73
 - parasitic channels and, 133–37
 - process extensions, 84–87
 - sample layout rules, 519–21
 - Standard bipolar electron guard rings, 456–57
 - Standard bipolar hole guard rings, 457–58
 - Standard bipolar lateral PNP transistors, 283–90
 - Standard bipolar NPN transistors, 72, 77–79, 274–79
 - construction of, 276–79
 - Standard bipolar substrate PNP transistors, 279–83
 - Standard deviation of the mismatches, 215–16
 - Star nodes. *See* Kelvin connections
 - Starting material
 - analog BiCMOS, 106
 - polysilicon-gate CMOS, 89
 - standard bipolar, 73
 - Stepped working plates, 42
 - Steppers, 42
 - Stepping, 42
 - Stick diagrams, 461–62
 - Stitch bonds, 68
 - Straggle, 54
 - Stress distribution, 229, 235–36, 251, 256
 - Stress effects, 433–35
 - minimizing, 508–10
 - Stress gradients, 229, 433–34
 - matching bipolar transistors, 332–34
 - package shifts and, 226–36
 - Stress triangles, 508–9
 - Stretched-base transistors, 278
 - Stretched-collector transistors, 277–78
 - Strike voltage, 478–79
 - Strong inversion, 207
 - Substrate debiasing, 79, 140–43
 - effects of, 140–42
 - preventative measures, 142–43
 - Substrate injection, 146–50
 - Substrate PNP transistors, 79–80, 81, 98, 112–13, 279–83, 345
 - construction of, 281–83

- Subsurface Zeners. *See* Buried Zeners
 Subthreshold conduction, 30, 370
 Super-beta NPNs, 293
 Super-beta transistors, 24, 293
 standard bipolar and, 86–87
 Super self-aligned (SSA) transistors, 301–2
 Surface effects, 128–39
 hot carrier injection, 128–31
 parasitic channels and charge spreading, 131–39
 Surface state charge, 369–70
 Surface state charges, 43
 Surface states, 43
 Surface Zener diodes, 347–49
 Sustain voltage, 372–73, 478–79
 Switched-mode applications, 311
 Symmetric extended-drain NMOS transistors, 404
 Symmetric extended-drain PMOS transistors, 405
 Symmetric MOS transistors, 26
 Systematic mismatch, 216
 Syst me Internationale (SI), 156–57, 156*n*, 194
- T**
 Tank modulation, 165–66, 172, 242, 252
 Tanks, 72–73
 Temperature variations
 resistivity and, 163
 thermoelectrics and, 236–41
 voltage modulation and, 201–3
 Test dice, 65–66
 Testpads, 67, 445, 468–71
 Tetraethoxysilane (TEOS), 64
 Thermal effects, 433–35
 Thermal feedback, 329
 Thermal gradients, 238–39, 434–35
 matching bipolar transistors, 328–32
 Thermal impedance, 237
 Thermal runaway, 264–66, 309–10, 407–8
 Thermal voltage, 261
 Thermodynamics, 4
 Thermoelectric effects, 19–20, 240–41
 Thick emitter oxide, 76
 Thick-field oxide, 376
 Thick-field thresholds, 73
 Thick-field transistors, 481
 Thin emitter oxide, 76
 Thin-film capacitors, 197, 200, 201, 211–12
 Thin-film interference, 44
 Thin-film resistors, 181–82
 Thin gate oxide, 376
 Three-sigma mismatch, 216
 Three-terminal NPNs, 272
 Threshold adjust, 92–93, 109
 Threshold adjust implant mask, 384
 Threshold adjust implants, 27, 383–86
 Threshold voltage, 25–26, 27–28, 364, 367–70
 Tiling, 234
 Tilted implants, 436
 Tilted wafers, 437
 Time-dependent dielectric breakdown (TDDb), 366, 374, 472
 Tombstone PNP, 282
 Top-level interconnection, 500–510
 Transconductance, 25, 87, 96, 97, 103–4, 305, 429
 device, 365–67, 400, 408, 427, 433–35
 process, 365–66
 Trigger voltage, 372–73, 478–79
 Trimmers, 182
 Trimming, 182, 185–91, 328–29
 Trimpads, 186, 445, 468–71
 Triode region, 29, 365
 Trombone slides, 184
 Tubs, 72–73
 Tunneling, 18
 Tunnels, 85, 171, 445, 460–61, 464
 types of, 464–66
 Turnoff time, 266
 Turnoff voltage, 33
 Tweaking resistors, 182–85
 Tweaks, 182
 Twin-well processes, 380
 Two-dimensional arrays, 234–35
 Two-stage Zener clamps, 475–76
- U**
 Unconnected dummies, 223–24
 Unit capacitors, 220, 254
 Unit cells, 38–39, 516
- V**
 Valence electrons, 2, 4, 5
 Valence shells, 2–4
 Variability
 of capacitors, 200–203
 of resistors, 162–67
 Variant structures, 388–93
 V_{BE} , 261, 261*n*, 264, 267, 268
 V_{CBO} , 262, 263, 272, 273–74
 V_{CBOP} , 291
 V_{CEO} , 262–64, 265–66, 274–75, 291
 V_{CES} clamps, 478–80
 V_{EBO} , 262, 263, 272, 273–74, 344, 347
 Vertical DMOS transistors, 418
 Vertical resistance, 141, 141*n*
 Verti-lat PNP, 282–83
 Voltage matching, 440
 Voltage modulation, 242–45
 resistivity and, 163–66
 temperature variation and, 201–3
 Voltage proportional to absolute temperature (VPTAT), 329–30
 Voltmeters, 11–12
- W**
 Wafer boats, 43
 Wafer probing, 66
 Wafers, 38, 40
 manufacturing, 38–39. *See also* Fabrication
 Wafer utilization factor, 494–95
 Waffle transistors, 416–17
 Walled-emitter transistors, 301
 Washed-emitter transistors, 299–300
 Wedge bonding, 67–68
 Well resistors, 99
 Wet etching, 45–46
 Wet oxides, 44
 Whiskers, 506
 Wide-emitter narrow-contact transistors, 313, 314–15
 Width, 524
 Width bias, of resistors, 159–60, 161
 Wiresweep, 469–70
- Z**
 Zapping, 189
 Zener breakdown, 18
 Zener clamps, 473–78
 buffered, 476–78
 two-stage, 475–76
 Zener diodes, 17–18, 112, 131, 346–52, 454
 buried, 131, 349–52
 matching, 360–61
 surface, 347–49
 Zener walkout, 129–30, 129*n*, 131, 348
 Zener zaps, 185, 189–90
 Zero bias, 13
 Zero-bias capacitance, 197–98