

## Index

### **a**

- ab-initio* technique 145
- A-DEEP technologies 534
- Alexander–Haasen (AH) model
  - 201–202, 206, 209–211, 218–220
  - governing equations 206
  - vs. Groma model 206–211 *see also* Groma model
  - physical system and model setup 206–209
  - physical vapor transport (PVT) technique 206
  - plastic shear strain 209–211
  - resolved shear stress 209, 210
- AlGa<sub>N</sub>/Ga<sub>N</sub> heterojunction 555
- AlGa<sub>N</sub>/Ga<sub>N</sub> hetero structure 557, 562
- AlGa<sub>N</sub>/Ga<sub>N</sub> HFET
  - depletion-mode 566
  - E-mode operation 566–567
- (AlGa)<sub>2</sub>O<sub>3</sub>/Ga<sub>2</sub>O<sub>3</sub>
  - modulation-doped field-effect transistors (MODFETs) 671
- AlInGa<sub>N</sub> material system 556
- alkaline earth elements 335
- α-Ga<sub>2</sub>O<sub>3</sub> SBDs 665–668
- ammonobasic crystallization 537
- ammonothermal Ga<sub>N</sub> (Am-GaN)
  - substrate
  - crystallization limiting factors 541
  - electrical properties 540
  - enlargement of seeds 538
  - HVPE-GaN growth
    - challenges 543–546
    - doping with acceptors 549–550
    - doping with donors 546–549
    - impurities 542
  - with mechanically blocked side facets 542
  - morphology 539, 540
  - multiplication of seeds 539
  - plastic deformation 541
  - star-like defects 541
  - wafering procedures 539
- ammonothermal method 532, 533, 536–542, 545
- angular-resolved photo electron spectroscopy (ARPES) 250
- anode metal, work function 327–329
- anti-phase boundaries (APB) 95, 101, 105

- artificial diamond
  - chemical vapor deposition (CVD) 633
  - HPHT method 633, 634
- atmospheric-pressure HVPE
  - system, for Ga<sub>2</sub>O<sub>3</sub> growth 664
- atomic force microscopy (AFM) 122, 125, 292, 611
- avalanche capability 403–411
  
- b**
- Bachmann diagram 636
- backside ohmic contact 305
- backside thinning systems 300
- backside wafer thinning 300
- Ba interlayer (Ba IL) 336
- Baliga's FOM (BFOM) 645
- Baliga's high frequency FOM (BHFOM) 645
- barrel reactor 78, 80
- basal-plane dislocations (BPDs) 3, 8, 48, 56, 171, 188, 192, 293
- B-doped p-type diamond epilayers 645
- Berman–Simon equilibrium line 584
- β-Ga<sub>2</sub>O<sub>3</sub>
  - atomic unit cell 660
  - donor dopants 661
  - material properties 661
  - melt bulk growth 662
  - phonon modes 661
  - polarized transmittance and reflectance spectra 661
  - room-temperature electron mobility 661
- bias-enhanced nucleation (BEN) 600–602, 608–610, 636
- bias temperature instability (BTI) 233–235
- bias temperature stress (BTS) phase 233
- bilayer graphene (BLG) 251, 252
- bipolar amplification effect (BAE) 238
- bipolar device
  - 16 kV class SiC-IGBT 378–381
  - 20 kV class SiC-IGBT 381–383
  - carrier lifetime dependence 372
  - current status 378
  - loss estimation 373–378
  - remaining issue 383–384
- blue graphene layers 257
- boron-doped diamond crystals 591
- box-car method 142
- breakdown voltages (BVs) 273, 331, 332, 342, 344, 355, 357–358, 378, 405–407, 409, 414, 415, 434, 436, 490, 491, 495, 557, 559–562, 570, 571, 646, 665
- bulk crystal growth 58, 66, 559
- bunched BPDs 13–18
  
- c**
- Candela optical surface analyzer 84, 85
- capacitance-DLTS (C-DLTS) 142
- capacitance–voltage (C–V) measurements 123, 256, 336, 495
- capture-emission time (CET) 229
- carbon antisite–vacancy (CAV) pair defect 504, 506, 511, 513–514
- carbon vacancy 64, 138, 140, 145–152

- carrier lifetime dependence
  - 360–373
- charge accumulation layer (CSL)
  - 379
- charge pumping (CP)
  - measurements 230
- charging/discharging effect 230
- chemical mechanical polishing (CMP) 44, 122, 289, 378
- chemical vapor deposition (CVD)
  - 94, 104, 290, 301
  - artificial diamond growth 633
  - atomic hydrogen 592
  - bias-enhanced nucleation (BEN)
    - 600–602, 608–610
  - DC plasma jet 597
  - diamond, growth mechanism
    - 637
  - direct current (DC) plasma
    - 595–597
  - experimental setups 595–599
  - gas mixtures 593–595
  - growth rate and gas temperature
    - 599
  - heteroepitaxial deposition,
    - growth substrates 606–608
  - heteroepitaxial growth
    - film thickness, structural
      - improvements with 610
    - intrinsic stress and dislocations
      - 615
    - microneedle approach 618
    - multilayer substrates for scaling
      - 610–614
    - on (111)-oriented substrates
      - 615
    - scaling and mosaic spread
      - 614–615
  - homoepitaxial growth on crystal
    - faces 603–604
  - hot filament CVD 595
  - H-shifting reactions 592
  - microwave plasma chemical
    - vapor deposition (MWPCVD)
      - 597–599
  - nucleation by seeding 600
  - polycrystalline CVD diamond
    - layers 602–603
  - principal elements 592
  - single crystal seed recovery
    - 604–605
  - size increase and mosaic growth
    - 605
  - trace gases, role 594–595
  - C–H–O diagram for diamond
    - deposition 593–594
  - Clas-SiC foundry 307
  - CO<sub>2</sub> emissions 353, 467–469, 489
  - commercial foundries
    - cost model 303–304
    - vs. dedicated foundries 306–307
    - for Si and SiC devices 303
  - commercial SiC wafers 169, 213
  - conduction band (CBM) 93, 101,
    - 117, 119, 120, 124, 150, 230,
      - 237, 239–241, 294–296, 320,
        - 336, 341, 433, 505, 566, 637,
          - 638
  - conductive atomic force microscope (C-AFM) 256–257
  - conductivity modulation 346,
    - 356, 371, 372, 382, 434, 567,
      - 568
  - constant current mode (CCM)
    - 322
  - continuous conduction mode (CCM) 439
  - continuous-feed PVT (CF-PVT)
    - method 104

- continuum dislocation dynamics (CDD) theory
    - Alexander–Haasen (AH) model 201–202
    - Groma model 203, 204
    - Kröner–Nye tensor 204
    - straight parallel dislocation 203
    - 3D models 204–205
  - cosmic-ray failure 412–415
  - cosmic-ray stability 412–415
  - cost model 303–304
  - cost roadmap, for WBG devices 303–304
  - cubic polytype of silicon carbide (3C-SiC) 93
    - bulk growth
      - continuous fast CVD growth 110–117
      - sublimation growth, 3C-SiC CVD seeding layers 105–108, 110–117
      - sublimation growth, hexagonal SiC substrates 104–105
    - device processing 117–118
    - ion implantation 126–127
    - MOSFET fabrication 121
    - MOS processing 118–120
    - N-type 3C-SiC ohmic contacts 126
    - nucleation and epitaxial growth
      - defects 98–102
      - growth process 95–98
      - stress 102–103
    - ohmic contact metalization 123–125
    - polytype 48–52
    - power electronic devices 117
    - surface morphology effects 121–122
    - 3C-SiC/SiO<sub>2</sub> interface passivation 120–121
    - thermal oxidation temperature effects 122–123
  - current aperture FET 673
  - current spreading epilayer (CSL) 340
  - current spreading layer (CSL) 340
  - Cu-sintering 423
  - cylindrical resonator with annular slots (CYRANNUS) design 598
  - Czochralski method 557
- d**
- Danfoss bond buffer (DBB) 424
  - Dash necking technique 199
  - DC breakers 451, 452, 454
  - DC/DC converters 437–442, 444, 445, 447, 451, 457, 459, 575
  - DC-grids
    - DC-breakers 452
    - low and medium voltage 451–452
  - DC performance, of GIT 569–570
  - Debye–Waller (DW) factor 508
  - dedicated foundries vs. commercial foundries 306–307
  - deep-level transient spectroscopy (DLTS)
    - capacitance-DLTS (C-DLTS) 142
    - Laplace DLTS 143
    - Poole–Frenkel effect 143
    - profile measurements 143
    - Shockley–Read–Hall model 141
  - Deep-P structure (PDS) 491
  - defect-rich transition layer 110
  - defect-selective etching (DSE) 13, 16, 59, 539
  - demand response (DR) 353

- density functional theory (DFT)
  - 145–146, 200, 237, 503
- depletion layer 273, 357, 360, 361, 366, 646, 650
- depletion mode (D-mode) Ga<sub>2</sub>O<sub>3</sub> MOSFET 669, 670
  - DC output characteristics 669, 670
  - Si-ion implantation doping 669, 670
  - vertical FETs 672–674
- device under test (DUT) 419
- diamond 583
  - Baliga's figure of merit (BFM) 583
  - classification 587–589
  - current density of 650
  - DC-plasma jet CVD 595–597
  - electrical and thermal
    - characteristics 633, 634
  - enthalpy of formation 583
  - epitaxial-growth 638
  - growth, by CVD, 591–593
  - hetero-epitaxial 636
  - high-pressure high temperature (HPHT) synthesis 584–591
  - phase diagram 584
- dichlorosilane (H<sub>2</sub>SiCl<sub>2</sub>) 547
- die-attach technologies 422–423
- die top system (DTS) 424
- differential interference contrast (DIC) 6, 60, 61, 541
- dimethyldichlorosilane 79
- direct bonding copper (DBC) 380
- direct current (DC) plasma CVD 595–597
- direct current (DC) self bias 288
- direct pressed die (DPD) 424
- discrete dislocation dynamics (DDD) simulations 200
- dislocation
  - semiconductors in 199
  - total line length vs. time 217, 219
- dislocation density 3, 57–59, 72, 88, 199, 200, 202, 203, 205, 209, 211, 215, 216, 534, 535, 558, 605, 610, 613, 615–616, 618–619, 633, 635, 636, 643–645
- dislocation flow between veins 211–219
- dislocation formation
  - formation mechanism, of BPD networks 23–28
  - 4H-SiC wafers, preparation 18–19
  - grown-crystal/seed interface 18–27
  - PVT growth, of 4H-SiC crystals
    - BPD distribution 13–15
    - BPD multiplication 15–18
    - cross-sectional X-ray topography 9–13
    - plan-view X-ray topography 5–9
  - X-ray topography observations, grown-crystal/seed interface 22–23
- dislocation glide 10
- dislocation loops 216
  - CDD field values for
    - quasi-discrete 215, 216
  - expansion in channel 217
- dislocation mediated metal plasticity simulation 213
- dislocation motion 200, 211
- dislocation multiplication 10
- dislocation patterns 199, 211, 213
- dislocation propagation 57

- divacancy 503, 504, 506, 508–510, 517
- DMOSFET, 4H-SiC
  - optimization 335–337
  - resistance components 333–335
- domestic systems 446
- donor-like defect 235
- double positioning grain boundaries (DPBs) 95
- drain current–gate voltage 226
- drain-induced-barrier lowering (DIBL) 390
- dry etching 273, 275, 279, 280, 283, 288–290, 292, 295, 300, 301, 305, 327, 565, 569
- e**
- electrical detection of magnetic resonance (EDMR) 508
- electrically active defects
  - deep-level transient spectroscopy (DLTS) 141–143
  - density functional theory (DFT) 145–146
  - intrinsic 146–153
  - low-energy muon spin rotation spectroscopy 144–145
  - and other impurity levels 153–159
  - transition metals (TM) 153–159
- electrically active traps
  - intrinsic electron trap 238–240
  - $P_{bc}$  defect 237–238
  - point defect candidates 240–242
  - and reduced MOSFET mobility 238–240
  - and subthreshold sweep hysteresis 237–238
- electrically detected magnetic resonance (EDMR) 237
- electric vehicles 76, 271, 307, 353, 422, 459, 467–469, 478, 484
- electroluminescence (EL) 403–405, 517, 568
- electron beam lithography 258
- electron-donating interface 250
- electronic spin resonance (ESR) 63
- electron paramagnetic resonance (EPR) 141, 237, 549
- electron–phonon interaction 251
- electron spin resonance 510
- elemental semiconductor 78, 293, 600
- ellipsoidal plasma reactor 598
- E-mode operation, of vertical  $Ga_2O_3$  MOSFETs 673
- epilayer deposition 51
- epitaxial graphene 249–250
  - intercalation 251–252
  - light–matter interaction *see* light-matter interaction
  - monolithic electronic devices and circuits 257–260
  - structuring layers and partial intercalation 252–253
  - tailorable metal/semiconductor contact *see* tailorable metal/semiconductor contact
  - thermal decomposition 250–251
- epitaxial lateral overgrowth (ELO) 605, 616–618, 643
- epitaxial sublimation growth (SE) method 104–108, 110
- equivalent series resistor (ESR) 456
- etch pit density (EPD) 535, 613
- extrinsic point defects 62, 63, 66, 137, 162

**f**

- Fabless Foundry concept 303
- facet 6
- field-effect transistors (FETs) 437, 473, 567, 642, 646, 659
- field-plated Schottky barrier diode (FP-SBD) 666, 667
- figure of merit (FOM) 249, 330, 555, 570, 583, 645
- film resistivity 642, 645
- fin channel FET 673–674
- first step annealing (SFA) 301
- flip-chip assembly 570
- floating zone method 199
- flux of dislocation density 202
- 4H-SiC homoepitaxial growth 47
  - point defects
    - carrier lifetime 64–69
    - characterization methods 59–62
    - classification 56–57, 62–64
    - dislocation reactions 57, 58
    - epiwafers and devices 68–69
    - extended defects, in
      - homoepitaxial layers 55–62
  - power electronic devices
    - chemical vapor deposition process 52–53
    - doping in 53–55
    - vicinal substrates 48–52
- 4H-SiC polytype 47–52
- 4H-silicon carbide (4H-SiC)
  - basal plane dislocations (BPDs) 171, 188–190
- DMOSFET
  - optimization 335–337
  - resistance components 333–335
- Frank–Read source 171–173
- homepitaxial layers 191
- JBS diodes
  - anode metal 327–329
  - benefit 322
  - p<sup>+</sup> regions, surge operation 324–326
- local basal plane bending vs. basal plane dislocations 181
- micropipes (MPs) 170–171
- prismatic slip, PVT 180–181
- power MOSFET
  - DMOSFET 332–337
  - JBS diodes 345–346
  - superjunction structure 342–345
- PVT 180–184
- Schottky diodes 322, 325
- threading edge dislocations 171–173, 188–190
- threading mixed dislocations 173–174
- threading screw dislocations 170–171, 188–190
- V and Y shaped Frank-type stacking faults 192
- Frank–Read Source 58, 171–173
- Frenkel pair generation 63
- fuel cell electric vehicles (FCEVs) 470
- fuel-cell vehicles (FCV) 468, 472, 490
- fuel cell voltage-boosting converter (FCVCU)
  - circuit configuration 473
  - control method 475–477
  - full SiC-IPM 473
  - magnetic coupling 474–475
  - noise countermeasures 478–479
  - quietness 478

- fuel cell voltage-boosting converter (FCVCU) (*contd.*)
  - smaller size and higher efficiency 477
  - structure of 479
- full-width-at-half-maximum (FWHM) 107, 114, 535, 610
- g**
- gallium arsenide (GaAs)
  - dislocations 211
- gallium nitride
  - bulk crystal growth 533
  - material properties 661
  - epitaxial growth
    - GaN substrate 557–558
    - sapphire substrates 558
    - SiC substrates 558–559
    - Si substrates GaN epitaxial growth 559
  - epitaxy on Si substrate
    - AlGaN/GaN active layer with polarization effect 561–564
    - AlN nucleation layer 560
    - buffer layer 560–561
    - crystal orientation 559
    - metal-organic chemical vapor deposition (MOCVD) 556
    - n-type doping 556
    - p-type doping 556
    - semi-insulation layers, doping 557
  - field-plated MOSFET structure 671
  - field-plated SBD 666–667
  - gate-injection transistor (GIT) on Si substrate
    - DC performance 568–570
    - device structure and operational principal 567–568
    - switching performance 570–571
- HFET
  - application of 571–573
  - dry etching process 565
  - inverter application 571
  - ion implantation technique 565
  - ohmic contact for 564
  - Schottky contact 565
  - surface passivation 565
- HEMT development 558
- MESFET 668–671
- gallium oxide ( $\text{Ga}_2\text{O}_3$ )
  - DC output characteristics 669
  - epitaxial growth technologies 662, 663
  - halide vapor phase epitaxy (HVPE) 664
  - material properties 660–662
  - metalorganic chemical vapor deposition (MOCVD) 664–665
  - mist CVD, 665
  - ozone/RF-plasma MBE system 663
  - physical properties 660–662
  - polymorphs 660
  - SBDs 665–668
  - thermal conductivity 661, 662
- GaN-based materials 555, 565
- GaN-on-Si 54, 435, 555–577
- gas-flow stream lines 78
- gas mixtures, for diamond CVD, 593
- gate oxidation 121, 123, 305
- Gauss's law 330
- geometrically necessary
  - dislocations (GNDs) 201, 203–205, 215–216



- GIT *see* gate-injection transistor (GIT)
- grain misorientations 99
- graphene-silicon carbide field-effect transistor (GraSFET) 257
- graphite enthalpy, of formation 583
- graphite spacer 106
- Groma model 203–204, 206–211, 218
- growth front 6
- growth initiation 18
- guard rings (GRs) 273, 275, 278, 359, 648, 666–667
- h**
- half-loop array (HLA) 191
- halide vapor phase epitaxy (HVPE)
- advantage 534
  - gallium oxide thin films 664
  - GaN growth
    - on MOCVD-GaN/sapphire, morphology 535, 536
    - void assisted separation (VAS) 535
  - history 533–536
  - method 532
  - scheme of 533, 534
- Hall effect 236
- heteroepitaxial diamond 601, 606–607, 613, 615, 617–618, 643
- heteroepitaxial growth 48, 615, 636, 660, 665
- heterojunction *p*-amorphous oxide/*n*-Ga<sub>2</sub>O<sub>3</sub> diode 668
- hexagonal polytypes 93, 94, 103, 512, 514
- high electron mobility transistors (HEMTs) 436, 531, 558
- high-level injection 362–364, 367, 368
- high nitrogen pressure solution (HNPS) method 538
- high-pressure high-temperature (HPHT)
- artificial diamond production 633, 634
  - Berman–Simon equilibrium line 584
  - boron doping 591
  - chemical purity and classification 587–589
  - crystal size 590–591
  - morphology and structural quality 589–590
  - setups 585, 586
  - temperature gradient method 585–587
- high-purity semi-insulating (HPSI) 257, 505
- high-resolution X-ray diffraction (HRXRD) 14, 54, 181
- high-voltage direct current (HVDC) 353
- breakers 454–455
  - transmission 452–454
- high-voltage transmission electron microscopy (HVTEM) 22
- Honda motor
- electric power plant system 472–473
  - fuel cell vehicles (FCV) 472–473
- horizontal hot-wall reactors 82, 86, 88, 113
- hot filament (HF) CVD 595, 634, 644
- hot-wall configuration 80, 81
- hybrid electric vehicles (HEVs) 459, 467, 469

**i**

ideal switch 439  
 image force 8  
 inductive heating  
   domestic systems 446  
   industrial systems 446–447  
 inductive power transfer (IPT) 445  
 industrial drives 455–457  
 industrial systems 433–460  
 input series output-parallel (ISOP)  
   topology 444  
 insulated-gate bipolar transistors  
   (IGBTs) 236, 329, 355, 376,  
   490  
 intensity mapping 19  
 Internet of Things (IoT) 353  
 intrinsic defects 137  
   carbon vacancy 147–152  
   silicon vacancy 152–153  
 intrinsic electron trap 238–240  
 intrinsic properties, of SiC material  
   65  
 inversion-type p-MOSFET 650  
 inverted silicon pyramids (ISP)  
   100  
 ion activation annealing 290  
 ion bombardment induced buried  
   lateral growth (IBI-BLG)  
   608  
 ion-implantation technique 68,  
   290, 305, 565, 642

**j**

Jahn–Teller distortion 146, 147,  
 160  
 JEDEC Solid State Technology  
   Association (JEDEC)-like  
   measurements 232  
 JFET resistance 333, 334, 338, 340,  
 491–494

junction barrier Schottky diodes  
   (JBSDs) 646  
   anode metal 327  
   4H-SiC, MOSFET 345  
   4H-silicon carbide 320  
   p<sup>+</sup> regions, surge operation 324  
 junction FETs (JFETs) 648  
 junction gate field-effect transistor  
   (JFET) 3, 272, 390, 491  
 junction termination extension  
   (JTE) 273, 358, 379, 642

**k**

kinematics of dislocations 202  
 Kröner–Nye tensor 204

**l**

Laplace DLTS 143, 149, 153, 154,  
 160  
 latent heat 24  
 lateral Ga<sub>2</sub>O<sub>3</sub> field plated-MOSFETs  
   671  
 lateral GaN power devices  
   advantages 573  
   device structure and fabrication  
   564–566  
   E-mode GaN gate-injection  
   transistor 567–571  
   E-mode operation 566–567  
   integration 573–576  
   semi-insulation layers 557  
 law of similitude 211  
 lifetime-killing defects 138  
 light emitting diodes (LEDs) 33,  
 531, 555  
 lightly doped n-type 138, 150, 336  
 light-matter interaction  
   and ultimate speed limits  
   260–263

- high-frequency operation
  - 260–263
- of Schottky diodes 260–263
- transparent electrical access
  - 263–264
- line commutated converters (LCC)
  - 453
- lithography 252, 258, 275, 283, 648
- longitudinal mode (LO) 108
- longitudinal optical
  - phonon–plasmon coupled (LOPC) 19, 20
- loss estimation, bipolar device
  - 373–378
- low-angle grain boundaries (LAGBs) 6, 171
- low-energy muon spin rotation spectroscopy 144–145
- low level injection 360–362, 368
- low pressure chemical vapor deposition (LPCVD) 298
- m**
- magnetic coupling reactor 474, 477
- magneto-optical system 517
- maximum power point (MPP) 447
- merged PiN Schottky (MPS) diode 321
- metal-assisted termination (MAT) 618, 644
- metal–insulator–semiconductor FETs (MISFETs) 648
- metal–intrinsic–p-type diodes (MiPDs) 646
- metallization 125, 126, 272, 273, 283, 301–302, 397, 398, 400, 402, 418, 424, 559, 564, 565
- metalorganic chemical vapor deposition (MOCVD) 663–665
- metalorganic precursors 556
- metal-oxide-semiconductor (MOS) 93, 298, 319, 648
- metal-oxide-semiconductor field-effect transistor (MOSFET) 117, 489
- bias temperature instability 233–235
- preconditioning measurement 231–233
- reduced channel electron mobility 235–236
- sub threshold sweep hysteresis 226–230
- metal oxide semiconductor capacitors (MOSCAPs) 226
- metal-oxide varistors (MOVs) 452
- metal–semiconductor field-effect transistor (MESFET) 76, 257, 301, 642, 648, 668
- metal–semiconductor interface 249–265
- metal–semiconductor system 264, 321
- micro-electron mechanical systems (MEMS) 103
- microneedle approach 615, 618
- micropipes (MPs) 8, 34, 35, 57, 59, 169–171, 193
- microwave detected photoconductivity decay ( $\mu$ -PCD) 68
- microwave plasma chemical vapor deposition (MWPCVD) 597–599, 602–604, 619
- microwave reactor geometries 598
- mist-CVD 665, 667

- modified PVT (M-PVT) 104, 105
- modular multi-level converter  
(MMC or M<sup>2</sup>LC) 443, 453
- modulation-doped FETs  
(MODFETs) 671–672
- molecular beam epitaxy (MBE)  
96, 556, 614, 662–664
- molybdenum (Mo) 155, 327, 426,  
515, 517, 546
- monolayer graphene (MLG) 249,  
251, 252
- monolithic epitaxial graphene  
discrete epitaxial graphene  
devices 257–259  
monolithic integrated circuits  
259–260
- MOSIS 307
- multi exponential analysis (MEA)  
229, 235
- multilayer system  
diamond/Ir/YSZ/Si(001)  
structure 612
- muon spin rotation ( $\mu$ SR)  
spectroscopy 140, 144–145
- n**
- negative bias temperature stress  
(NBTS) 233, 321
- negative differential resistance  
(NDR) 394, 395, 404
- neutral point clamp (NPC) 450
- New York Power Electronics  
Manufacturing Consortium  
(PEMC) 306
- next-generation power devices  
659
- Ni micro-plating bonding (NMPB)  
483–485
- nitrogen-vacancy pair 514–515
- non-facet (NF) regions 4, 6, 7
- non-radiative recombination  
processes 64
- no-photon exciton generation  
(electro)chemistry (NPEGEC)  
505
- normally-off operation 563, 566,  
672
- N-type 3C-SiC Ohmic Contacts  
126
- n-type doping and processing  
638–642
- n-type substrates 65, 67, 532
- nuclear magnetic resonance (NMR)  
144
- nucleation 600  
bias enhanced 600  
BPDs 188–190  
of dislocation half-loop arrays  
191–192  
and epitaxial growth 95–103  
layer 559–560  
opposite pair of *c+a* dislocations  
175–177  
by seeding 600  
TEDs 188–190  
TSDs 188–190
- o**
- ohmic contacts 254–256  
metalization 123–125, 301–302  
N-type 3C-SiC 126  
rapid thermal anneal (RTA) 280,  
305
- open-circuit voltage decay (OCVD)  
69, 366–368
- optical absorption 141, 509, 661
- optical-isothermal capacitance  
transient spectroscopy  
(OICTS) 542

- optically detected magnetic resonance (ODMR) 141, 508
- Orowan equation 202, 203, 205
- orthogonal Deep-P structure (ODS) 491
- oxidation and oxide 293–296
- oxide semiconductors 120, 659, 663, 665
- p**
- Pauli blocking 263
- $P_{bc}$  defect 237–238
- PDPlus LLC, 467–468
- persistent slip band (PSB) 213–214
- phase diagram of carbon 584
- phosphorus-doped diamond films 639
- photoelectron spectroscopy 256
- photoluminescence excitation (PLE) 508–509
- photoluminescence spectroscopy (PL) 63
- Photoresists 292
- photothermionic emission (PTFE) 263
- photovoltaics
  - commercial, industrial and utility size systems 449
  - residential systems 447
- physical vapor transport (PVT) 3, 5, 206
- PiN diode 356
  - IGBT 376
- planar enhancement-mode (E-mode)  $Ga_2O_3$  MOSFETs 672
- plasma-assisted MBE (PAMBE) gallium oxide thin films 663
- plasma-enhanced chemical vapor deposition (PECVD) 639
- plasma etching 252, 258, 643
- plastic slip 204, 215–216
- plug-in hybrid electric vehicles (PHEVs) 467
- pn diode
  - carrier life, drift layer thickness 364
  - drift layer voltage drop 364
  - high level injection 362
  - low level injection 360
  - open circuit voltage decay 367
  - reverse and forward recovery 366
  - reverse leakage current characteristics 365
- point defect candidates 240–242
- point defects 28, 47, 62–69, 94, 137–163, 225–243, 263, 371, 417, 503–518, 549, 588, 605
- polyamic acid (PAA) solution 302
- polycrystalline 101
- polyimide deposition 302
- poly-Si deposition 298
- Poole–Frenkel effect 143
- positive bias 321
- positive bias temperature stress (PBTS) 233
- positive/negative bias threshold voltage instability (PBTI/NBTI) tests 297
- post implantation anneal 305
- post implantation annealing (PIA) 126
- post metallization annealing (PMA) 126
- post oxidation annealing (POA) 296
- post-epi chemo-mechanical polishing (CMP) processes 48

- post-metal annealing (PMA)
    - 301
  - power-cycling test 416, 419
  - power devices 353
  - Power Electronic Traction
    - Transformer (PETT) 444
  - power electronics 353
  - power factor correction (PFC)
    - 322, 437, 439, 440
  - power grid 444
  - power module technologies
    - die-attach technologies 422
    - top-side interconnections 424
  - power MOSFET 329
    - advantage of 329
  - 4H-SiC
    - DMOSFET 332
    - JBS diodes 345
    - superjunction structure 342
  - IGBT 329
  - trench MOSFET 337
    - optimization 339
    - resistance components 338
  - power switching devices 659
  - preconditioning measurement
    - 231–233
  - prompt internal photoemission (PIPE) 262
  - pseudo-vertical SBD (pVSBD)
    - structure 646
  - P-type doping and processing
    - 642
  - p-type-intrinsic-n-type diodes (PiNDs) 646
  - pulse-mode discharge 635
  - PVT-grown SiC crystals 3
- q**
- quantum bits 503, 507–517
  - quartz cold-wall reactors 79
  - quasicubic 504–506, 511, 516
  - quasi-freestanding 252
  - quasi-freestanding bilayer graphene (QFBLG) 251, 252, 259
  - quasi-freestanding monolayer graphene (QFMLG) 252
  - quasihexagonal 504–506, 516
- r**
- radiation hard 412
  - radiative recombination 64
  - Raman line width
    - heteroepitaxial diamond film on iridium 613
  - Raman microscopy imaging 15
  - Raman-spectroscopy 107
  - random telegraph noise (RTN)
    - 241
  - Reactive Ion Etching (RIE) 327
  - reciprocal recombination 64
  - recombination enhanced
    - dislocation glide (REDG) 184
  - reduced channel electron mobility
    - 235–236
  - reduced MOSFET mobility
    - 238–240
  - residential systems 447
  - resistor–transistor-logic 259
  - Ruggedness
    - avalanche capability 403
    - SiC MOSFETs 387
    - surge-current ruggedness 394
- s**
- sapphire substrates, for GaN epitaxial growth 558
  - scanning electron microscopy (SEM) 257, 344, 608

- Schottky barrier 126, 155,
  - 253–257, 260, 262, 320–322,
  - 346, 409, 411, 435, 471, 563,
  - 565, 566, 591, 619, 641, 642,
  - 644, 645, 650, 659
- Schottky barrier diodes (SBDs)
  - 155, 321, 471, 619, 642, 644,
  - 648, 659
- Schottky-junction diodes (SJD) 93,
  - 397, 404, 421
- Schottky layer production 81
- Schottky pn diodes (SPNDs) 646
- secondary mass ion spectroscopy (SIMS) 123, 542, 544, 548, 640
- second step annealing (SSA) 301
- self-aligned silicide process (Salicide) 301
- shielded DMOSFET 291
- Shockley–Read–Hall (SRH) model 64, 138, 141, 230
- SiC bandgap 293, 295, 297
- SiC bipolar device
  - drift layer and breakdown voltage 357–358
  - pn diode
    - carrier life, drift layer thickness 364–365
    - drift layer voltage drop 364–365
    - high-level injection 362–364
    - low-level injection 360–362
    - open-circuit voltage decay 367–368
    - reverse and forward recovery 366
    - reverse leakage current characteristics 365–366
    - termination structure 358–360
- SiC bulk growth
  - raw materials 36–37
  - cost considerations 35–36
  - crystal grind 41–42
  - reactor hot zone 37–38
- SiC substrates
  - for GaN LEDs 33–34
  - for high-frequency devices 35
  - for power SiC devices 34–35
  - system equipment 39
  - turning boules, into wafers 41
  - wafer polish 44
  - wafer slicing 42–44
  - yield 39–41
- SiC devices 403
  - benefits of 433–436
  - commercial foundries 303–306
  - competition 436–437
  - DC/DC converters 437–442
  - DC grids 451–452
  - drives 455–458
  - high-voltage DC (HVDC) 453–455
  - inductive heating 446–447
  - photovoltaic 447–450
  - solid-state transformer (SST) 443–445
  - wireless charging 445–446
- SiC dislocation cell structures 213
- SiC DMOSFETs, process integration 273
- SiC-IGBT 355, 356, 378–384, 453, 454, 457
- SiC, material properties 661
- SiC MOSFETs 271
  - short-circuit ruggedness 387–394
  - surge-current ruggedness 394–403
- TO-247 393

- SiC MPS diodes 396–398, 400, 402–405, 407–409, 411, 413
- SiC planar power DMOSFET
  - guard rings 278
  - JFET mask 275
  - lithography 283
  - mask layout 273
  - N<sup>+</sup> source mask 277
  - n-type polysilicon on gate oxide 279
  - ohmic metal 280
  - overlayer metal 286
  - P<sup>+</sup> mask 277
  - P-well mask 276
  - sacrificial oxidation 276
  - stack oxide layer deposition 280
- SiC power-cycling tests 421–422
- SiC power devices
  - electrification progress 469–470
  - electrified vehicles 470–471
- SiC power DMOSFET
  - backside thinning and wafer substrates 300–301
  - dedicated foundries vs. commercial foundries 306–307
  - ion implantation and activation annealing 290–293
  - ohmic contacts and metallization 301–302
  - oxidation and oxide 293–296
  - poly-Si deposition 298
  - polyimide deposition 302
  - post oxidation annealing 296–298
  - SiC etching 283–290
- SiC reliability aspects
  - cosmic-ray stability 412–415
  - sufficient reliability
    - die-attach technologies 422–423
    - top-side interconnections 424–426
  - thermomechanical reliability
    - power-cycling tests 419–421
    - SiC power-cycling tests 421–422
    - temperature-sensitive electrical parameters 416–419
- SiC substrates, for GaN epitaxial growth 558
- SiC vertical power DMOSFET 271, 272
- SiC wafers substrates 33
- Si devices, commercial foundries for 303–306
- signal-to-noise ratio 237
- Si-insulated gate bipolar transistor (Si-IGBTs) 76, 236, 319, 329, 355, 387, 434, 468, 567
- silicon carbide (SiC) epitaxy
  - basics 76–77
  - benefits and challenges 86
  - epitaxial wafers 75
  - high-throughput epitaxial reactor status 82–85
  - historical origin 78–80
  - horizontal hot-wall reactors 82
  - increasing diameters 86–89
  - multi-wafer layer 76
  - planetary multi-wafer epitaxial reactor design consideration 80–81
  - rapidly rotating reactors 81–82
- silicon vacancy 140, 152–153, 238, 264, 503–505, 510, 513
- Si, material properties 661
- similitude relation 212
- single crystal CVD growth 603



- single crystal seed recovery
    - epitaxial lateral overgrowth using SiO<sub>2</sub> masks 605
    - high-energy ion implantation 604
    - by laser cutting 604
  - single crystal wafer diameter 34
  - single event burnout (SEB) 412
  - single-event effect (SEE) 412
  - single photon sources
    - carbon antisite–vacancy (CAV) pair defect 513–514
    - divacancy 508–510
    - nitrogen–vacancy pair 514–515
    - other defects 515–517
    - silicon vacancy 510–513
  - SiO<sub>2</sub>, thermal growth of 294
  - Society of Automobile Engineers (SAE) Standard 445
  - solid state transformer (SST) 443
    - power grid 444–445
    - traction 443–444
  - spontaneous nucleation of diamond 585
  - spontaneous polarization 561, 563, 660
  - sputtering 96, 301, 481
  - stable dislocation agglomerations 213
  - stacking faults (SF) 99, 105, 110, 293
  - Stark tuning 264, 509
  - star-like defects 539, 541
  - statistically stored dislocation (SSD) 201, 203, 204
  - sub threshold sweep hysteresis 226–230, 237–238
  - superjunction (SJ) 329, 342–345, 355, 436, 495, 570
  - superjunction MOSFETs 342–345, 347
  - supersaturation 48, 52, 53, 76, 77, 79, 81, 86, 95, 104, 106–110, 535, 543, 546
  - switched-mode power supply (SMPS) 437
  - switching performance, of GIT 570–571
  - synchrotron white beam X-ray topography (SWBXT) 169–171, 173, 176–182, 539
- t**
- tail current 139, 140, 330, 381, 393
  - tailorable metal/semiconductor contact
    - ohmic contacts 254–256
    - Schottky contacts 256–257
  - Taylor relationship 211, 213
  - temperature gradient method 585–587, 589
  - temperature-sensitive electrical parameter (TSEP) 416–419
  - thermal expansion coefficients (TEC) 98, 102, 206, 208, 534, 535, 558, 559
  - thermal oxidation 67, 68, 121–123, 273, 294–296, 336, 371, 372, 517
  - thermal stress 181, 200, 481, 612–613, 615
  - thermoelastic stress 4
  - thermomechanical reliability 414
    - evaluation of SiC power-cycling tests 421–422
    - execution of power-cycling tests 419–421
    - temperature-sensitive electrical parameters 416–419

- threading dislocation density (TDD) 535
  - threading dislocations (TDs) 3, 9, 18, 27, 57, 59, 60, 173–175, 177, 180, 192, 535, 605, 619, 643
  - threading edge dislocations (TEDs) 6, 56, 171–173, 191, 218
  - threading mixed dislocations (TMDs) 56, 173–174
  - threading screw dislocations (TSDs) 3, 8, 56, 170–171, 175
  - three-dimensional continuum dislocation dynamics (CDD) 204–205
  - tiled-clones 636
  - tiling 636
  - time dependent defect spectroscopy (TDDS) 235, 241
  - time-resolved photoluminescence (TR-PL) 68
  - total ionizing dose (TID) 412
  - traction 442–444, 458, 459, 472, 473, 485
  - transfer length method (TLM) 254, 255, 641
  - transient liquid phase (TLP) 481–483
  - transient voltage suppression (TVS) 452
  - transition metals (TM) 140, 153–160, 162, 163, 506, 515, 518
  - transmission electron microscopy (TEM) 125
  - transmission X-ray topographs 5, 9–11, 13, 170, 590
  - transparent wafers 305
  - transverse optical (TO) mode 107, 108
  - trench MOSFET
    - optimization 339–341
    - resistance components 338–339
    - structure 337
  - trench SBD structure 667
  - triangular current mode (TCM) 439
  - trichlorosilane 52, 113
  - two-dimensional electron gas (2DEG) 555, 672
  - two-dimensional mapping 15
- u**
- ultimate semiconductor 583, 645
  - ultra-high-voltage SiC
    - bipolar device
      - 16 kV class SiC-IGBT 378–381
      - 20 kV class SiC-IGBT 381–383
    - carrier lifetime dependence 372–371
    - current status 378–384
    - loss estimation 373–378
    - remaining issue 383–384
  - PiN diode 356
  - SiC bipolar device
    - drift layer and breakdown voltage 357–358
    - pn diode 360–365
    - termination structure 358–360
  - SiC-IGBT 356–381
- UMOSFETs 341
- unintentionally doped (UID) GaN growth 536
- UV-excited photoluminescence (UVPL) imaging 59, 60, 191
- v**
- vacancy 28
  - valence bands (VBM) 230, 242, 433, 505, 514, 543, 637, 642, 661, 662

- vertical Ga<sub>2</sub>O<sub>3</sub> FETs 672
- vertical Ga<sub>2</sub>O<sub>3</sub> FP-SBD structure 667, 668
- vertical Ga<sub>2</sub>O<sub>3</sub> SBD structure 666
- vertical Schottky barrier 591, 665
- virtual power plants (VPP) 353
- void assisted separation (VAS) 535
- voltage shift 123, 232, 233, 298, 299, 336
- voltage source converters (VSC) 453
- Von Mises stress distribution, in HVPE-GaN 545
  
- w**
- wafer polish 44
- wafer slicing 41–44
- wide bandgap (WBG) 3, 76, 169, 290, 303, 319, 330, 355, 433, 435, 503, 531, 567, 646, 659
  
- wind energy 457
- wireless charging 445–446
  
- x**
- X-ray diffraction (XRD) 27, 105, 107, 302, 610
- X-ray photoelectron spectroscopy (XPS) 120, 256
- X-ray topography (XRT) 5–13, 17–20, 22–23, 59, 89, 169, 177, 184, 187–189, 192, 539, 540
  
- y**
- yttrium-stabilized zirconia (YSZ) 636
  
- z**
- zero-field-splitting (ZFS) 508
- zero-phonon line (ZPL) 508, 512
- zero-voltage switching (ZVS) 447















