Index

Adatom energetics, 59
Aluminum oxide films (alumina), 247–250
   Crystalline phases, 249
   Hardness, 250–251
Aluminum oxinitride (AlO\textsubscript{x}N\textsubscript{y}) films, 253
AlCrN films, 188, 197–199
Amorphous silicon (a-Si)
   Deposition processes, 377
   Solar cells, 378, 460
Amorphous silicon solar cell, 458
Angle of incidence (AOI), 286, 288, 295, 318, 325, 328, 329
Artificially structured materials, 444
Atomic force microscope, 24, 25
Atomic layer deposition (ALD)
   Advantages, 108–109
   Reaction steps, 109, 111
   Precursors, 110
   Al\textsubscript{2}O\textsubscript{3}, 112
   Materials deposited, by ALD 112–113
Biophotonics
   Hierarchy of cell structure, 541
   Laser therapy, 552–555
   Optical interactions of light a tissue, 542–545
   Photodynamic therapy, 547–550
   Bio-solar cell, 513–514
Bloch wave function, 400–402
Boron nitride (BN) films, 200
   c-BN films, 200–205
   B-N Allotropes, 201
   Deposition processes, 201
BN/CN films, 211
Boron carbide (B\textsubscript{C}\textsubscript{3}) films, 200
   B,C films, 205–207
   CVD films, 207–208
   Deposition processes, 202, 207
   Hardness, 209
Boron carbon nitride (B\textsubscript{x}C\textsubscript{y}N) films, 200, 209–210
   Deposition processes, 202
   B,C films, 205–207
   Boron carbon silicon nitride (BCS\textsubscript{3}N) films, 200
Carbon films
   Binary carbon, 233
   Coefficient of friction, 234–235
   Hardness, 235
   ta-C 226, 231, 234
Carbon nanotubes, 397
   Density of states: metal, 413.
   Density of states: semiconductor, 413, 418
   Dye sensitized solar cell, 428
   Energy band structure, 415
   Optical properties, 413, 417
   Optical transitions, 418
   p-n junction, 424
Photoconductivity, 422–424
Photoluminescence, 419–422
Properties, 410
Structure, 411ff
Synthesis, 427
Carbon nitride (CN) films, 236 ff
Chemical reactions in plasmas, 344–346

Chemical vapor deposition, (CVD)
CVD process family, 91–93
Basic CVD, 93
Process parameters, 95
Common precursors, 96
Reactors, 97–102
Reaction zones, 98

Chlorophyll
Optical absorption, 513

Chromium films
Plating, 212
Health concerns, 212
CrN films, 217–220
CrAlN films, 219
1931 C.I.E chromaticity
  diagram, 310
C.I.E RGB model, 313
C.I.E XYZ chromaticity
  diagram, 312
Cloaking device, 439
Coefficient of friction, 14

Color
Color perception, 308
Color matching functions, 311
Lab color space system, 314
Tristimulus chromaticity
  model, 309
1931 C.I.E chromaticity
  diagram, 310
C.I.E RGB model, 313
C.I.E XYZ chromaticity
  diagram, 312

Color in thin films
Angle of incidence (AOI), 286, 288, 295, 318, 325, 328, 329
Decorative hard coatings, 331–332

Color shift in multilayer
cOatings, 318–322
Metal reflector, 316–517
Reflected color, 315–323
Antireflection coating,
  325, 326
Transmitted color, 324–330
Antireflection coating, 326–327
Low-e window, 328
Transition metal nitrides,
  322–324

Color shift in multilayer coatings,
  318–322

Composite nanostructures,
  534–536

Contact angle, 519–520
Copper indium gallium deselenide
  solar cell (CIGS), 458
Corrosion of solid surfaces, 34
Cyanobacteria, 516
Cylindrical magnetron
cathode, 68
Rotatable, 69
Post magnetron, 70
Thin film materials, 71

Decorative hard coatings and
  colors, 331–332

Diamond like carbon (DLC) films
Allotropes, 222
Bonding configurations, 221, 227
Coefficient of friction
  (COF), 230 ff
Films deposited by PECVD,
  228–230
Mechanical properties, 227
Properties of DLC films,
  223–226
Diels–Adler reaction, 526–529
Diffusion in solids
  Diffusion coefficient, 486–489
  Minimization, 488
Direct electron transitions, 391
Dye sensitized solar cell,
  426–428, 430
### Index

<table>
<thead>
<tr>
<th>Electrical properties of solid surfaces</th>
<th>29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conductivity</td>
<td>30</td>
</tr>
<tr>
<td>Frequency dependence of electrical conductivity</td>
<td>33</td>
</tr>
<tr>
<td>Electrochromic coatings (EC)</td>
<td></td>
</tr>
<tr>
<td>EC window layer design</td>
<td>481</td>
</tr>
<tr>
<td>EC materials</td>
<td>482</td>
</tr>
<tr>
<td>EC reaction</td>
<td>483</td>
</tr>
<tr>
<td>Spectral switching</td>
<td>483–484</td>
</tr>
<tr>
<td>Electron beam evaporation</td>
<td>42</td>
</tr>
<tr>
<td>Evaporated materials</td>
<td>47</td>
</tr>
<tr>
<td>Electromigration</td>
<td>362–368</td>
</tr>
<tr>
<td>Humidity effects</td>
<td>366</td>
</tr>
<tr>
<td>Mechanical stress</td>
<td>365</td>
</tr>
<tr>
<td>Structure effects</td>
<td>363</td>
</tr>
<tr>
<td>Electro-optical property modification</td>
<td>337</td>
</tr>
<tr>
<td>Energy band structure</td>
<td>389</td>
</tr>
<tr>
<td>Fermi level</td>
<td>390</td>
</tr>
<tr>
<td>Germanium</td>
<td>407</td>
</tr>
<tr>
<td>Silicon</td>
<td>407</td>
</tr>
<tr>
<td>Engineered band structure</td>
<td>405ff</td>
</tr>
<tr>
<td>Engineered materials</td>
<td>6</td>
</tr>
<tr>
<td>Engineered surface structures</td>
<td>521</td>
</tr>
<tr>
<td>Environmental stability of thin films</td>
<td>48</td>
</tr>
<tr>
<td>Etch parameters</td>
<td>347</td>
</tr>
<tr>
<td>Evanescent wave</td>
<td>291</td>
</tr>
<tr>
<td>Ferroelectric films</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>374–375</td>
</tr>
<tr>
<td>Fermi level</td>
<td>390</td>
</tr>
<tr>
<td>Fick’s first law of diffusion</td>
<td>483, 487</td>
</tr>
<tr>
<td>Filtered cathodic arc deposition (FCAD or FCA)</td>
<td></td>
</tr>
<tr>
<td>Macroparticle issues</td>
<td>86</td>
</tr>
<tr>
<td>Drawbacks</td>
<td>88, 90</td>
</tr>
<tr>
<td>Thin film materials</td>
<td>89</td>
</tr>
<tr>
<td>Fluorides</td>
<td>129–130</td>
</tr>
<tr>
<td>Free energy</td>
<td>161</td>
</tr>
<tr>
<td>Frequency selective surfaces (FSS)</td>
<td></td>
</tr>
<tr>
<td>Complementary FSS structures</td>
<td>500</td>
</tr>
<tr>
<td>Element shapes</td>
<td>499</td>
</tr>
<tr>
<td>Mesh parameters</td>
<td>501</td>
</tr>
<tr>
<td>Optical transmission</td>
<td>502</td>
</tr>
<tr>
<td>Functional biomaterials</td>
<td></td>
</tr>
<tr>
<td>Applications</td>
<td>510</td>
</tr>
<tr>
<td>Cyanobacteria</td>
<td>516</td>
</tr>
<tr>
<td>Lotus leaf effect</td>
<td>517–518</td>
</tr>
<tr>
<td>Self cleaning biological materials</td>
<td>515ff</td>
</tr>
<tr>
<td>Self healing biological materials</td>
<td>522</td>
</tr>
<tr>
<td>Wound healing</td>
<td>522</td>
</tr>
</tbody>
</table>

**Glancing angle deposition (GLAD)**
- Microstructures | 437 |
| Grain and texture evolution in thin films | 158 |
| Grain boundary | 159 |
| General observations | 160 |
| Stress in grain boundaries | 163 |
| Grain boundary energy | 164 |
| Grätzel cell | 426 |
| Germanium quantum dots | 532–534 |

*Henry’s law | 486 |
| Hierarchy of cell structure | 541 |
| High power pulsed magnetron sputtering (HPPMS) | 73 |
| Power supplies | 74 |
| Improved tribological properties | 77 |

| Indirect electron transitions | 391 |
| Indium tin oxide (ITO) | |  
| Electron mobility | 470 |
| Magnetron sputtering | 473–474 |
| Sheet resistance | 470, 472 |
| Spectral transmittance | 471 |
| Ion assisted deposition | 50 |
| Factors that affect film growth | 52 |
| Property modification | 53 |
| Ion sources | 53, 55 |
| Ion beam sputtering (IBS) | 81ff |
| Ion plating | 54, 57 |
Kronig-Penny model, 402

Lab color space system, 314
Lotus leaf effect, 517–518
Low dimensional structures
  Density of states: 3D, 2D, 394
  Density of states: 1D, 0D, 395
  Minibands, 396
  Quantum well, 392
  Quantum dots, 398

Metallization, 360
  Electromigration, 362
  Subtractive, 361
Metamaterials
  Cloaking device, 439
  Dimensional scales, 445
  Metallic wire array, 447
  Negative refractive index materials, 437–444
  Split ring resonators, 450–452
  Stacked cylinder array, 449
  Super lens, 443
Microhardness of PVD and CVD films, 189
Microstructure/surface properties, 143
Minibands, 396
Molybdenum disulfide (MoS$_2$) films, 245
  As solid lubricants, 245
  Nanocomposite films, 246
Moore’s law, 431, 531
Multilayer optical coatings
  Antireflection coating, 297–299
  High pass filter, 306
  High reflectance coatings
    Dielectric enhanced, 301
    Quarter wave dielectric, 301–305
  Low pass filter, 306
  Structure, 297
  Types, 284
Multilayer structures
  Deposition, 120–121

Nanocomposite
  Structure, 261
  Materials, 257–260
Nanocomposite films
  MoS$_2$ based films, 246
  Cr-Ni-N, 264
  Hardness, 266
Industrial applications, 270–271
ncMeN films, 265
TiC$_N$/SiCN superhard films, 267–268
Zr-Cu-N, 264
Nanolaminate, 262
  Cu/Al nanolaminate, 269, 272
  Structure, 270
Nanoindentation, 23
Nanostructured coatings, 263
Nanotubes-polymer composites, 429
Nearly free electron approximation, 403
Negative photoresist, 370

Optical properties of solid surfaces, 25
  Absorptance, 27
  Modification, 283
  Polarization, 287–291
  Reflectance, 26, 286
  Color, 28
  Refraction, 286
  Transmittance, 26
Optical properties of thin films, 293–296
Optical interactions of light a tissue, 542–545
Optoelectronic properties of solid surfaces, 29
Optoelectronic transitions of electrons, 32
Plasma frequency, 33
Organic solar cell, 476
Parallel plate plasma etch system, 354
Photocatalytic processes in water, 512
Photocatalytic thin films
   Hydrophilic surfaces, 493
   Materials, 497
   Photocatalytic processes in
   TiO₂, 425
   Photocatalytic reaction, 494, 495, 497, 511
   Photosynthesis, 497
   TiO₂ solar cell, 426
Photolithography
   Photoresist stripping, 372
   Positive photoresist, 370
   Negative photoresist, 370
   Steps, 368–370
Photolytically driven electrochemistry (PDEC), 495–496
Photonic band gap materials
   Forbidden bands, 432–433
Physical vapor deposition, 40–42
Photodynamic therapy, 547–550
Photosystem I (PSI), 513
Photosystem II (PSII), 494–496
Photosynthesis, 497
   In thylakoid membrane, 514
   Process steps, 539
Piezoelectric films
   AlN, 374–375
   Piezoelectric equations, 373
p-i-n junction, 459
Planar magnetron sputtering, 60
   Optical thin film materials, 64
Plasma enhanced chemical deposition (PECVD)
   Reactors, 103–107
Plasma etching, 348–350
   Etch profile, 349
   Etch rates, 355
   Etchants, 353
   Microscopic processes, 351
   Pattern transfer, 350
   Process steps, 352
   Reactors, 358
   Plasma-film interactions, 346
   Plasma properties, 339
   Plasma processing, 338–346
   p-n junction, 459
   p-type transparent conductors
   Energy band structure, 479
   Materials, 480
   Polarization of light, 287–291
   Positive photoresist, 370
   Pulsed laser deposition (PLD)
      Benefits, 114, 118
      Chamber configuration, 115
      Nucleation and growth, 117
   Pulsed magnetron sputtering, 79ff
Quantum dots, 398
   Germanium, 532–534
   InGaAs solar cell, 535
   PbTeSe/PbTe, 535
   Quantum well
      Energy profile, 392–393
      Allowed wave functions, 394
   RAFT reaction, 529–530
   Ranges of plasmas, 340
   Reactive sputtering, 62–63
   Resonant mesh, 501–503
   Self assembled nanostructures
      Critical issues, 531
      Ge quantum dots, 532–534
      Self cleaning biological materials, 515ff
      Lotus leaf effect, 517–518
   Self healing biological materials, 522
   Self healing process, 523
   Self healing structures, 524–530
   Wound healing, 522
Semiconductor thin films
- Aluminum gallium arsenide (AlGaAs), 379, 408
- Amorphous silicon, 378
- Cadmium telluride (CdTe), 379–383
- Copper indium diselenide, CIS (CuInSe2), 383
- Copper indium gallium diselenide, CIGS (CuInxGa1-xSe2), 383
- Gallium arsenide (GaAs), 379–383
- Process goals, 376
- Silica films: see Silicon dioxide films
- Silicon carbide (SiC) films, 233
- Hardness, 240–241
- Silicon carbon nitride (Si-C-N) films, 238
- Hardness, 238–239
- Silicon dioxide (SiO2) films, 252
- Microhardness, 255
- Silicon nitride (SiN) films, 252
- Hardness, 253
- CVD deposited films, 254
- Silicon oxinitride (SiOxNy) films, 253
- SE applications, 2, 5
- SE benefits, 3
- Solar cell: also see Thin film solar cell
  - Intermediate band, 537
- Solid surfaces
  - Tribological properties, 7
  - Tribological coatings, 8
  - Wear, 8
    - Wear mechanisms, 9
    - Adhesive friction, 10
    - Abrasive wear, 11
    - Plowing, 11
    - Fragmentation, 12
    - Erosive wear, 13
    - Setting wear, 13
    - Lubricity, 14
- Hardness, 15
  - Hardness tests, 16
  - Mohs hardness, 17
  - Brinell hardness, 17
  - Rockwell hardness, 19
  - Vickers hardness, 19–20
  - Knoop hardness, 19–22
- Structure of thin films
  - Microstructures, 156
  - Types, 156
  - Short range and intermediate range order, 157
  - Amorphous thin films, 156–158
  - Columnar structure, 163
  - Pathological structures, 168–170
  - GLAD structures, 171
- Structure zone model
  - Movchan and Demchishin, 173
  - Evaporated films, 174
  - Sputtered films, 175–177
  - Ion plating, 177
  - Monte Carlo simulation, 179
  - Updates, 180–185
  - Superlattice, 262
  - Super lens, 443
  - Surface engineering defined, 1
  - Thermal rule, 166
- Thermal barrier coating, 255
- Thermal evaporation, 42
- Thermoelastic coating, 484
- Tight binding approximation, 403
- Tissue engineering, 551–555
- Thin film optical materials
  - Spectral ranges, 284–285
- Thin film permeation barrier
  - Applications, 485
  - Oxygen and water vapor barrier coatings, 490
  - Permeation factors, 488
Polymer multilayer coatings, 489
Vacuum polymer deposition technology, 491
Thin film solar cell
Amorphous silicon, 458, 460
CdTe, 458, 460
CIGS, 458, 461
Intermediate band, 537
Organic solar cell, 476
Thin film nucleation and growth
Surface kinetic processes, 144
Pressure, 146
Thermodynamics, 147
Frank-van der Merwe (FM) growth mode, 150–152
Volmer-Weber (VW) growth mode, 152–153
Stranski-Krastanov (SK) growth mode, 154–155
Titanium diboride (TiB$_2$) films, 188–190
Titanium boron carbide (TiBC) films, 188
Titanium carbide (TiC) films, 188, 190–194
TiN films, 188, 213–215
Cutting tools, 214
Decorative coatings, 214
Hardness, 215
Replacement for chromium, 213–214
Resistivity, 215
TiC films, 216–219
TiCN films, 188, 194
TiAlN films, 188, 195–197
TiBCN films, 188
Tristimulus chromaticity model, 309
Transparent conductive oxide
Dielectric constant, 468
Electrical properties, 463–467
Indium tin oxide (ITO), 469
Optical properties, 467–468
Zinc oxide (ZnO) and related materials, 476
Tungsten carbide (WC) films
Deposition processes, 242
Wear rate, 243
WC-Co films, 244
Unbalanced magnetron sputtering, 65, 133
Closed field magnetron, 65
Thin film materials, 67
Advantages, 68
Vacuum polymer deposition (VPD)
Chamber configuration, 125
Advantages, 125
Applications, 126–128
Vacuum polymer deposition technology, 491
Layer structure, 489, 492–493
WC-Co films, 244
Nanostructured films, 244–245
Wet chemical etching, 349–351
Common wet etchants for metals, 360
Pattern transfer, 350
Yttria stabilized zirconia films, 256
Zinc oxide (ZnO) and related materials, 476
ZnO family of thin films, 477
Zirconia films: see Zirconium dioxide films
Zirconium dioxide (ZrO$_2$) films
Cubic ZrO$_2$ (cubic zirconia) films, 255