

Index

a

- Abbe limit 163
- adhesion weak method 195
- ammonium perrhenate 46
- angle/angular-resolved photoemission spectroscopy (ARPES) 126, 146, 147
- antimonene 7
- atmospheric pressure chemical vapor deposition (APCVD) 40
 - graphene 42
 - low-pressure chemical vapor deposition 48–53
 - multi-element materials 48
 - single-element materials 40–42
 - TMDCs bi-element materials 42–47
- atomic layer deposition (ALD) 18, 201, 299
- auxiliary glue compound 89

b

- band alignment 47, 99, 104, 105, 111, 112, 126–129, 142, 144, 147, 159, 169, 172, 175, 211, 212, 223, 228, 231–233, 296, 300
- battery 271
 - lithium-ion battery 273
 - supercapacitors 276–277
- bilayer graphene 133–135, 139, 140, 145, 147, 164, 165

- biosensors 12, 282–284
- bismuthene 7
- black phosphorus (BP) 6, 269
 - capsulated by hBN 141–142
- Boltzmann equation 141
- boron nitride (BN) 90
- borophene 7, 8

c

- carbon fiber cloth (CFC) 114
- carbon sublattices 14
- catalyst 12, 41, 47, 111, 112, 268, 269, 277–282
- charge transfer 50, 57, 98, 107, 111, 126–129, 142, 157, 159, 175, 229, 234, 243, 271, 272, 277, 283, 299, 303
- chemical etching 70, 72, 74, 279, 281
- chemical sensors 102–104
- chemical vapor deposition (CVD)
 - method 3, 7, 9, 17–18, 38–52, 54, 56–57, 69–71, 78, 82, 86, 88, 99, 101, 105, 108, 115, 131, 177, 188, 197, 228, 264, 275, 277, 297, 301, 304, 307
- conduct band minimum (CBM) 135, 268, 269
- contact resistance 112, 171, 190, 192–195, 200, 208, 304, 307, 308
- continuum Dirac model 135

- controllable synthesis
 of 2D-1D heterostructures 82–84
 of 2D-2D heterostructures 76–82
 of 2D-3D heterostructures 85–86
 Coulomb interaction 15, 37, 135, 172,
 175, 200, 239
- d**
 dark field optical microscopy 91
 density functional theory (DFT) 11,
 45–47, 50, 126, 127, 129, 135, 141,
 169, 173, 268, 280
 dimethyl sulfide (DES) 60
 direct bandgap 1, 5, 7, 8, 11, 46, 47, 60,
 108, 110, 167, 173, 206, 236, 239
 direct growth method 99, 100
 doping's intrinsic 126
 dry transfer method
 pick-up 89–92
 stamps 88–89
 thermal-release tape 86–88
- e**
 electric-field integrated STM-STs
 technique 159–160
 electrochemical delamination
 methods 72–74
 electrochemical reaction 72, 270,
 274, 275
 electrostatic force microscopy
 (EFM) 145
 encapsulator 137
 energy dispersive spectroscopy (EDS)
 mode 161, 162
 exciton diffusion length (L_E) 175
 exfoliated 2D materials 34
 liquid 35–37
 mechanical 34–36
 exfoliation 6, 7, 9, 17–18, 33–37, 90, 114,
 195, 297, 301, 310
 exhaust gas treatment system 58
 external gate voltage 169, 170
- f**
 face centered cubic (FCC) 14, 17
 Fermi level 15, 107, 108, 111, 127, 132,
 137, 138, 159, 170, 176, 177, 188,
 190, 193, 195, 212, 234, 243,
 280, 304
 field-effect transistor (FET) 82,
 101–102, 197
 advantages characteristics 199
 basic structure 198–199
 dielectric materials 199–201
- g**
 gas transportation system 58
 gateway 173
 germanene 6
 Goodenough–Kanamori–Anderson
 rules 131
 graphene processes 247, 284
 bilayer graphene 133–135, 139, 140,
 145, 147, 164, 165
 planar graphene 33
 graphite-diacetylene 5, 6
 guided tissue regeneration (GTR)
 membrane 285
- h**
 half integer quantum Hall effect
 (HIQHE) 139
 Hall effect 6, 125, 130, 138, 139
 Hall mobility 52, 141
 hexaethynylbenzene 5
 hexagonal boron nitride (h-BN) 3, 8–9,
 45, 56, 90, 92, 137–138
 black phosphorus (BP) capsulated
 by 141–142
 graphene capsulated by 138–140
 transition metal dichalcogenides
 capsulated by 140
 with honeycomb lattice 137
 high-angle annular dark-field (HAADF)
 detector 142, 143

- highly ordered pyrolytic graphite (HOPG) 86, 130
- horizontal 2D-2D heterostructures 79–80
- Hubbard model 135
- hydrogen energy 267
 - by water electrolysis 270–271
 - by water photolysis 268–270
- hydrogen evolution reaction 12, 36, 37, 112, 271
- hydrogen gas 40, 48, 49, 112
- i**
- indirect band gaps 1, 8, 11, 46, 110, 167, 173, 239
- integer quantum Hall effect (IQHE) 136, 138, 139, 141
- ion intercalation 35, 37
- Ising model 129
- j**
- junction FET (JFET) 201
 - applications 205–208
 - current-voltage features 202–203
 - device structure 205
 - working principle 203–204
- k**
- Kelvin probe force microscopy (KPFM) 145, 160, 162–163
- l**
- laser 3, 18, 78, 80, 81, 110, 126, 166, 195, 242–245, 269
- Laudau level (LL) 139
- light absorption spectrum 50
- light emission 110, 172
 - light-emitting diode 236–242
- liquid exfoliation 7, 297
 - of 2D materials 35–37
- liquid-precursor CVD method (LCVD) 177
- lithium-ion batteries (LIBs) 112–114, 273–277
- lithium ion battery 273
- low-pressure chemical vapor deposition (LPCVD)
 - multi-element materials 51–53
 - single-element materials 48–49
 - TMDCs bi-element materials 49–50
- m**
- magnetic coupling 126, 129–134
- magnetic proximity effect 133
- magnetic/magneto tunneling junction (MTJ) 132, 134, 212
- massless Dirac fermions 138
- mechanical exfoliation 9
 - Au-assisted 35
 - of 2D materials 34–36
- melamine 42
- metal etching method 70
- metal foil 69, 71
- metal organic chemical vapor deposition (MOCVD) 39
 - overview 57–59
 - III–V group semiconductor by 59–60
 - TMDCs by 60–63
- methane gas 40, 42
- microelectronic devices 188
- micromechanical exfoliation 17
- microwave (MW) plasma 53
- mixed-dimensional VdWHs
 - categorization of 97–99
 - chemical sensors 102–104
 - direct growth of 100–101
 - transfer-assisted assembly of 99–100
 - transistors and spintronics 101–102
- modified element reactor (MER) 76
- modulated-elemental-reactant (MER) method 76
- Moiré excitons 135–136

- Moiré lattice
 band structure in 134–135
 bilayer graphene in 135
 excitons 135–136
 topological 136–137
- Moiré pattern 49, 134–137, 140, 142–145, 160, 161, 163, 166
- molecular beam epitaxy (MBE) 6, 7, 18, 82, 137
- molecular evaporator deposition 5
- molybdenum disulfide 56, 86, 191, 194–196
- Moore's Law 207, 301, 305, 306
- MoS₂/GaN 85, 268
- Mott metal-insulator transition 135
- multi-element materials
 atmospheric pressure chemical vapor deposition (APCVD) 48
 low-pressure chemical vapor deposition (LPCVD) 51, 53–57
- multi-field microscopy techniques 158
 electric-field integrated STM-STs technique 159–160
 optical-field integrated KPFM technique 162–163
 TEM technique 161–162
 thermal-field integrated STM-STs technique 160–161
- multi-field optical spectroscopy
 technique 163
- S-SNOM 165–166
- TERS technique and Raman spectroscopy 163–165
- MXene 12, 13, 275, 276
- n**
- nanomaterials 37, 45, 75, 99, 102, 105, 107, 111, 112, 114, 276, 282, 283, 285
- o**
- Ohmic contact 47, 192, 193, 195, 205, 267, 304
- one-dimension heterostructures 80–82
- optical and vibrational spectroscopy 145–147
- optical-field integrated KPFM
 technique 162–163
- optoelectronic applications 5, 7, 34, 83, 104–110, 175
- optoelectronic device system 306, 309
- p**
- Peakforce Tapping™ mode 144
- phase engineering 51, 171, 194, 277–279
- phosphorene 176, 177, 269, 270
- photocatalytic water splitting 111–112
- photodetector(s) 82, 223
 improvement strategies 234–236
- light emission
 laser 242–243
 light-emitting diode 236–242
 single photon 244–245
- optical modulators 245–247
 all-optical modulators 245–246
 electro-optic modulators 246–247
 thermo-optic modulators 247
- photoconductive effect 229–231
- photo-thermoelectric effect 233–234
- photovoltaic effect 228–229
- tunneling effect 231–232
- photoelectric conversion 162, 263, 264
- photogating effect 104, 170, 230, 235
- photoluminescence spectroscopy (PL) 7, 9, 45, 49, 50, 51, 85, 106, 126, 127, 145, 146, 167, 168, 170, 173–177, 238, 240, 241, 245, 283, 284, 298, 299
- photonic applications 104–111
- photoresponse enhancement 104
- pick-up methods 89–92
- planar graphene 33
- plasma enhanced chemical vapor deposition (PECVD)
 graphene 54–56
 overview 53–54
 TMDCs 56–57
 VG nanosheets 56
- plasmon resonance frequency 105
- PMMA/PVA 72
- polydimethylsiloxane (PDMS) 74, 75, 88–91, 195, 197, 300

- polymethyl methacrylate (PMMA) 42,
 70–74, 86, 88, 89, 195, 300
 polypropylene carbonate
 (PPC) 89–90, 197
 polyvinyl alcohol (PVA) 72, 89, 276, 285
 polyvinylpyrrolidone (PVP) 35
 power conversion efficiency (PCE) 108,
 229, 267
 power-efficient electro-optic
 modulators 246
 pseudo-Van der Waals growth
 method 60
 pulsed laser deposition (PLD) 18
- q**
- qPlus technique 144
 quantum electrodynamics 138
 quantum light-emitting 108
- r**
- radio frequency (RF) plasma 53, 192
 Raman scattering 146, 177
 Raman spectroscopy 50, 85, 130, 132,
 146, 158, 163, 297, 299
 rechargeable batteries 112–114, 273
 reflective magnetic circular dichroism
 (RMCD) 132
- s**
- scanning magneto-optic Kerr
 microscopy 130
 scanning photocurrent microscope
 (SPCM) 165
 scanning probe
 microscopy 142, 144–145
 scanning transmission electron
 microscope (STEM) 47, 48, 52,
 142–143, 161, 281, 285
 scanning tunneling spectroscopy
 (STS) 126, 135, 144, 145, 159–161
 scattering-type scanning near-field optical
 microscope (s-SNOM) 165–166
 Schottky barrier 37, 107, 171, 193–196,
 201, 208, 233, 241
 Schottky diodes 47, 192
 Schottky junction 105, 106, 108, 109,
 111, 112, 192, 193, 196, 213
 selenium powder 42, 43
 semiconducting 2D materials 34
 short-wave infrared (SWIR) 104
 single-element materials
 atmospheric pressure chemical vapor
 deposition (APCVD) 40–48
 low-pressure chemical vapor deposition
 (LPCVD) 48–53
 single photon 108, 173, 244–245
 single quantum emitters
 (SQEs) 244, 245
 SiO₂/Si substrate 4, 9, 44, 45, 56, 70, 71,
 74, 75, 82, 86, 92, 108, 139
 sodium-ion batteries (SIBs) 113,
 114, 273–277
 soft-chemical method 131
 solar energy 111, 173, 261–267, 269
 solvothermal 18, 99, 114, 276–278, 280
 spintronics 101–102, 134
 stacking fault phases 14
 stamps 88–89
 STEM-ADF 52
 strain-engineered optical
 properties 173–175
 strain-induced bandgap transition 167
 strain-induced piezopotential 175
 substrate etching techniques 69–72
 supercapacitors 111, 113–115, 273, 276,
 277, 284
- t**
- thermal emission equations 171
 thermal-field integrated STM-STs
 technique 160–161
 thermal-release tape 86–88
 thermo-optic modulators 247
 III–V group semiconductor 59–60
 3D material systems 295
 time-dependent density functional
 theory-molecular dynamics
 (TDDFT-MD) 129
 time-domain density functional (TDDFT)
 method 129

- tissue engineering 282–285
 - transfer-assisted assembly 99–100
 - transistors 101–102
 - field-effect transistor 197–212
 - and spintronics 101–102
 - transition metal carbides (TMCs) 12–15
 - transition metal dichalcogenides (TMDCs) 9, 12
 - bi-element materials
 - atmospheric pressure chemical vapor deposition (APCVD) 40–48
 - low-pressure chemical vapor deposition (LPCVD) 48, 49
 - capsulated by hBN 140
 - by MOCVD 60–63
 - by PECVD 56–57
 - transition metal oxides (TMOs) 15–18, 275, 284
 - transmission electron microscopy (TEM) 49, 50, 77, 78, 81, 83, 84, 142–143, 158, 161–162, 166, 196, 270, 278, 281, 297
 - tungsten 48, 56, 62
 - tunneling conductance 159
 - tunneling current 46, 132, 144, 159, 190, 210–212, 231
 - tunneling FET (TFET) 208
 - applications 211–212
 - history 208–209
 - mechanism 209–211
 - tunneling magnetoresistance 134
 - twisted bilayer graphene (TBG) 134, 135, 164, 165
 - 2D-0D hybridization 104–105
 - 2D-1D hybridization 105–108
 - 2D-2D heterostructures
 - horizontal 79–80
 - vertical 76–79
 - 2D-3D hybridization 108–110
 - 2D layered materials (2DLMs) 295–296
 - classification 3
 - elemental 3
 - V group A 6–7
 - IV A group 3–6
 - hexagonal boron nitride (h-BN) 8–9
 - industry-compatible integration
 - process 299–301
 - mass production 297
 - metrology 297–299
 - silicon technology 301–307
 - compatibility 301–307
 - III A group 7–8
 - transition metal carbides (TMCs) 12–14
 - transition metal dichalcogenides (TMDCs) 9–12
 - transition metal oxides (TMOs) 15–18
 - 2D Van der Waals structures
 - electrical properties 167–169
 - electric field-engineered 169–170
 - strain-engineered 167–169
 - thermal-engineered 171–172
 - multi-field coupling effect
 - characterization for 158–166
 - multi-field integration
 - characterization 166
 - multi-field microscopy
 - technique 158–163
 - multi-field optical spectroscopy
 - technique 163–166
 - optical properties 172–177
 - electrical-engineered 175–177
 - strain-engineered 173–175
 - thermal-engineered 177
- u**
- ultrasonication 35–37
 - assisted liquid exfoliation 37
- v**
- vacuum annealing 70
 - valence band maximum (VBM) 135, 228, 268, 269
 - valleytronics 132–134
 - Van der Waals (VdW)
 - integration 213–216
 - heterojunctions 187–188
 - Van der Waals heterostructures (vdWHs) 2, 223
 - band alignment in 126–129

characterization techniques
for 142–147
charge transfer in 126–129
field-effect transistor 197–201
junction field-effect
transistor 201–208
magnetic coupling in 129–134
metal-semiconductor
junctions 192–197
Moiré pattern 134–137
PN junctions 188–192
for protection 137–142
roadmap 307–308
spintronics in 134
tunneling field-effect
transistor 208–212
valleytronics in 132–134
vertical 2D-2D heterostructures 76–77
VG nanosheets 56

W

water film 74, 75
wedging transfer method 74–75
wet transfer 69
electrochemical delamination
methods 72–74
substrate etching techniques 69–72
wedging transfer methods 74–75
white graphene 8

X

XPS 50, 278

Y

Young's modulus 4

Z

Zeeman splitting 132, 133

