

Index

- a-Si *see* amorphous silicon
- a-Si/a-SiGe tandem solar cells 546–51
- a-Si/a-SiGe/a-SiGe triple-junction solar cells 546–51
- a-Si:H 29
- a-Si:H solar cells, optical design 537–40
- ABAQUS 245
- ABN Amro Bank NV 1108
- absorber layer design of *pin* solar cell 533–4
- absorber region 87
- absorption coefficient 70, 72–4, 341, 507
- absorption coefficient spectra 519
- acceptors 69–70
- accumulator capacity 957–62
- activation energy 807
- ADO louver system 1032
- Advanced Photovoltaic Solar Array (APSA) 435
- Advanced Photovoltaics Systems, Inc. 512
- African Development Bank 1114
- Air Mass 62–3, 914, 916
- Air Mass Zero (AM0) spectrum 417
- air pollution 997–9
- albedo-collecting modules 472
- albedo irradiance 931
- AlGaAs 360
- AlGaAs/GaInP TJIC 397
- AlInP window layers 391–2
- alternating current (AC) 34
- alternative peak power ratings 715
- aluminothermic reduction of silica 201
- aluminum alloys 158
- aluminum back surface field 281
- aluminum industry 158
- Alwitra Evalon roofing foil 1030
- AM/PM method 716
- ambient temperature, diurnal variations of 933–4
- ambipolar diffusion coefficient 108
- Amonix Inc 496
- amorphous silicon (a-Si) 21, 27–9, 153, 176, 505
 - alloying 518–20
 - atomic structure 513–14
 - defects 514–15
 - deposition, miscellaneous methods 526
 - deposition techniques 520–1
 - metastability 514–15
 - optical properties 518–20
- amorphous silicon (a-Si)-based
 - photovoltaics, critical issues for further enhancement and future potential 559
- amorphous silicon (a-Si)-based solar cells
 - continuous roll-to-roll manufacturing on stainless steel substrates 553–5
 - module manufacturing 553–8
- amorphous silicon (a-Si) module 955
 - manufacturing cost, safety, and miscellaneous issues 556–7
 - performance 557–8
 - production on glass superstrate 555–6
- amorphous silicon (a-Si) photovoltaics, status and competitiveness 558
- amorphous silicon (a-Si) *pin* cells 528–41
- amorphous silicon (a-Si)/single-crystalline silicon 176
- amorphous silicon (a-Si) solar cells
 - 505–65, 1033–4
 - designs for 508–13
 - overview 505–13
 - substrate and superstrate designs 509–10

- ampere-hour efficiency 810
- angle of incidence
 - effects 934–7
 - relative transmittance plotted against 935
- angular distribution of sky irradiance 929
- angular losses calculation 936
- annealing 343–4
- annual energy production, economic analysis 983
- annual energy value, economic analysis 984
- annual performance and energy cost
 - summary for central station plants 36
- annual radiation availability 941
- ANSYS 245
- antireflection (AR) coatings 205, 268–9, 274, 283, 307, 326
 - and encapsulation 287
- antireflective (AR) coatings, high-efficiency III-V multijunction solar cells 375–6
- aperture efficiency 322
- Apollo Telescope Mount array 414
- Applied Solar Energy Corporation (ASEC) 466
- architecture 1005–42
 - challenge of photovoltaics 1005–6
 - functions of PV modules 1008–10
 - see also* BIPV
- Argentina, rural electrification 1061
- Array field 965
- ASHRAE model 934–5
- Asian Development Bank (ADB) 1111
- ASN Bank 1104–5
- aspheric lens 486
- astronomical unit 907
- Atlantis sunslates 1017
- atmospheric pressure chemical vapor deposition (APCVD) 547
- Auger recombination 76
- Australian National University (ANU) 496
- autonomous emergency phone and information system 58
- autonomous power supply systems 799, 808
 - applications 856
 - energy-flow diagram 814
 - for telecommunications 856
 - investment and lifetime costs 857–9
 - requirements to electrical storage systems 800
 - system designs 801
- autumn equinox 907
- auxiliary generators 790–1
- back reflectors 537, 539
- back-surface field (BSF) 88, 258, 281
 - recombination velocity 98
- balance equation 120
- balance of system (BOS) 5, 11, 14, 32–7, 863
- Ballistic Missile Defence Organization (BMDO) 416
- band diagram of solar cell 120
- band gap 37–8, 99–100, 132–4, 516–17, 540
 - a-Si alloys 546
 - as function of lattice constant 361
 - cell efficiencies as function of 415
 - grading 546
 - narrowing (BGN) 70, 73
 - silicon alloys 544–6
- bandedges 516–17, 528–9
- bandtails 516–17
- batteries 33, 54, 1052
 - capacity 811–12
 - classification of operating conditions 813–17
 - for photovoltaic systems 835
 - further developments 860
 - general concept 801–12
 - lifetime 787, 811, 860
 - operating conditions 786–7, 811–12
 - secondary electrochemical systems with external storage 849–57
 - state of charge 811–12
 - state of health 811
 - system indicators 816
 - technical terms and definitions 809–11
 - with internal and external storage 807–9
 - see also* lead acid batteries and specific types
- battery chargers 843
- battery charging 56
- battery charging stations 763
- battery currents 810
- battery storage 784–7
- battery voltage and current during charging 870
- beam radiation 913
- beginning-of-life (BOL) output 419
- belt furnaces 274
- bi-directional step-up/step-down conversion 893
- bifacial modules 294
- BIPV 15, 294, 775–6, 1006, 1014
 - basics 1026–35
 - categories and type of buildings 1026–35
 - categories of cell and modules 1026
 - categories of integration 1027

- cells and modules 1029–35
- design process 1036–40
- distance between buildings 1036
- function of integration 1028–9
- module temperature 1034–5
- orientation and angle 1036
- practical rules 1037–8
- reflection 1037
- solar cell materials 1030–4
- space required for balance of systems and interconnections 1039
- step-by-step design 1038–9
- strategic planning 1039–40
- trees 1036–7
- types of buildings and functions 1027
- urban aspects 1036
- zoning 1037
- black body, radiation spectrum for 63
- block-casting process 215
- body-mounted arrays 432
- Bolivia, rural electrification 1061–3
- boron back surface field 281
- boron-doped *p*-type material 216
- Bose–Einstein function 122
- boundary condition 338–41
- BP Solar 496
- BP Solface vertical wall system 1032
- Bragg reflectors 124
- Brazil, rural electrification 1063–4
- Bridgman technology 214–16
- Brundtland Centre, Toftlund (DK), case study 1022–6
- BSF 266–7, 288
- Buck converter 885–7
- building integration
 - definition of 1006–8
 - well-integrated systems 1014–18
- building-integrated PV systems *see* BIPV
- built-in voltage 83, 85
- bulk multicrystalline silicon 214–23
- bulk *p*-type material lifetime 419
- bulk silicon crystallization, simulation of 247–9
- buried contact solar cell process 289–91
- Butler–Volmer equation 804–6
- calibration of space solar cells 424–5
- Canara Bank (India) 1111
- capacitance–voltage (*C*–*V*) characteristics 398
- carbon
 - as impurity in silicon 187
 - in multicrystalline silicon 221
- carbon dopant 391
- carbothermic reduction of quartz 167
- carbothermic reduction of silica 161–3, 198
- Carnot efficiency 125, 131–2, 148
- carrier–carrier scattering 81
- carrier mobility 78–9
- carrier transport 81
- cash flows 974
- casting alloys 158–9
- cause–effect diagram for failed system 1054
- CdCl₂ treatment 633–7
- CdS/CdTe couples
 - bulk diffusivities 639
 - grain-boundary diffusion process 639
- CdS/CdTe intermixing 637–42
- CdTe 21, 27, 30–1, 64
 - absorber layer 633–7
 - band structure 625
 - cell photon losses and quantum efficiency versus wavelength 648
 - close-space sublimation (CSS) 628–9
 - condensation/reaction of Cd and Te vapors on a surface 628–9
 - crystal structure 624
 - deposition methods 626–7
 - electrodeposition 629–30
 - galvanic reduction of Cd and Te ions at a surface 629–30
 - high-efficiency 645
 - material properties and thin-film fabrication methods 621–31
 - metal organic chemical vapor deposition (MOCVD) 630
 - optoelectronic properties 622
 - phase diagram 623
 - physical vapor deposition (PVD) 628
 - physicochemical properties 622
 - potential toxicity 10
 - precursor reaction at a surface 630–1
 - screen-print deposition 631
 - spray deposition 630–1
 - sputter deposition 629
 - thin-film deposition techniques 627
 - vapor transport deposition (VTD) 629
- CdTe modules 651–3
- CdTe thin-film solar cells 617–62
 - back contact 642–4
 - basic structure 632
 - capacitance measurements and hole-density determination 649
 - characterization 644–50
 - development overview 617–21
 - future 653–7
 - J*–*V* curves 647
 - summary of status 650
 - window layers 631–2
- CdTe/CdS 28
 - bulk-diffusion coefficient versus inverse of treatment temperature 640

- CdTe/CdS (*continued*)
 grain-boundary diffusion coefficient
 versus inverse of treatment
 temperature 641
 CdTe/CdS heterojunction solar cells 619
 CdTe/CdS junction band diagrams 644
 CdTe/CdS solar cells
 current–voltage and relative quantum
 efficiency curves 621
 quantitative assessment of film
 properties 626
 CdTe/CdS thin-film structures,
 time-progressive X-ray diffraction line
 profiles 640
 CdTe–CdS pseudobinary phase diagram
 639
 CdTe_{1-x}S_x alloy thin film optical band
 gap versus composition 638
 celestial equator 909
 celestial poles 909
 celestial sphere 908–9, 911
 cell potential 809
 cell technology and efficiency, effect on
 module price 36
 cell voltage 809
 Central and Southwest Services (CSW)
 467
 Centre for Sustainability De Kleine Aarde
 in Boxtel 1017
 centrifugal pump system 894
 chalcopyrite lattice structure 571
 characteristic curve 952
 characteristic parameters 951–2
 charge controllers 33, 787–8, 843,
 864–77
 appraisal factors 875–7
 compliance to codes 877
 design criteria 875–7
 efficiency 876–7
 linear 865
 safety aspects 877
 self-regulating PV systems 865
 with integrated voltage and current
 meter 874
 see also T-CHEQ system
 charge equaliser 843
 for long battery strings 877–80
 charge transfer between molecular orbitals
 39
 chemical etchants 397
 chemical leaching, post-treatment by
 195–6
 chemical potential 134, 140, 142, 145
 chemical processes 807
 chemical texturing 285–7
 chemical vapor deposition (CVD) 284,
 315
 Cherry Hill Conference 13
 CHP space-heating applications 855
 CIS flat-plate 36
 Clean Energy Fund 1105
 clearness index 920, 945
 close spaced sublimation (CSS) 30
 cloudiness index 921
 CO₂ emissions 48–9
 CO₂ reduction 22
 Cold Wall process 246
 Colt shading system 1012
 Commons Capital LP 1108–9
 Communication/Navigation Outage
 Forecast System (CNOFS) 440
 Compositeds Optics Incorporated (COI)
 440
 compound parabolic concentrator (CPC)
 454, 482–3
 concentrating arrays 436–8
 concentration PV systems 31–2
 concentration ratio 450, 455, 484
 concentrator cell and module efficiencies
 473
 Concentrator Initiative 465–6
 concentrators 106–7, 124, 376–80,
 406–7, 449–503, 946–7
 basic types 452–60
 compound parabolic (CPCs) 454,
 482–3
 current activities 495–500
 D-SMTS 494
 development dilemma 450–2
 dielectric-filled 491–2
 early demonstration projects 466–7
 historical overview 460–74
 history of performance improvements
 472–4
 innovative 492–4
 literature 450
 market barriers 449–503
 marketing 451
 miscellaneous programs 471–2
 optics 452–5, 474–95
 parabolic 479–82
 reflection and refraction 478
 reflective trough 494
 research 449–503
 RXI 494
 Sandia National Laboratories program
 461–2
 schematic representation 475
 secondary optics 489–91
 static 456–60, 470, 491–2
 two-stage 473
 types of tracking 456–60
 V-trough 483–5

- conduction band (CB) 4, 66–7, 74, 119–21, 129, 144–5, 536
- confidence coefficient 918
- confidence interval 918
- conservation of energy 71
- consumer products 57–9
- control strategies 870–1
- cost break down of solar home system 56
- cost distribution for modules and silicon wafers 223
- cost model 35
- cost of electricity for utility-scale PV plants 990–4
- cost projections 50
- costs 15–19
 - for TFSC 34
 - for very high-efficiency 1000 suns-concentrating systems 38
- of construction of PV central plant 35
- of small professional autonomous photovoltaic systems 55
- of stand-alone PV installation 33
- see also* economic analysis; system cost
- covalent bonds 183
- crystal defects 217–19
- crystal growth techniques, numerical simulations of 244–51
- crystal imperfections, effect of 182–5
- crystalline silicon 21, 27–8, 176, 230
 - bulk properties 257
 - contacting structures 260
 - contacts 257–8
 - progress and challenges 23–7
 - surfaces 256–9
 - wafer material for 245
- crystalline silicon Cz module 35
- crystalline silicon noncontacted surfaces 258–9
- crystalline silicon photovoltaic modules
 - 291–302, 948–9, 955
 - cell matrix 291–2
 - electrical characteristics 295–7
 - fabrication spread 297
 - field performance 301–2
 - lamination and curing 293
 - layers of the module 292–3
 - lifetime 301
 - local shading and hot spot formation 297–9
 - mismatch losses 297
 - optical properties 300
 - postlamination steps 294
 - qualification tests 301–2
 - special modules 294–5
 - thermal characteristics 295–7
 - with back contact cells 295
- crystalline silicon solar cells 255–91, 948
 - back contact print and dry 275
 - back surface 266
 - back surface passivation 281
 - cell structure 259–60
 - cofiring of metal contacts 275
 - front contact print and dry 274–5
 - front surface 263–6
 - manufacturing process 271–80
 - materials and processing 260–2
 - performance comparison 270
 - process flow 271–6
 - size effects 266–8
 - substrate 260–3
 - substrate thickness 263
 - testing and sorting 275
 - throughput and yield 279–80
 - variations to basic process 280–3
- crystalline silicon technology 40
- crystalline silicon wafer PV technology 28
- crystallization 193–4, 216–17, 219, 223
 - from aluminum melt 194
 - from silicon-melt 194
 - heat flow in 247
 - thermal modeling of 245–7
- Cu₂S/CdS thin-film solar cells 568
- Cu–In–Se system 571–2
- CuIn_{1–x}Ga_xSe₂, complex refractive index 575
- Cu(InGa)Se₂ 21, 27, 29, 31, 35
- Cu(InGa)Se₂ solar cells 567–616
 - absorption of light with different wavelengths 595
 - alternative buffer layers 588–90
 - back contact 580
 - buffer layers 591–2
 - chemical bath deposition (CBD) 585–6
 - coevaporation 580–3
 - commercial development 570
 - composition 571–3
 - critical materials with respect to primary supply 608
 - current loss 594
 - deposition methods 578–84, 587–8
 - device completion 592
 - device operation 592–602
 - efficiency 590, 593
 - electrical properties 574–6
 - environmental concerns 608–9
 - equipment 602–4
 - evolution of device record efficiencies 605
 - future outlook 609–11
 - grain boundaries 576–7
 - interface effects 586–7
 - junction and device formation 584–92

- Cu(InGa)Se₂ solar cells (*continued*)
 lack of comprehensive scientific base 570
 light-generated current 593
 manufacturing issues 602–9
 material properties 570–8
 module fabrication 604
 module performance 604–7
 optical properties 574
 outdoor testing results 606
 processes 602–4
 production costs 607
 quantum efficiency 593
 recombination 595–8
 scanning electron microscopy image 577
 schematic cross section 569
 structure 571–3
 substrates 578–9
 surface 576–7
 TEM cross section 569
 thin films 570
 transparent contacts 590–1
 two-step processes 583–4
 wide and graded band gap devices 600–2
 Cu(InGa)Se₂/CdS 28
 current–voltage (*J*–*V*) behavior 595–6
 Cu(InGa)Se₂/CdS interface 599–600
 Cu(InGa)Se₂/CdS solar cells
 quantum efficiency curves 596
 temperature dependence 597
 CuInSe₂ 570
 absorption coefficient 574
 complex refractive index 575
 electronic levels of intrinsic defects 576
 intrinsic defects 576
 selected properties 572
 CuInSe₂ solar cells 567, 569
 current density 82, 805
 versus voltage 506
 current flow, electrode kinetics at 803–7
 current matching 548
 current–voltage (*I*–*V*) characteristics 92–5, 103–4, 122, 335, 701
 current–voltage (*I*–*V*) measurements 721–38
 CVD 321, 343
 Czochralski (Cz) cell technology 24, 989–90
 Czochralski (Cz) crystal-pulling technique 205, 246
 Czochralski (Cz) flat-plate cell 989
 Czochralski (Cz)-grown crystalline silicon 206, 261
 Czochralski (Cz)-grown crystals and wafers 207–11, 989
 Czochralski (Cz) module 987
 Czochralski (Cz) web modules 989

 daily energy deficit 959
 daily irradiation 932–3
 on inclined surface 933
 daily radiation sequences 937
 dangling bonds 514–15, 517
 dark saturation current 91–2, 96
 daylight control 1013
 D&B Capital 1105
 DC–AC conversion 37
 declination 916
 deep discharge protection (DDP) 763, 873–6
 Deep Level Transient Spectroscopy (DLTS) 221
 Deep Space 1 spacecraft 416, 437
 deep trapping 531
 defect clustering 334
 defect levels 517–18
 demand side management options 15
 dendritic web (WEB) cells 989
 dendritic web (WEB) production 231
 dendritic web (WEB) technology 35, 232–5, 239–43, 288
 density of state 66–7
 depletion approximation 84
 depletion region 83–5, 88, 90–1
 depth of discharge (DOD) 810, 847–8
 developing countries 1074
 lack of electricity 1044–5
 see also remote areas; rural areas
 development 1043–71
 device diagnosis 401–3
 DFCC Bank (Sri Lanka) 1111–12
 diamond lattice 64
 diesel generator sets 54
 diffuse fraction
 of horizontal radiation 920–5
 of individual daily global irradiation 922
 of mean daily global irradiation 921
 diffuse irradiance 928–31
 diffuse radiation 913
 diffusion 78, 80
 diffusion coefficient 81, 185
 diffusion length 212–13, 263
 diffusion overvoltage 807
 diffusion processes 806
 digital synthesis, voltage shaping by 890–2
 diode ideality factor 103
 direct band gap materials 73
 direct band gap semiconductors 71, 76

- direct current (DC) 3, 5, 34
- direct irradiance 928
- direct irradiation 913
- direct subsidies (buy-downs) 1094–5
- dirt effects 934–7
- dirty surfaces 944
- Discovery Science Center, Santa Ana, Los Angeles 1018
- dislocations 184–5, 218
- dispersion parameter 532
- dispersive transport 532
- displacement current 81
- distributed power generation 53
- distribution coefficients 182
- distribution function of monthly electricity consumption 963
- diurnal variations of ambient temperature 933–4
- divergence operator 116
- doctor blade technique 679
- domestic appliances, energy-saving 793–4
- donor funding 1086–7
- donors 69–70, 186, 220
- doping 69, 216, 518
 - silicon alloys 528
- doping level and type 262–3
- double-layer capacitors 824–6, 859
- double-sided textured (DT) cells 329, 331
- drift 78–9
 - of electrons 534
 - of holes 531, 534
- dummy wafers 178
- dust-covered surface 935
- dye fixation onto TiO₂ film 680
- dye-sensitized solar cells (DSSC) 663–700
 - approach to commercialization 691–4
 - background 663–4
 - cell assembly 681–2
 - cell performance 681–2
 - characteristics 678
 - charge recombination 675
 - charge-transfer kinetics 673–8
 - counter electrode 669, 681
 - efficiency improvement 695–6
 - electron injection process 673–5
 - fabrication 678–82
 - materials 664–70
 - metal complex photosensitizers 683–7
 - module fabrication 694
 - natural dye photosensitizers 687–8
 - new developments 682–90
 - new dye photosensitizers 683–8
 - new electrolytes 688–9
 - new oxide semiconductor film photoelectrodes 683
 - operating principle 670
 - organic dye photosensitizers 687–8
 - photovoltaic performance 672–3
 - primary processes 670–2
 - prospects 695–6
 - quasi-solid-state 689–90
 - recombination between injected electrons and tri-iodide ions (dark current) 676–7
 - redox electrolyte 681
 - regeneration of oxidized photosensitizers 676
 - sealing materials 670
 - solid electrolyte 696
 - solid-state 689–90
 - stability 691–4
 - structure 664–70
- E&Co 1109
- Earth–Sun position 912
- ecliptic plane 907, 909
- ecological dimension 48–54
- economic analysis 971–1003
 - annual energy production 983
 - annual energy value 984
 - capital recovery factor (CRF) 980
 - case studies 984–97
 - cash flows 973, 977
 - discount rate 975
 - discounted payback (DPB) 979, 984
 - energy payback 997–9
 - financial evaluation of system 976
 - general methodology 980–4
 - inflationary effects 977
 - internal rate of return 979
 - key concepts 973
 - key technical and financial parameters 986
 - levelized bus bar energy cost (LBEC) 980
 - levelized energy cost (LEC) 980, 983
 - net cash flow 978
 - overview 972–3
 - payback 984
 - payback period in years 979
 - present value or present worth 974–7
 - return on equity (ROE) 992
 - total capital requirements for central station plants 993–4
 - value of system 975
 - see also* cost(s); financing of PV growth
- Edge-defined Film-fed Growth (EFG) 230, 232, 234–5, 239–41, 244–5, 251, 288
- Edge-Stabilized Ribbon (ESR) 231
- Edge-Supported Pulling (ESP) 231
- effective concentration 803

- effective distribution function 182
- effective recombination velocity 87
- efficiency of photovoltaic conversion
 - 113–51
 - very high efficiency concepts 132–48
- efficiency calculation 125
- efficiency forecasts 113
- efficiency limit 113, 122–3
- efficiency upper limit of solar cell 120
- Einstein relationship 80–1, 86
- electric current 4
- electric field 86
- electric field profile 532
- Electric Power Research Institute (EPRI)
 - 467–71, 982, 992
- electric-vehicle batteries 835
- electricity
 - and development 1043–6
 - applications in rural setting 1046–7
 - basic sources 1047–8
 - centralized system 1045
 - future 2
 - lack in developing countries 1044–5
 - see also* photovoltaic electricity
- electricity consumption of household
 - appliances 794
- electricity generation 45
 - photovoltaics as long-term substitute 48–54
- electricity production scenarios 52
- electrochemical cells 809
 - fundamentals 801–7
- electrochemical equilibrium 804
- electrochemical potential 122, 143
- electrochemical processes 807
- electrochemical reactions, energy exchange 802
- electrochemical storage 799–862
 - schematics 808
- electrode kinetics at current flow 803–7
- electrodeposition (ED) 30
- electrodes 809
- electrolyte-agitation systems 844
- electrolytic transfer of silicon 201
- electromagnetic compatibility (EMC) 867
- electromagnetic radiation 61
- electron beam-induced current (EBIC)
 - 193
- electron behavior 531
- electron cyclotron resonance CVD (ECRCVD) 341
- electron effective mass 65
- electron fluence for silicon solar cell 421
- electron-hole pairs 62, 70, 74, 122, 143, 257
- electron parameters 531
- electron wave function 65
- electronic density-of-states 515–16
- electronic devices 59
- electronic modeling, thin-film silicon solar cells 333–41
- electrons
 - drift of 534
 - thermodynamic function of 119
- electrostatic potential difference 84–5
- electrostatically clean arrays 439–40
- ELYMAT 212–13
- emergency telephones 757–8
- emitter front 281–2
- emitter sheet resistivity 335
- emitter structures 264
- emitters 87, 93, 258
 - homogeneous 264–5
 - point 265
 - selective 265
- end-of-charge voltage 811
- end-of-discharge voltage 809
- energy and Early Man 1043–4
- energy band diagram 66
- energy band model 339
- energy band structure 65–6
- energy collection versus inclination angle 940
- energy conversion, characteristics of 45–8
- Energy Conversion Devices, Inc (ECD)
 - 553–4
- energy efficiency 810
- energy flow analysis 812–13
- energy gap 516
- energy losses in grid-connected systems 966
- energy-management systems (EMS) 873, 875
- energy market, liberalization 52
- energy payback 997–9
- energy-saving domestic appliances 793–4
- energy storage 55, 799
- energy yield of grid-connected systems 965–6
- Entech Inc 497
- Entech linear-focus Fresnel system
 - 463–5
- enthalpy 802
- entropy 802
- entropy production 116–17, 128
 - in Shockley–Queisser solar cell 129–31
- environmental considerations 997–9
- Environmental Enterprises Assistance Fund (EEAF) 1100
- environmental monitoring 10
- epilayers, characterization 398–400
- epilift technique 320–1

- EPRI 467–71, 992
 equilibrium carrier concentration 67–70
 equilibrium energy band diagram 86
 equilibrium potential 801–3
 equilibrium voltage 805, 809
 Ernst & Young Renewable Energy Unit 1105
 Ethyl Corporation process
 for semiconductor grade silicon 173–5
 simplification 198–201
 Euclides linear trough system 497
 Europe, PV programs 1097–9
 European Bank for Reconstruction and Development (EBRD) 1105–6
 European Commission DG XVII 1106
 European Investment Bank (EIB) 1106
 exchange current density 805
 excimer laser annealing (ELA) 350
 excimer laser recrystallization (ELR) 350
 experience curve 50–1
 experience factor 17, 38
 Explorer I 414
 extensive variables 114
 external collection efficiency 95
 extraction metallurgy in ladle,
 post-treatment by 196–8
 extraterrestrial applications 59–60
 extraterrestrial irradiance 915–16
 extraterrestrial radiation 913, 926

 FAC/Equities A Division of First Albany Corporation 1109
 facade systems 1014
 failed system, cause–effect diagram for 1054
 Fast Auroral Snapshot (FAST) solar array 440
 Fermi energy 68–9, 83, 88, 518
 Fermi function 68
 Fermi level 119, 529, 535
 figures of merit 444–6
 fill factor (*FF*) 309
 Final Yield 965
 financial characteristics 1077–9
 financing of PV growth 1073–115
 borrowers experience 1081
 capital requirements 1076–7
 example calculation 1082
 grid-connected residences 1079–82
 growth outlook 1075
 historical development 1073–4
 lenders issues 1081
 market drivers 1075
 organizations involved in 1100–14
 residential sector 1082
 rural areas 1083–6
 financing the PV industry 1091–2

 financial-support mechanisms 50
 fixed surfaces, irradiation on 943–5
 Flat Plate Array Project 230
 flat-plate, CIS 36
 flat-plate conventional PV modules 947
 flat-plate solar cells 268, 989
 flexible fold-out arrays 433–5
 flexible roll-out arrays 435–6
 float zone (FZ) monocrystals 205
 floating-zone technique 207
 flooded batteries 844
 flywheels 799
 foil *see* silicon ribbon and foil production
 forecasts 15–19
 long-term 18
 four-junction III-V cells 417
 Fourier Transform Infrared Spectroscopy (FTIR) 219
 Franz Keldysh effect 73
 Fraunhofer-Institut für Solare Energiesysteme 497–8
 free-carrier absorption 74
 free enthalpy 802
 Fresnel lens 36, 452–3, 462, 464, 466, 474, 485, 487–9, 496
 Fresnel module price 992
 Fresnel system 990
 front-polished and back-textured (FPBT) 329
 front-surface recombination velocity 97
 front-textured and back-polished (FTBP) 329, 331
 fuel cells 854–5
 fumed silica 159, 170
 functional silanes 160
 fundamental absorption 70

 GaAs 5, 20, 27, 60, 64, 123–4, 360, 426, 472
 back-surface fields 394
 optical properties 394
 properties at 298K 386
 window layers 394
 see also GaInP/GaAs; GaInP/GaAs/Ge
 GaAs cells 393–4, 994–7
 Ge(100) substrates 393–4
 GaAs tandem-junction cells 996
 GaAsP 360
 GaInAs 360
 GaInP 5, 20–1, 40, 426, 472
 absorption coefficient 388–9
 optical properties 387–9
 ordering in 387
 properties at 298K 386
 GaInP solar cells 383–93
 back-surface barrier 392–3
 characteristics 393

- GaInP solar cells (*continued*)
 - doping characteristics 389–91
 - lattice matching 383–7
 - window layers 391–2
- GaInP/GaAs cell efficiencies 361
- GaInP/GaAs multijunction solar cell 360
- GaInP/GaAs tandem solar cells 360, 362
- GaInP/GaAs/Ge concentrator cell 379–80
- GaInP/GaAs/Ge solar cells 361, 363
 - materials issues 382–98
 - MOCVD 382
 - refinements to 403–4
- GaInP/GaAs/Ge tandem cell 359
- Galaxy XI spacecraft 438
- gap states 517–18
- GaSb 472
- GE Capital Corporation 1109
- generator capacity 957–62
 - versus storage capacity 959
- Geospace Electrodynamical Connection (GEC) projects 440
- geosynchronous Earth orbits (GEO) 420
- German 100 000 photovoltaic roofs
 - programme 778–9
- germanium
 - optical properties 394
 - properties at 298K 386
 - see also* GaInP/GaAs/Ge
- germanium cells 394–6, 426–7
 - III–V heteroepitaxy 395–6
 - junction formation 394–5
- germanium substrates 393–4
- Germany 1074
- gettering 262, 283
- Global Approval Program for Photovoltaics (PV GAP) 1054
- Global Environment Facility (GEF)
 - 1089–91, 1101
- global horizontal irradiation 918
- global irradiance on inclined surface 927–33
- global radiation 913, 920–5
- global trends in performance and applications 20–3
- global warming 48
- glow discharge deposition at different frequencies 523–5
- goals of current solar cell research and manufacturing 19
- government funding of research and development 1096–100
- government incentives and programs 1092–6
- grain boundaries (GB) 183, 185, 217, 310, 333, 337
 - categorization 337–8
- grain boundary interface recombination velocities 342
- grain enhancement, thin-film silicon solar cells 343–50
- grain growth 349
- grain size 217–18, 340
- grain size distribution 349
- grains, categorization 337–8
- Grameen Shakti (Bangladesh) 1112
- grand canonical potential current density 129
- grand canonical potential flow for electrons 130
- grand potential 115
- green design, PV role in 1011
- grid-connected systems 754, 779–80
 - block diagram 775
 - decentralized 774–9
 - dependence of annually used solar energy from 792
 - energy losses in 966
 - energy yield of 965–6
 - future developments 796–7
 - inverters 788–9, 881–902
 - joint ownership 779–80
- grid-independent systems, for small devices and appliances 755–9
- Group IB formation in QD arrays 147
- Group IB material 144–5
- Group IB solar cell
 - limiting efficiency 147
 - structure 146
- Group III–V semiconductor compounds and alloys 362
- Group III–V solar cells, space applications 426–31
- Group VB 120–1, 129, 144–5
- H-type bridge 892, 895–6
- H-type bridge inverter 892
- hazard classification 10
- Heat Exchange Method (HEM) 246
- heat flow in crystallization 247
- heat load and daylight control systems 1013
- Helios unmanned prototype aircraft 783, 785
- Heller Financial Incorporated 1109–10
- heterojunction with intrinsic thin-layer (HIT) solar cells 271, 288–9
- high-efficiency III–V multijunction solar cells 359–411
 - antireflective (AR) coating effects 375–6
 - cell configuration 365–6
 - chromatic aberration 375
 - concentration 376–80

- concentration dependence of efficiency 378
- current matching 376
- current-matching effect on fill factor and V_{OC} 373
- efficiency 382
- efficiency versus band gap 370–2
- fill factor 382
- four-terminal connection 365
- growth on other substrates 405–6
- implementation into terrestrial systems 406–7
- materials availability 398
- metallization 378–9
- multijunction J – V curves 368–70
- overview 359–63
- physics of 363–5
- series-connected device performance 366–82
- series resistance 378–9
- single-junction solar cells, physics of 363–5
- space applications 363
- spectral effects 374–5
- spectral fluctuations 374–5
- spectrum 377
- spectrum splitting 364–5
- temperature dependence 380–2
- terrestrial energy production 363
- theoretical limits to multijunction efficiencies 364
- three-terminal voltage-matched interconnections 366
- top and bottom subcell QE and J_{SC} 367–8
- top-cell thinning 372–3
- troubleshooting 398–403
- two-terminal series-connected (current matched) 366
- high-efficiency multijunction solar cells 551
- high-efficiency silicon (HES) cells 415, 426
- high-level injection 107–9
- high-radiation environment solar arrays 443–4
- high specific power arrays 443
- high-temperature/intensity arrays 438–9
- holes, drift of 531, 534
- horizontal radiation, diffuse fraction of 920–5
- hot electron solar cells 141–4
 - band structure 143
- hot-wire chemical vapor deposition (HWCVD) 341, 345–7, 525–6
- household appliances, electricity consumption of 794
- housing projects 1020–1, 1023
- HS601 spacecraft 426
- HS702 spacecraft 426
- Hubble space telescope 436–7
- human development index (HDI) 2
- hybrid systems 763–6, 768, 860
- hydrogen, passivation with 283–5
- hydrogen dilution 526–7
- hydrogen/oxygen storage systems 852–7
 - applications 855–7
 - electrolysers 853
 - gas storage 853–4
- hydrogen storage systems 860
- hydrogenated amorphous silicon 507
- IFU 1106–7
- IMCAP 985
- impact ionization 76
- Impax Capital Corporation Ltd 1106
- impurities 219–23
- inclination angle versus latitude 942
- inclined surface
 - daily irradiation on 933
 - global irradiance on 927–33
 - solar radiation on 920–33
- income tax deductions and credits 1096
- indirect band gap semiconductors 72, 76
- indium-tin-oxide (ITO) layer 547
- ING Bank Nederland 1107
- ingot fabrication 214–16
- In_2Se_3 – Cu_2Se equilibrium phase diagram 573
- inside efficiency 322
- institutional uses 1083–4
- integrated power systems 442–3
- integrated PV building *see* BIPV; building integration
- intensive variables 114
- Inter-American Development Bank (IADB) 1114
- interest subsidies 1095–6
- interface condition 338–41
- intermediate band (IB)
 - concept 39
 - solar cell band diagram 145
- internal gettering 351
- international aid 1086–7
- International Finance Corporation (IFC) 1089, 1101
- international financing sources 1086–91
- International Panel on Climate Change 48–9
- International Space Organization 422
- International Space Station (ISS) 415–16, 434, 782, 784
- interstitial impurities 184
- interstitial oxygen 219

- intragrain defects 333
- inverters 5, 788, 881–902
 - active quality control in the grid 900
 - combination of step-down converter with 890
 - general characteristics 881
 - grid-connected systems 788–9, 881–902
 - H-bridge-type 885
 - high-frequency concepts 894–6
 - power factor as function of output power 899
 - power quality 896–9
 - principles 884–96
 - safety aspects for grid-connected systems 900–2
 - square-wave-type 884–5
 - stand-alone operation 883
 - stand-alone systems 789–90
 - three-phase PWM 894
 - with sinusoidal AC output 885–96
- Ioffe Physical-Technical Institute 498
- ionizing radiation 419
- IREDA (India) 1112
- iron concentration 222
- irradiance 913, 915
- irradiance measurements 721–2
- irradiance to daily irradiation ratios 926
- irradiation 913
 - of most widely studied surfaces 940–1
 - on fixed surfaces 943–5
- IT Power India Pvt. Ltd. 1112
- I–V* characteristics 92–5, 336
- I–V* curves 275–6, 299, 867, 949–50
- I–V* measurements
 - cell and module systems 731–6
 - multijunction cells 400–1
 - simulator-based 722–3
- I–V* performance 548–9
- Japan, PV programs 1097
- Japanese residential PV promotion program 777
- Jet Propulsion Laboratory (JPL) Flat Plate Array Project 230
- joint ownership project 781
- JRC Ispra guidelines 965
- junction isolation 274
- J–V* characteristics 544
- J–V* curves 341–2, 368–70
 - for series-connected subcells 369
- Kyoto Protocol 22
- Lafarge Braas PV 700 roof tile system 1015
- Lagrange invariant 118
- Landsberg efficiency 148
- laser-grooved buried-grid (LGBG) industrial cells 264
- laser-grooved buried-grid (LGBG) solar cell process 290–1
- laser-induced recrystallization 350
- laser-pulse time-of-flight measurements 531
- law of the junction 88
- lead acid batteries 806, 817, 826–49, 856
 - acid stratification 837–9
 - ageing processes and their influences of properties 837
 - applications 829–35
 - charge/discharge process in lead electrode 828
 - charging 845–6
 - chemistry 827–9
 - concepts 829–35
 - corrosion 840
 - deep-discharge protection 847–9
 - discharge capacity 836–7
 - discharge curves 849
 - erosion 840–1
 - fundamentals 829–35
 - ice formation 842–3
 - operation strategies 844–9
 - peripherals 843–4
 - reverse charging 842
 - short circuits 841–2
 - sulphation 839
 - technology 829–35
 - voltage thresholds 875–6
- lead sulphate crystals 807
- Legendre's transformation 114–15
- less-developed areas 972
- light absorption 70–4
- light emitting diode (LED) 76, 137–8, 148
- light-induced degradation (LID) 212–13
- light-soaking effects 541
- light-trapping 269–70, 320, 325–7, 333, 537–8
- lithium batteries 859
- lithium-ion batteries 822–4
- lithium-polymer batteries 822–4
- local apparent time 909
- local horizon 939
- long-base approximation 96
- Loss of Load Probability (LLP) 956–7, 960–1, 963–4
- low intensity low temperature (LILT) cells 441–2
- low pressure chemical vapor deposition (LPCVD) method 213
- low-Earth orbit (LEO) 414, 420

- MACD 307–8, 311, 327–31
 influence of bottom angle of texture pits 331–2
 influence of density of texture pits 332
 influence of texture height 331
 magnesium dopant 391
 Malaprabha Grameena Bank (India) 1112–13
 Manipal Finance Corp. Ltd. (India) 1113
 MARC 245
 market demand 1084
 market distribution by technologies 21
 market evolution 47
 market expansion 39–40
 market growth rates 50
 market share of monocrystalline and multicrystalline solar cells 256
 market volume 56
 markets 15–19
 Mars Pathfinder Sojourner Rover 432
 Mars solar arrays 440
 Mars solar electric propulsion (SEP) vehicle 428
 Martin Marietta point-focus Fresnel system 462–3
 Mataro Library, Barcelona, Spain 776
 matching component cells in multijunction designs 550
 matching DC/DC converter (MDC) 871
 Mathiessen's rule 79
 maximum achievable current density *see* MACD
 maximum power calculation 950
 maximum power point (MPP) 93–4, 866, 881–2, 900, 952–3
 deviations 883
 maximum power point tracking (MPPT) 871–3, 881, 894
 mean global daily irradiations 917
 mechanical stacks 404–5
 mechanical texturing 285–6
 median cracks 228
 MESSENGER Discovery mission 439
 metal-induced crystallization (MIC) 344–9
 metal-insulator-semiconductor (MIS) contacts 258
 metallization techniques 263–4
 metallurgical grade silicon 24, 157–8, 161–7, 176–7
 casting 166
 crushing 166
 economics 167
 furnace for production of 164
 refining 163–6
 upgrading purity 194–8
 metalorganic chemical vapor deposition (MOCVD) 360
 GaInP/GaAs/Ge solar cells 382
 Meteosat weather satellite 783
 Mexico, rural electrification 1064–5
 microcrystalline silicon solar cells 551–2
 microenterprise 1083
 micromorph devices 552–3
 microwave glow discharge deposition 525
 micro-X-ray 347
 mid-Earth orbits (MEO) 420
 Miller indices 65
 minority-carrier diffusion equation 82–3, 89
 minority-carrier diffusion length (MCDL) 307, 351
 minority-carrier lifetime 77
 minority-carrier recombination 185
 mobility edges 517
 modularity 56
 module aperture area 35
 module manufacturing, a-Si-based solar cells 553–8
 module price for silicon cell technology 985–90
 module temperature, BIPV 1034–5
 monitoring systems and interfaces 843, 874
 monochromatic cell 124–6
 monochromatic cell efficiency versus photon energy 125
 monocrystalline float zone (FZ-Si) material 260
 monocrystalline Si cells 1031–2
 monoenergetic membrane 144
 morphological defects 401
 MOS-FETs 866, 868
 multicrystalline silicon (mc-Si) 21, 26, 206
 multicrystalline solar cells 256, 283–7
 multicrystalline wafers 285
 multijunction designs, matching component cells in 550
 multijunction III-V cells 427–8
 multijunction solar cells 20, 38, 132–5, 510–11, 542–53
 advantages 542–4
 I–V measurements 400–1
 measurement procedures 728–30
 principles and operation 362
 quantum efficiency measurements 549
 multilinear Lagrange invariant 118
 multi-wire sawing technique 224

 n-type material 77, 83
 n-type semiconductors 76
 n-type side 25

- n*-type silicon 184
- Nagarjuna Finance Ltd. (India) 1113
- nanotechnology 39
- National Meteorological Services 916
- National Renewable Energy Laboratory (NREL) 323, 360, 498
- natural integration 1015
- NEDO process 198
- Nernst equation 803
- New Alternatives Fund Inc. 1110
- New Century Finance Limited 1107
- New Energies Invest Ltd. 1107
- NiCd batteries 818–21
- nickel-metal hydride (NiMH) batteries 821–2
- Ni-Si phase diagram 190
- nominal operating cell temperature (NOCT) 714, 947, 951, 955
- noncrystalline semiconductors 517, 532
- n-p* junction 340
- Nth Power Technologies 1110
- nucleation 349
- numerical modeling of solar cells 109–10
- numerical simulations of crystal growth techniques 244–51
- off-grid energy supply systems, characteristics of 55
- off-grid power supply systems 54–7, 754
 - future developments 794–6
 - prerequisites 57
- off-grid rural electrification 768–71
 - categorization of delivery models 773–4
 - economic aspects 771–4
 - see also* rural electrification
- open-circuit voltage 309, 529, 534–7, 809, 951, 954
- optical confinement 285
- optical design, a-Si:H solar cells 537–40
- optical generation rate 89
- optical properties
 - crystalline silicon photovoltaic modules 300
 - GaAs 394
 - GaNP 387–9
 - germanium 394
 - thin-film silicon solar cells 328
- optics 268–70, 326–36
 - concentrators 452–5, 474–95
- optimal tilt angle for minimizing solar generator size 793
- Orbital Workshop array 414
- Ostwald ripening 185
- overcast skies, radiance distribution associated with 930
- overvoltage 806
- oxygen as impurity in silicon 187–8
- oxygen segregation 220
- p*-type material 77, 83
- p*-type multicrystalline silicon 217, 220
- p*-type semiconductors 76
- p*-type side 24
- pair formation 185
- parallel resistance 953
- parasitic power loss 37
- parasitic resistance effects of solar cell 102
- partial-shunting controller 869
- passivated emitter rear contact (PERC) cell 466
- passivated emitter rear floating junction (PERF) cells 266
- passivated emitter rear locally diffused (PERL) cells 261, 263, 266, 270–1, 314–15, 469
- passivated emitter rear totally diffused (PERT) cell 266, 314
- passivation with hydrogen 283–5
- Pathfinder unpiloted prototype 782
- Pb/H₂SO₄/PbO₂ cell 830
- PCID 334
- peak load 51
- peak-load-reduction technology 14
- performance rating methods, energy-based 716–17
- performance ratio (PR) 965
- periodic table of elements 64
- personal digital assistant 58
- phonon absorption 72
- phonons 72
- phosphorus diffusion 273
- phosphorus doping 518
- photocurrent drift in absorber layers 530–3
- photoconductivity 505
- photoluminescence (PL) intensity 400
- photon absorption 71–2
- photon conversion efficiency, wavelength dependence of 363–4
- photon energy 61, 70, 73, 130
 - monochromatic cell efficiency versus 125
- photon flux 74, 121
- photon flux absorption 313
- photons 3, 5, 61, 117–18, 127–8, 142, 144
- photosynthesis 39
- photovoltaic cells 57
 - and BIPV modules 1029–35
 - manufacturers 22
 - measurement and characterization 701–52

- Photovoltaic Concentrator Applications
 - Experiments 462
- photovoltaic concentrators *see* concentrators
- photovoltaic conversion, efficiency of 113–51
- photovoltaic converters 59, 120–31
- photovoltaic-diesel-hybrid system 768
- photovoltaic efficiency 701
 - annual 717
- photovoltaic electricity 39
 - contribution of 40–1
 - technical potential 54
- Photovoltaic Energy Project (PEP) 727
- photovoltaic engineering problems 925
- photovoltaic generator behavior under real operation conditions 947–56
- photovoltaic industry 153
- photovoltaic integrated as roofing louvres, façades and shading 1011–14
- photovoltaic module cell temperature 955
- photovoltaic module orientations 925
- photovoltaic module placement and shadowing 1039
- photovoltaic modules 5, 7, 34, 46, 60
 - BIPV 1029–35
 - certification 745–6
 - energy collection and delivery 905–70
 - I – V curve 867
 - integration in architecture 1019–21
 - measurement and characterization 701–52
 - net energy loss 10–11
 - qualification 745–6
 - rating 947
 - solar radiation available for fixed flat-plate conventional 947
 - transparent 1009
 - world production 22
- photovoltaic performance, annual 718
- photovoltaic performance rating 701–20
- photovoltaic rating criterion 716
- photovoltaics 753–98, 972
 - advantages and disadvantages 3
 - and all of the world's needs 7
 - and development 1043–71
 - areas of application 45, 754
 - as empowering technology 1–2
 - as environmentally clean and green technology 9
 - as long-term substitute for electricity generation 48–54
 - as small-scale cottage industry 7
 - basic R&D 19
 - components 784–94
 - consumer applications 756–7
 - development dimension 54–7
 - economic assessment 980–4
 - experience curve for 1976 to 1998 17
 - funding 8–9
 - future developments 794–6
 - future of emerging technologies 37–9
 - future potential 40
 - future prospects 999–1002
 - history 11–15
 - immediate and exclusive use 7
 - land area requirement 6–7
 - motivation for application and development 45–60
 - myths of 5–11
 - notable events in history of 12
 - overview 753–4
 - public funding for R&D 9
 - public support 8
 - rational decision to develop 972
 - status 1
 - trend in worldwide applications 8
 - use of term 3–5
 - Utility-Scale Applications (PVUSA) project 467, 715, 736
- Photovoltaics/Market Transformation Initiative (PV/MTI) 1101
- pin* device, electronic structure 528–30
- pin* photodiodes 508–9
- pin* solar cell 109
 - absorber layer design 533–4
 - band diagram 110
 - power output 533
- planar cell structures 310
- plant cost 34
- plasma-deposited silicon thin film 527
- plasma-enhanced chemical vapor deposition (PECVD) 28, 243, 258, 284–5, 314, 324, 341, 353, 520–1
- pn* junction 5, 24–5, 29
 - n*-type 30
 - p*-type 30
- PN*-junction diode electrostatics 83–7
- point-contact cell design 469
- point defects 184
- point-focus Fresnel modules and systems 462
- point-focus optics 456
- Poisson's equation 81, 83
- polar tracking 946
- polycrystalline silicon 21, 26, 310
- polycrystalline silicon wafers 1032–3
- polymethyl methacrylate (PMMA) 453, 495
- polysilicon 24, 161
 - historical processes to manufacture 199
 - rejects 178–9
 - research projects 199
 - see also* semiconductor grade silicon

- Polytechnical University of Madrid
496–9
- porous-Si layer on single-crystal substrate
317
- post-treatment
by chemical leaching 195–6
by extraction metallurgy in ladle
196–8
- power conditioning 863–903
- power distribution of solar irradiation 966
- Power Management and Distribution
(PMAD) 441
- powerguard flat-roof PV system 1012
- precipitates in silicon 190–3
- precipitation 185
- pre-electrification 1068
- premature capacity loss 832
- price–experience curve 47–8
- primary reference cell calibration methods
723–6
- Production of High Silicon Alloys 167
- professional industrial systems 57
- proton exchange membrane fuel cell
(PEMFC) 854
- pumping stations 56
- pumping systems 768
- PVUSA 467, 715, 736
- PWM controllers 871, 895
- pyrogenic silica 170
- QD arrays, IB formation in 147
- quality-assurance and quality-control
(QA/QC) evaluation 555
- quantum dot (QD) arrays 148
- IB formation in 147
- quantum dot (QD) solar cells 442
- quantum efficiency 538
- quantum efficiency measurements,
multijunction cells 549
- quantum efficiency spectra 545
- quartz, carbothermic reduction 167
- quartz-furnaces 273
- quasi-Fermi energy 535–6
- quasi-Fermi levels 119–20, 122, 126, 145
- quasi-neutral region 83
- R&D
funding sources 1099–100
future programs 1099
government funding 1096–100
- Rabobank Nederland/Groen Management
BV 1107
- radiance distribution associated with
overcast skies 930
- radiation, use of term 913
- radiation spectrum for black body 63
- Radio Corporation of America (RCA)
506
- rapid thermal processes (RTP) 282–3,
314, 350, 353
- reactive ion etching (RIE) 286–7
- realistic reporting conditions (RRC) 716
- receiver position 912
- rechargeable alkali mangan (RAM)
batteries 822
- recombination current 339
- recombination mechanisms 113
- recombination process 74–7, 121
- recombination sites 185
- recombinators 844
- redox batteries 860
- redox electrolyte 667–8
- redox-flow batteries 850–2
- reference cell calibration procedures
intercomparison 727–8
uncertainty estimates 726–7
- Reference Year 937
- Reference Yield 965
- reflective concentrator configurations 454
- reflective secondary concentrators 463
- refractive lenses 485–9
- Regional Solar Programme (RSP) 1067
- relative transmittance plotted against angle
of incidence 935
- reliability, stand-alone systems 953–6
- reliability maps 959, 961
- remote areas 57, 761–74, 1048
see also rural electrification
- remote low power systems 57
- remote (or village) systems 972
- renewable energies 54
- Renewable Energy and Energy Efficiency
Fund (REEF) 1101
- renewable energy sources 45
current use and current potentials 46
- repeater station 762–3
- residential sector
financing for 1079–82
financing of PV growth 1082
rooftop system 1079
- reverse bias 139
- RF glow discharge deposition 521–3
- Ribbon Growth on Substrate (RGS)
231–2, 236–41, 246, 249–50
- RIGES 17
- rigid panel planar arrays 432–3
- rolling-grain model 227
- roof-integrated photovoltaic system 53,
1008
- rooftop PV generators 774
- Rossi X-Ray Timing Explorer (XTE) 433
- Ru complex photosensitizers 666–7,
685–6

- rural areas 56–7, 1049–51, 1053, 1083–6
 - financing PV 1083–6
- rural electrification 14, 1045–6
 - advantages of PV technology 1048–9
 - applications 1046–7
 - Argentina 1061
 - barriers to PV implementation 1051–60
 - Bolivia 1061–3
 - Brazil 1063–4
 - initial cost 1055–60
 - Mexico 1064–5
 - nontechnical issues 1055–9
 - Sri Lanka 1065–7
 - toward a new paradigm 1068–9
 - trained human resources for 1059–60
 - see also* off-grid
- rural energy scene 1046
- safety procedures 9–10
- Sahel, water pumping 1067–8
- SAM Equity Partners Ltd. 1110
- Sandia Baseline III point-focus module design 465
- Sandia National Laboratories Concentrator Program 461–2
- satellites 59–60, 363
- SAVANT radiation degradation modeling computer 420
- saw damage 271–2
 - and wafer quality 229–30
- Scanning Electron Microscopy (SEM) 193, 221
- SCARLET arrays 416, 427–8, 437
- Scarlet Deep Space One Satellite 59
- scattering mechanisms 79
- Schrödinger equation 65
- Schüco façade profile system 1031
- Schüco roof profile system 1030
- screen printing 261, 265, 275–9, 679–80
- SEA Corporation 466
- second-order effects 953–6
- secondary electrochemical accumulators
 - with internal storage 817–49
- secondary optical element (SOE) 454
- segregation coefficient 219
- selenium 505
- selenium dopant 389–90
- selenization 29
- self-discharge 811
- self-interstitial 184
- self-regulating PV system 865
- semiconductor band gap 121, 153
- semiconductor equations 81–2
- semiconductor grade silicon 24, 176–7
 - economics and industry 175
 - Ethyl Corporation process for 173–5
 - production 167–75
 - Siemens process for 168–72
 - Union Carbide process for 172–3
- semiconductor lasers 76
- semiconductors 5
 - crystal structure 64–5
 - electronic grade 64–5
 - fundamental properties 64–83
 - n*-type 69–70
 - nondegenerate 68
 - p*-type 69–70
- semitransparent cells 1034
- series resistance 951
- shading structure 1013
- shading system 1014
- shadows and trajectory maps 939
- Shell Solar/BOAL profiles 1008
- Shockley–Queisser cell
 - entropy production in 129–31
 - thermodynamic consistence of 126–9
- Shockley–Read–Hall (SRH) lifetimes 257, 261
- Shockley–Read–Hall (SRH) recombination 75, 620
- shopping mall, Lausanne 1024
- short-circuit current 92, 422, 540, 951, 953
- short-circuit current density 536
- shunt resistances 102–4
- SiC 163
- SiC bond 156
- SiC formation 221
- Siemens process for semiconductor grade silicon 168–72
- Siemens Solar Boron Back Surface Field (BSF) process 213
- SiGe alloys 519
- silica
 - aluminothermic reduction of 201
 - carbothermic reduction of 161–3, 198
- silicon 5, 154–61, 182
 - bulk monocrystalline material 206–13
 - carbon as impurity in 187
 - cell technology, module price for 985–90
 - chemical properties relevant for photovoltaics 156
 - crystalline 153–4
 - current feedstock to solar cells 175–9
 - dopant 390
 - effect of various impurities 186–93
 - electrolytic transfer of 201
 - feedstock for crystalline cells 178
 - group IIIA impurities 186–7
 - group VA impurities 186–7
 - health factors 156–7

- silicon (*continued*)
 - history 157–61
 - impurities 155
 - mechanical properties 155
 - miscellaneous applications 161
 - multicrystalline wafers 176
 - occurrence 154
 - oxygen as impurity in 187–8
 - physical properties relevant for photovoltaics 154–5
 - precipitates in 190–3
 - refractive index 155
 - requirements for crystalline solar cells 179
 - semiconductor material 160–1
 - single-crystal wafers 154, 176
 - solar grade feedstock 153–204
 - solidification 179–82
 - thermal properties 155
 - transition-metal impurities in 188–90
 - ultra-pure 160–1
 - see also* metallurgical grade silicon; semiconductor grade silicon; solar grade silicon routes
- silicon alloys 157
 - band gaps 544–6
 - doping 528
- silicon applications 157–61
 - in aluminum industry 158–9
 - in chemistry 159–60
- Silicon Film (SF) 230, 239–42, 244, 251
- silicon metal 157–8, 161
- silicon monoxide 163
- silicon multicrystalline sawn wafers 154
- silicon nitride 243, 283
 - passivation 281
- silicon ribbon crystal growth technology, productivity comparisons 238–9
- silicon ribbon/foil growth techniques 232
- silicon ribbon/foil production 230–44
 - manufacturing technology 239–40
 - process description 232–8
- silicon ribbon/foil technology 231
 - future directions 243–4
- silicon ribbon material properties and solar cells 240–3
- silicon ribbon/multicrystalline film 176
- silicon ribbon wafer/foil technologies 251
- silicon ribbons 288
- silicon solar cells 240–3
 - power density 421
 - space applications 425–6
 - temperature coefficients 719
- silicon tetrachloride 159, 171
- silicon-wafer-based PV module costs 25
- silicones 159
- SIMS (secondary ion mass spectroscopy) 347
- simulation of bulk silicon crystallization 247–9
- simulation of silicon ribbon growth 249–51
- simulation tools 245
- single level trap (SLT) 75
- single-crystal silicon 207
- single-crystalline solar cells 256
- single-junction solar cells 37, 74
- physics of 363–5
- sizing
 - stand-alone systems 953–6
 - system 791–3
- sky irradiance, angular distribution of 929
- Skylab 1 414
- SLI (starting, lighting, ignition) batteries 809, 834
- small area champion cells 20
- smart cut method 317
- Sofrel flat-roof system 1018
- soft loans 1095–6
- solar altitude 909
- solar arrays, space applications 431–41
- solar azimuth 909
- solar batteries 1052
- solar cell 3, 5
 - spectral response of 100–2
- solar cells
 - back-contact 108
 - band diagram of 120
 - basic structure 87
 - boundary conditions 87–9
 - circuit model 92, 102
 - color 1035
 - cost 26
 - current-voltage characteristic of 103
 - design 62
 - efficiency 99–100, 362
 - efficiency levels 242
 - efficiency versus impurity concentration 192
 - efficiency versus thickness 242
 - equilibrium conditions 86
 - fabrication 26
 - fundamentals 87–99
 - future-generation 403–6
 - higher-than-one quantum efficiency 140–1
 - intermediate band 144–8
 - lifetime 96–7
 - manufacturing 26
 - materials, BIPV 1030–4
 - model parameters 94
 - numerical modeling of 109–10
 - operation 63, 84, 98–9

- parasitic resistance effects of 102
- performance 62, 96–8
- physics 61–112
- power density as function of time 422
- properties of 95–6
- schematic 4, 62
- short-circuit current versus open-circuit voltage 105
- silicon current feedstock to 175–9
- technology 14
- temperature effects on 104–6
- Solar Cells and Optics for Photovoltaic Concentration 492, 498
- solar constant 912
- solar converters, technical efficiency limit for 131–2
- solar declination 907
- solar design 1038–9
- Solar Development Capital 1102
- Solar Development Foundation (SDF) 1102–3
- solar electric farms 23
- Solar Electric Light Fund (SELF) 1103
- solar electricity, *see also* photovoltaic electricity
- solar energy, availability 799
- solar grade silicon 359
- solar grade silicon routes 193–201
- solar home systems (SHS) 56, 759–60, 813–14, 865, 873, 962–4, 1052, 1054, 1083, 1088
 - cost breakdown 56, 772
- solar hour 909
- solar illumination 540
- Solar International Management Inc. (SolarBank Program) 1103
- solar irradiation, power distributions of 966
- solar lantern for rural households in developing countries 758–9
- solar modules
 - architecture 1035
 - color 1035
 - shipment by technology 176
- solar office, Doxford, Sunderland 1019
- solar radiation 6
 - and uncertainty 915–20
 - available for fixed flat-plate conventional PV modules 947
 - components 912–15
 - estimation of hourly irradiation from
 - daily irradiation 925–7
 - on inclined surfaces 920–33
 - on surfaces on arbitrary orientation 927–33
 - parameters 919
- Solar Research Corporation Pty Ltd 499
- solar shading 1010
- solar simulators 736–8
- solar spectrum 915
- Solar Terrestrial Probe (STP) Program Magnetospheric Multiscale (MMS) 440
- solar time 911
- solar zenith angle 909
- SOLERAS 466–7
- Solgreen flat-roof system 1031
- solid-phase crystallization 343
- solid solutions 184
- solidification, silicon 179–82
- Solidification by Planar Interface (SOPLIN) processes 246–7, 249
- Solrif solar profile system 1029
- space applications 780–3
 - high-efficiency III-V multijunction solar cells 363
 - silicon solar cells 425–6
 - solar arrays 431–41
 - thin-film solar cells 428
- space charge region (SCR) 83, 339
- space environment 417–20
- space solar cells 413–31
 - calibration and measurement 424–5
 - challenge for 416–25
 - history 413
 - performance 416
 - technology requirements 418
- space vehicles 363
- spacecraft 59–60
- Spanish National Meteorological Institute 916
- specialty markets 7
- spectral effects 955
- spectral response 100–2
 - modeling 955
- spectral responsivity, versus wavelength characteristics 701
- spectral responsivity error sources
 - for measurement of light power 744
 - for measurement of photocurrent 743
 - for monochromatic light 745
- spectral responsivity measurements 738–44
 - filter-based 739–41
 - grating-based systems 741–2
 - uncertainty 742–4
- Spectrolab Spectrosun Large Area Pulsed Solar Simulator 425, 466, 499
- spectrum-splitting 364–5, 406, 510, 543
- spherical radiator 476
- spray pyrolysis (SP) 30
- spring equinox 907
- Sri Lanka, rural electrification 1065–7
- Staebler–Wronski effect 511–12

- STAMP program 982, 985, 989–90, 992
 stand-alone systems 39, 937, 945
 inverters 789–90, 883
 reliability 956–63
 sizing 956–63
 standard hydrogen electrode (SHE) 803
 standard reporting conditions (SRC)
 701–15
 standard test conditions (STC) 905, 947,
 950, 955
 Standard Year 937
 Stanford Advanced Back Contact cells
 990
 STAR 496
 starting, lighting, ignition (SLI) battery
 809, 834
 state of charge (SOC) 809, 849
 state-of-charge meters 843
 stationary batteries 835
 Stefan-Boltzman law 119
 step-down converter 885–7, 889
 combination with inverters 890
 step-down principle, integration into
 inverting process 892
 step-up converter 887–9
 Strategic Analysis of Manufacturing
 Product and Price *see* STAMP
 program
 String Ribbon (STR) 230, 232, 235–7,
 239–40, 243, 245, 288
 structural façades 1010
 structural glazing 1010
 sub-array switching controller 869
 substitutional impurities 184, 186
 substrate texturing 537
 summer solstice 907–8
 Sun–Earth movement 906–12
 Sun–Earth position 910, 912
 Sun-tracking surfaces 945–6
 sunlight 5, 40
 SunPower Corporation 466, 496,
 499–500
 sun's rays incidence angle 912
 Sun's trajectory maps 939
 surface recombination 77, 96–7
 surface recombination velocity (SRV)
 258–9, 338
 Surface Texture and enhanced Absorption
 with a back Reflector (STAR) cell
 321
 surface texturing 269
 surface to volume relation (SV) 246
 Survivable COncentrating Photovoltaic
 Array (SCOPA) 439
 SURvivable Power System (SUPER) 439
 switching controllers 867–70
 Syndicate Bank (India) 1113
 synthetic silica 159–60
 system cost 980–4
 manufacturing-cost modeling 982–3
 system-mounting structure 34
 system sizing 791–3
 Tafel equation 805
 Tafel lines 805
 tandem cells 134
 T-CHEQ 879
 experimental set-up 880
 operating experience 879
 voltages and currents of 16
 series-connected cells during
 charging 880
 technical efficiency limit for solar
 converters 131–2
 telecommunications 761–2
 autonomous power supply system for
 856
 Telstar 414
 temperature coefficients 423
 for module and cell temperature
 estimation 956
 temperature dependence, high-efficiency
 III-V multijunction solar cells 380–2
 temperature determination under
 considered operating conditions 952
 temperature effects on solar cells 104–6
 terminal characteristics 89–92
 terrestrial applications 363
 terrestrial concentrator systems,
 implementation of multijunction III-V
 cells 406–7
 terrestrial energy production,
 high-efficiency III-V multijunction
 solar cells 363
 terrestrial spectrum 407
 texturing 269, 273, 539
 thermal environment 420–3
 thermal modeling of crystallization
 techniques 245–7
 thermionic emission model 537
 thermodynamic consistence of
 Shockley–Queisser photovoltaic cell
 126–9
 thermodynamic converters 790
 thermodynamic current densities 115, 117
 thermodynamic currents 117
 thermodynamic efficiency 125
 thermodynamic fluxes 119
 thermodynamic functions of electrons 119
 thermodynamic functions of radiation
 117–19
 thermodynamic variables 117–19
 thermodynamics
 background 114–19

- basic relationships 114–16
- laws of 116, 130
- thermoelectric generators (TEG) 790
- thermophotonic (TPH) converter 136–40
- thermophotovoltaic (TPV) conversion
 - 135–6, 468–9
- thermophotovoltaic (TPV) generators 790
- thin-film progress and challenges 27–31
- thin-film PV materials 1034
- thin-film PV modules 53
- thin-film silicon solar cells 307–57
 - carrier collection 316
 - carrier generation 316
 - deposition techniques 341
 - design concepts 324–53
 - electronic modeling 333–41
 - generic device structure 325
 - grain enhancement 343–50
 - mechanical support 316–17
 - multicrystalline-Si substrates 320
 - non-Si substrates 321–4
 - optical properties 328
 - overview 307–10
 - processing considerations 350–3
 - review of current position 310–24
 - single-crystal Si substrates 317–20
 - summary from optical modeling 333
 - summary of types 318–19
 - surface structures 312
 - surface texture 311–12
 - thermodynamic considerations 311
- thin-film solar cells 27–9
 - CdTe *see* CdTe thin-film solar cells; silicon thin-film solar cells
 - space applications 428–31
- thin-film technology 40
- thin-film transistor (TFT) 350
- third generation PV converters 148
- time variation of generated daily energy 958
- TiO₂ 274
 - colloid preparation 678–9
 - dye fixation onto film 680
 - electrode preparation 679–80
 - electron transport 677–8
 - photoelectrode 666
 - solar cell, photocurrent–voltage curve 674
- Tokyo A&T University 500
- total harmonic distortion (THD) 890, 897, 899
- total irradiation 958
- TPH converter 148–9
- TPV converter 139, 148–9
- trackers *see* concentrators
- traction batteries 835
- transition metals (TM) 351
 - impurities in silicon 188–90
- translation equations to reference conditions 719–20
- transmission line measurements 400
- transparent conducting oxide (TCO) 440, 509–10, 539–40, 555
- transparent conducting oxide (TCO)-coated glass substrate 664–6
- travel time of electron under short-circuit conditions 531
- trichlorosilane 168
- tri-crystalline silicon (tri-Si) 211–13, 251
- Triodos Bank NV 1108
- triple-junction cells 426, 506
- triple-junction III-V semiconductor cells 416
- triple-junction module 512
- triple-junction *nip* substrate-type solar cells 547
- Tropical Rainfall Measuring Mission (TRMM) 433
- true solar time 909
- TU Electric Power Park 467
- tubular-plate battery 844
- tunnel junction 548
- tunnel-junction interconnects (TJICs) 379, 396–7
- twin boundaries 183
- Typical Meteorological Year (TMY) 937–8, 960
- uncertainty
 - and solar radiation 915–20
 - spectral responsivity measurements 742–4
- uncertainty estimates, reference cell calibration procedures 726–7
- uncertainty parameters 919
- underdevelopment, breaking the chains of 1046–8
- UNDP 1087–8
 - Sustainable Energy & Environment Division (SEED) 1103–4
- UNEP 1088
 - Collaborating Centre on Energy and Environment 1104
- uninterruptible power supplies (UPS) 34, 835
- Union Carbide process
 - for semiconductor grade silicon 172–3
 - simplification 198–201
- United States, PV programs 1096–7
- University of New South Wales (UNSW) 324

- University of Reading 500
- US Agency for International Development (USAID) 1111
- utility systems 779
- vacancies 184
- valence band (VB) 4, 66–7, 74, 119
- valve-regulated lead acid (VRLA) batteries 831–2, 846
- Vanguard I 413–16
- vapor deposition (VD) 30
- VHF glow discharge deposition 524–5
- village power supply systems 766–7
- vision or view factor 118
- volatiles 169
- voltage shaping by digital synthesis 890–2
- VTZ Green Money for the Blue Planet Ltd. 1108
- wafer cost 206xx
- wafer material for crystalline silicon 245
- wafer quality 205
 - and saw damage 229–30
- wafering 223–30, 280–1
 - cost and size considerations 230
 - microscopic process 226–8
 - multi-wire technique 224–6
- water pumping
 - for irrigation 1083
 - Sahel 1067–8
- water purification systems 768
- wavelength dependence of photon conversion efficiency 363–4
- WEB *see* dendritic WEB
- well-integrated systems 1014–18
- Wind Fund Plc, The 1108
- window layer 530
- Winrock International 1104, 1113–14
- winter solstice 908
- World Bank solar home system projects 1088
- World Photovoltaic Scale (WPVS) 728
- wrought alloys 159
- xerography 505
- X-ray diffraction 345–8
- Zentrum fur Sonnenenergie und Wasserstoff Forschung Baden Wurttemberg (ZSW) 500
- zero-energy project, Etten-Leur 1024
- zinc dopant 390–1
- zinblende lattice 64
- zone-melting recrystallization (ZMR) 315, 350

Index compiled by Geoffrey Jones.