

Index

a

$A_2B(II)B_2(III)X_{12}$: B(II), B(III)
 substitution + vacancies 135
 $A_2B(IV)X_6$: B(IV) substitution + vacancies
 134
 $A_3B(III)X_9$: B(III) substitution +
 vacancies 135
 ABC model 330, 331, 338
 ABO_3 metal oxide structure 49
 absorption measurements 337, 338, 427
 ABX_3 perovskite unit cell 3, 50
 acid-base equilibrium 53
 additives manipulation
 crystallization regulators 155
 deoxidizers 156
 interfaces passivating materials 156
 air mass (AM) 131
 all-inorganic perovskite single crystals
 9, 13–14
 alloyed perovskite compositions 459,
 461
 alternating cations in the interlayer space
 (ACI) 170
 amplified spontaneous emission (ASE)
 336, 343
 Anharmonic effects 216, 228, 231
 annealing time 35, 52, 63–64, 429, 431
 annular dark field (ADF) 399
 anodized aluminum oxide (AAO) 81, 82
 antireflection coating 296
 antisolvent vapor-assisted crystallization
 (AVC) method 14–15

antisolvent vapor crystallization 14, 39,
 84
 atmospheric light annealing 340
 atomic force microscopy (AFM) 83, 309,
 363, 448
 atomic model 50
 atom probe tomography (APT) 389
 Auger heating 268, 269
 Auger process 286, 331, 336
 Auger recombination (AR) 38, 268, 339,
 344
 Avogadro's constant 305

b

backscattered electrons (BSE) 380, 381,
 389, 392
 ball-milling process 55–56
 band alignment 40, 99, 100, 124, 148,
 157–158, 265
 band gap renormalization (BGR) 270
 bar coating 193
 bathocuproine (BCP) 37, 274
 bathophenanthroline (BPhen) 274
 beam damage 377, 384–386, 389, 392,
 399–402, 406, 435–437, 462–469,
 471
 Bethe–Salpeter equation (BSE) 232,
 239–240
 bimolecular processes 334, 336
 bismuth oxybromide (BiOBr) 129
 black box synthesis 411, 412
 blade coating methods 193–197
 Bohr diameter 57, 59

- Bohr radius 50, 57, 58
 Boltzmann constant 18, 22, 97, 271, 306
 Born–Oppenheimer approximation 217, 222, 227
 bound excitons (BEs) 23, 232, 242
 Bragg–Brentano geometry 413
 Bragg’s law 413
 Bridgman method 13, 14, 16–17, 84
 B-site dopants 67, 68
 bulky-oleylammonium ions 57
 1,4-butanediamine (BEA) 154
 butylammonium 3, 133
 BX_6 octahedral 3
- C**
- cadmium selenide (CdSe) 283
 capping ligand 54, 56, 58, 63, 64, 69, 71, 104
 carrier lifetime 5, 21, 22, 26, 28, 30, 103, 104, 127, 128, 131, 151, 256, 259, 320, 324, 359, 360, 447, 452, 454
 carrier multiplication (CM) 280, 281
 carrier thermalization 265–266, 269
 cathodoluminescence (CL) 381
 beam damage 384–385
 damage reduction 385–386
 inorganic perovskites 383–384
 photoluminescence 382
 spectroscopy 464
 working principle 382
 cation displacement 202, 203
 cavitation-triggered asymmetrical crystallization (CTAC) 38
 charge carrier recombination 129, 330–341, 382, 456
 charge-couple device (CCD) 392
 charge selective transport layers (CSTLs) 263
 chemical doping 121
 chemical vapor deposition (CVD) 39, 81, 82, 99, 358
 CO_2 reduction reaction (CRR) 131
 colloidal quantum dots (cQDs) 342
 colloidal synthesis methods 51, 83, 84
 color rendering index (CRI) 125
 complementary
 metal-oxide-semiconductor (CMOS) 392
 Compton scattering 31
 conduction band (CB) 121, 124, 149, 235, 236, 240, 242, 254, 334, 338, 341, 342, 381, 382
 conduction band minimum (CBM) 118, 149, 237, 318, 332
 continuous inkjet printing (CIP) 199
 continuous wave (CW) 103, 272, 273, 283, 339, 386
 cooling loss to lattice 263, 277–279
 Coulomb coupling 284, 286
 Coulomb interaction 221, 234, 235, 239, 240, 284, 285, 335
 COVID-19 pandemic 471, 472
 cross-sectional EBIC 387, 388
 crystal growth mechanism
 basic growth theory 176–178
 grain-coarsening theory 178–179
 crystallization kinetics 97, 104, 416–418
 crystallization mechanism
 influences on nucleation 176
 nucleation theory 173–176
 crystallographic orientations 171, 173, 179, 377, 379, 381, 393, 395, 399, 452
 crystallographic twinning 403, 404
 crystal orientation 104, 154, 200, 391, 392, 413, 454, 467
 crystal surface 17, 38, 96, 97
 $Cs_2AgBiCl_6$ band 121
 $Cs_2AgTlCl_6$ band 121
 Cs + GA-doped syntheses 418
 Cs–Pb–Br-based perovskites 39
 CsPbIBr₂ film surface 384
 Cs-precursor to PbX_2 ratio 53
- d**
- Debye length 308, 321
 Debye-type dielectric relaxation 26
 defect management 344
 density functional perturbation theory (DFPT) 223

- density functional theory (DFT) 89, 157, 215, 217–223, 333, 361, 423, 451
- density of state (DOS) 89, 149, 229, 235, 272
- deoxidizers 155, 156
- device architecture engineering
band alignment 157–158
normal and inverted structures 156–157
- dichloromethane (DCM) 14
- dimensional reduction 132–133
- dimethylammonium iodide (DMAI) 201
- dimethylformamide (DMF) 14, 82, 200
- dimethyl sulfoxide (DMSO) 14, 20, 87, 152, 181, 200, 360
- Dion–Jacobson (D-J) phase 3, 4, 96, 118, 132, 154, 170, 242
- direct electron detector 391, 392
- direct X-ray detector 129
- distributed Bragg reflector (DBR) 343
- distributed feedback (DFB) 343
- doped perovskite PNCs 67
- doping effects 67, 68, 151, 320
- drop casting method 180, 183
- Drude model 257
- dual-source coevaporation 184
- Dyson equation 234
- e**
- electro/chemical bath deposition 190
- electron backscatter diffraction (EBSD)
389, 451
beam damages and EBSD detectors 392
for crystal quality 394
for grain size 392–393
for intragrain defects 393–394
for orientation 393
working principle of 391–392
XRD and TEM 390
- electron-beam-induced current (EBIC)
387, 389, 456, 464
- electron-beam-induced damage 389
- electron dispersive X-ray spectroscopy (EDX) 381, 399
- electron–hole pairs (EHPs) 39, 57, 128, 131, 240–242, 254, 268, 280, 283, 382, 387, 423
- electronic band structures
predictive band structure 237–239
tight-binding perspective 235–237
- electronic properties
impedance spectroscopy 26–29
space-charge-limited current 23–26
- electron microscopy 82, 310, 360, 377–406, 444, 450, 467, 469, 472
- electron transport layers (ETLs) 124, 148, 182, 251, 263, 275
- Elliott models 241, 242
- elpasolites 116
- energy dispersive X-ray spectrometry (EDS) 392
- energy selective contacts (ESCs) 275, 279
- epilayer–substrate relation 357
- epitaxial substrates 353, 354, 366
- epitaxy, thin film and nanostructures
epitaxial substrates 353, 354
experimental progresses 358–360
growth and mechanisms 355–357
- 1,2-ethanedithiol (EDT) 296
- ethylenediammonium diiodide (EDAI₂)
153
- Euclidean space 415
- exact (Fock-like) exchange (EXX) 221
- exciton–exciton annihilation (EEA) 336, 337
- excitonic systems 336, 337
- exploitation decision policy (EPLT) 473
- external quantum efficiency (EQE) 6, 29, 125, 127, 295
- f**
- FAPbI₃ single crystals 11
- Fermi–Dirac distribution 271
- ferroelasticity 452
- first principles atomistic theory 215–243
- five-step growth
from solutions

- five-step growth (*contd.*)
- electro/chemical bath deposition
 - 190
 - immersion method 187–189
 - spin-coating method 189–190
 - from vapor phase
 - sequential vapor deposition
 - 191–192
 - vapor-assisted solution processing
 - 190–191
 - fluorescence-based techniques 272–274
 - fluorescence delay mechanisms 335
 - fluorine-doped tin oxide (FTO) 183, 299
 - focused ion beam (FIB) milling 396, 462, 465
 - formamidinium (FA) 2, 51, 101, 147, 167, 289, 332, 360, 416
 - Fourier transform 229, 415
 - Frank–van der Merwe model 177
 - free excitons (FEs) 23, 84, 87, 90, 125
 - full-width at half maximum (FWHM) 424
- g**
- γ -butyrolactone (GBL) 14, 181, 200
 - gamma (γ) photons 30
 - gas quenching 194–196
 - Geurst theory 25
 - Geurst's SCLC model 24
 - GHz regime 251
 - Gibbs free energy 18, 97, 174
 - Goldschmidt tolerance factor 3, 10, 118, 167
 - grain boundaries (GBs) 17, 21, 26, 27, 32, 33, 39, 42, 43, 153, 171, 172, 253, 307, 309, 310, 315–317, 323, 335, 351, 382–384, 389, 391–394, 397, 398, 400, 402, 403, 418, 429, 446, 450, 451, 454–457, 459, 462, 467
 - grain-coarsening theory 178–179
 - grain size distribution 173, 390
 - grazing incidence small-angle X-ray scattering (GISAXS) 412, 414
 - grazing incidence wide-angle X-ray scattering (GIWAXS) 104, 413
 - grazing incident X-ray diffraction (GIXRD) 365, 413
 - Green's function 215, 232–234, 239, 240, 242
 - ground state bleach (GSB) 271, 338
 - guanidinium iodide (GAI) 416
 - GW approach 233–235, 240
- h**
- halide double perovskites (HDPs)
 - definition 116–118
 - dimensional reduction 132–133
 - light-emitting diodes 125
 - memristors 130
 - photocatalysis 131
 - photodetectors
 - UV detectors 128
 - X-ray detectors 128–130
 - photovoltaic solar cells 123
 - properties
 - chemical doping 121–122
 - random ordering 122
 - stability 122–123
 - sensors 131–132
 - structure 116–118
 - vacancy ordered perovskites
 - $A_2B(II)B_2(III)X_{12}$: B(II), B(III) substitution + vacancies 135
 - $A_2B(IV)X_6$: B(IV) substitution + vacancies 134
 - $A_3B(III)X_9$: B(III) substitution + vacancies 135
 - halide perovskite-based photodetectors 6
 - halide perovskite nanocrystals (PNC)
 - lead-free perovskite nanocrystals 69–70
 - methodology
 - ball-milling process 55–56
 - hot-injection (HI) method 51–54
 - ligand-assisted reprecipitation method 54–55
 - microwave-assisted synthesis 55
 - nanocrystals doping
 - B-site dopants 67

- lanthanide doping 65–67
 - Mn²⁺ doping 65
 - postsynthesis doping 67–69
 - post-synthesis defect-recovery 61–62
 - quantum confinement effect
 - nanocubes 57–58
 - nanoplatelets 58–59
 - nanowires 59
 - shape-controlling reaction parameters
 - annealing time 63–64
 - capping-ligand role 64
 - temperature 63
 - solution-processed halide exchange 59–60
 - halide perovskite single crystals
 - applications
 - γ-ray detection and scintillators 30–32
 - light emitting diodes 38–41
 - memristors 41–43
 - photodetectors 29–30
 - solar cells 32–38
 - X-ray detection 30
 - crystal structure
 - all-inorganic perovskite single crystals 13–14
 - lead-based perovskite single crystals 10–12
 - lead-free perovskite single crystals 12
 - electronic properties
 - impedance spectroscopy 26–29
 - space-charge-limited current 23–26
 - optoelectronic properties 21–29
 - synthesis methods
 - antisolvent vapor-assisted crystallization 14–15
 - Bridgman method 16–17
 - inverse temperature crystallization method 19–20
 - slow evaporation method 17–19
 - solution temperature lowering method 15–16
 - 2D and 1D perovskite single crystals
 - method 20–21
 - halide perovskite, structural tunability 105
 - Hartree–Fock theory 232
 - healing effects 315
 - helium ion microscopy with secondary ion mass spectroscopy (HIM-SIMS) 448
 - Hellmann–Feynman theorem 220, 222, 227
 - heterovalent substitutions 118, 135
 - high-angle annular dark field (HAADF) 399, 462
 - high-angle annular dark field-STEM (HAADF-STEM) 89
 - high multiple exciton generation efficiency 291
 - high-performance solar cells 21
 - high-resistance state (HRS) 43
 - high-resolution TEM (HRTEM) 89, 473
 - HI reaction methodology 54
 - Hohenberg–Kohn theorem 217
 - homogeneous nucleation 174, 175, 178
 - hot carrier cooling 264–275, 277, 280, 281, 283, 285, 286, 299
 - hot carrier extraction 274–275, 279
 - hot carrier solar cell (HCSC) 263, 275–280
 - hot carriers in halide perovskites
 - cooling mechanisms 265–266
 - next-generation photovoltaics 264–265
 - hot-injection (HI) method 51–54
 - hot-injection temperature 53
 - hot phonon bottleneck 266–269
 - hydrogen evolution reaction (HER) 131
- i**
- immersion method 187–189
 - impedance spectroscopy (IS) 23, 26–29, 308
 - incident-photon-to-current efficiency (IPCE) 295
 - independent particle (IP) approximation 240

- indirect X-ray detector 129–130
 - indium tin oxide (ITO) 191, 299
 - inkjet printing 199–200
 - inorganic–organic metal halide perovskite
 - solar cell 147
 - inorganic perovskites 384
 - inorganic single crystal 13
 - in situ GIWAXS 2D/3D interface
 - formation 420–423
 - in situ optical spectroscopy
 - design for 425–426
 - multimodal characterization 430–435
 - photoluminescence characterization 428–430
 - reflectance measurements 426–427
 - UV–vis absorbance characterization 427–428
 - instrument response function (IRF) 271
 - interface band alignment 157–158
 - interfaces passivating materials 156
 - internal quantum efficiency (IQE) 338
 - inverse temperature crystallization (ITC)
 - method 19–21, 25, 36, 39
 - ionic epitaxy 355, 358, 359, 363
 - ionic transport, in perovskite
 - semiconductors
 - characterizations of 306–309
 - degradation in functional devices 322
 - doping effects 320
 - grain boundary 315–317
 - lattice strain 317–318
 - light illumination 311
 - moisture 311
 - perovskite composition 313–315
 - perovskite film under electric field 309–311
 - phase segregation 318–320
 - SCLC and TFT devices 321–322
 - theoretical basis of 305–306
 - ion migration 28, 49, 103, 129, 182, 217, 229–231, 260, 306, 307, 311, 313–315, 323, 324, 330, 365, 444, 446–448, 471
- k**
- K_2PtCl_6 -type perovskites 134
 - Kelvin probe force microscopy (KPFM) 310, 390, 447, 448, 470
 - Kikuchi pattern 391
 - kinetic energy density 221
 - kinetic parameters 255, 257, 260, 432
 - Klemens channel 267
 - knife coating 193
 - Kohn–Sham equations 218–220, 222, 223, 232–235
 - Koopman’s theorem 232
- l**
- Lamella cross section 466
 - lanthanide doping 65–67
 - large-scale fabrication method 82, 193, 196
 - lasing death 343, 344
 - lattice strain 317–318
 - lattice thermalization 266, 276, 277
 - layered solution method (LSM) 90, 97
 - lead-based halide perovskites 69, 118
 - lead-based perovskite single crystals 10–12
 - lead-free MHPS 168–169
 - lead-free perovskite nanocrystals 69–70
 - lead-free perovskite single crystals 12, 39
 - lead-free PNCs (LF-PNCs) 69
 - lead-halide perovskites (LHP)
 - bimolecular recombination 334–335
 - excitonic systems 336–337
 - lasing 341–345
 - monomolecular recombination 331–334
 - tailoring recombination 344–336
 - lead perovskite solar cells (LPSCs) 147
 - ligand-assisted reprecipitation (LARP)
 - method 54, 55, 81
 - light emission of halide perovskites
 - charge carrier recombination 338–341
 - dynamics measurement techniques 337
 - lead halide perovskites

- bimolecular recombination
 - 334–335
 - excitonic systems 336–337
 - lasing 341–345
 - monomolecular recombination
 - 331–334
 - light emitting devices 21, 87, 342, 345
 - light-emitting diodes (LEDs) 2, 6, 9,
 - 38–41, 49, 101, 123, 125, 165, 345,
 - 351, 365, 425, 443
 - light soaking 340
 - linear dynamic range (LDR) 29, 30, 127
 - local density approximation (LDA) 220
 - longitudinal acoustic (LA) 266
 - longitudinal optical (LO) phonons 266
 - loss of cold carriers 279–280
 - low-angle annular dark field (LAADF)
 - 399, 402, 462, 467
 - low-dimensional halide perovskites
 - applications of 101–103
 - structure of 80
 - low-dimensional perovskites 3, 79–80,
 - 83, 104, 106, 153, 154, 166, 168, 170
 - low-dimensional TPSC 147, 153–155
 - lowest unoccupied molecular orbital (LUMO) 158
 - low-resistance state (LRS) 43
 - low-temperature vapor-assisted solution process (LT-VASP) 152
- m**
- $\text{MA}_{1-x}\text{FA}_x\text{PbI}_3$ 402
 - MASnI_3 band structure 150
 - maximally localized Wannier functions (MLWF) 236
 - maximum power point (MPP) 153, 469
 - Maxwell-Boltzmann (MB) fitting method 271
 - Maxwell-Boltzmann (MB) distribution 271, 272
 - mechanochemical synthesis 55, 56
 - memristive property 6
 - memristors 4–6, 9, 41–43, 127, 130
 - Meniscus-assisted solution printing (MASP) 197–198
 - metal-halide perovskite (MHP) 165, 215,
 - 257, 263
 - crystal growth mechanism
 - basic growth theory 176–178
 - grain-coarsening theory 178–179
 - crystallization mechanism
 - influences on nucleation 176
 - nucleation theory 173–176
 - crystal structures and compositions
 - 2D MHPs 170–171
 - 3D MHPs 167–168
 - lead-free MHPs 168–169
 - five-step growth
 - from solutions 187–190
 - from vapor phase 190–192
 - microstructures
 - crystallographic orientations 173
 - GBs types 171–172
 - grain size and distribution 172–173
 - one-step growth
 - from solutions 180–183
 - from vapor phase 184–186
 - organic-gas dosing 201–203
 - post-deposition treatments
 - solvent annealing 200–201
 - vacuum-assisted annealing 201
 - scalable growth methods
 - blade coating 193–195
 - inkjet printing 199–200
 - Meniscus-assisted solution printing 197–198
 - slot-die coating 195–196
 - spray-coating 196–197
 - metal-insulator-metal (MIM) 42
 - metal-to-metal charge transfer (MMCT) 119, 121
 - methylamine (MA) gas 201
 - methylammonium (MA) 1, 2, 10, 36, 50,
 - 56, 64, 82, 115, 117, 147, 167, 196,
 - 223, 289, 332, 358, 416, 465
 - methylammonium iodide (MAI) 82
 - methylammonium lead iodide (MAPbI_3) 196
 - methylammonium lead triiodide (MAPbI_3) 36

- microbeam X-ray diffraction (μ XRD) 453
 - microstructures
 - crystallographic orientations 173
 - GBs types 171–172
 - grain size and distribution 172–173
 - microwave-assisted synthesis 55, 56
 - Miller indices 413
 - Mn(II) dopant, in PNCs 65
 - Mn²⁺ doping 65
 - molecular dynamics (MD)
 - DFT 227–228
 - harmonic approximation 228–229
 - ion migration 229–231
 - molecular low-dimensional (non-ABX₃)
 - halide perovskites
 - 0D perovskites 83–88
 - 1D perovskites 88–90
 - 2D and quasi-2D 90–101
 - monocrystalline solar cells 34
 - monomolecular recombination 151, 331–334
 - morphological 2D nanoplatelets 82
 - morphological low-dimensional (ABX₃) perovskites
 - size reduction 79–80
 - structure tuning 80
 - synthesis and characterization
 - 0D quantum dots 80–81
 - 1D nanowires 81–82
 - 2D nanoplatelets 82–83
 - morphological low-dimensional halide perovskites 81
 - Mott–Gurney (MG) law 23
 - Mott–Gurney fitting equation 321
 - multimodal characterisation
 - atomic scale multimodal studies 462–464
 - beam damage 464–469
 - early work 445
 - facility access and data acquisition 471
 - image registration and sample fabrication 470–471
 - opportunities 471–475
 - resolution limits 469–470
 - strain and photophysics 453–462
 - subgrain features 450–453
 - multimodal techniques 471, 474
 - multiple exciton generation (MEG)
 - efficient MEG in perovskite 285–287
 - high multiple efficiency 291
 - low threshold 290–291
 - mechanism 283–289
 - metrics 281–283
 - photocharging and artefactual MEG signal 287–289
 - quantum yield 291–292
 - solar cells 296–298
 - spectroscopic signatures
 - photocurrent-based techniques 294–295
 - transient absorption spectroscopy 292–294
 - multiple exciton generation solar cell (MEGSC) 263–298
- n**
- nanobeam X-ray diffraction (nXRD) 453, 457
 - nanobeam X-ray fluorescence (nXRF) 456, 459
 - nanocrystals (NCs) 3, 49–71, 80, 81, 84, 86–90, 99–102, 125, 131, 192, 279, 337, 341, 429, 433, 473
 - nanocubes 54–59, 63, 64
 - nano-FTIR spectra 460, 461
 - nanoplatelets 3, 39, 54–59, 61–64, 81–83
 - nanowires 3, 39, 57, 59, 63, 81–82, 103, 352, 358, 359, 467
 - N-electron system 218, 231–233
 - neutral excitations 232, 240–242
 - noise equivalent power (NEP) 29, 30
 - nonradiative recombination 6, 39, 61, 70, 103, 121, 126, 151, 158, 318, 332, 334–337, 339, 340, 344, 389, 390, 393, 394, 425, 444–446, 450, 453, 454, 471

- nucleation theory 173–176
- nudged elastic band method (NEB) 229, 230
- o**
- OLEDs 39
- oleic acid (OA) 52–54, 56, 64, 69, 82
- oleylamine (OLA) 52, 53, 56, 63, 64, 69, 82
- oleylammonium bromide (OLAm-Br) 57
- 1D halide perovskites 81, 103
- 1D nanowires 3, 81–82
- 1D perovskites 20–21, 83, 88, 90, 91, 103
- one-step growth
- from solutions
 - drop-coating 182–183
 - spin-coating 180–182
 - from vapor phase
 - pulsed laser deposition 185–186
 - thermal evaporation 184, 185
- optically pump terahertz probe
- measurements (OPTP) 257
- optical spectroscopy 412, 423, 425–430
- optoelectronic devices 6, 83, 88, 101, 104, 118, 165, 200, 260, 329, 351, 353, 386, 411, 443
- optoelectronic properties 231–232
- electronic band structures
 - band gaps of solids 232–233
 - GW approach 233–235
 - predictive band structure 237–239
 - tight-binding perspective 235–237
 - optical properties
 - Bethe–Salpeter Equation approach 239–240
 - neutral excitations 240–242
- ordered–vacancy perovskite 133
- organic ammonium salt solution 187–189, 196
- organic competitors 39
- organic-gas dosing 201–203
- organic–inorganic perovskite 1, 2, 5, 166, 216
- organic semiconductor-incorporated perovskites (OSiPs) 99
- orthorhombic, lattice parameters 225
- p**
- Pb-based halide perovskites 10
- Pb-based perovskite SCs 11
- Pb-site dopants 68
- Pb toxicity 168
- (PEA)₂(MA)Pb₂Br₇ perovskite 94
- Perdew, Burke and Ernzerhof (PBE) 220
- perfluorooctanoic acid (PFOA) 69
- perovskite-based memristors 42, 130
- perovskite-based solar cells 6, 103, 123, 263
- perovskite-based thin-film transistor 321
- perovskite composition 313–315
- low-dimensional TPSC 153–155
 - three-dimensional TPSC 151–153
- types of 2
- perovskite film-based solar cells 5
- perovskite hot carrier solar cells
- cooling loss to lattice 277–279
 - energy selective contacts 279
 - loss of cold carriers 279–280
- perovskite nanocrystals (PNCs)
- B-site dopants 67
 - lanthanide doping 65–67
 - Mn²⁺ doping 65
 - postsynthesis doping 67–69
- perovskite, structure of 2–4
- phase segregation 156, 314, 318–320, 383, 384
- phenethylammonium 3
- phenyl-C61-butyric acid methyl ester (PCBM) 37, 158
- phenylethylamine (PEA) 94, 153
- phosphorus 126
- photobleaching (PB) 264, 270, 286, 292
- photobrightening 446, 447
- photocatalysis 7, 131
- photocharging 287–289, 293
- photocurrent-based techniques 294–295
- photo-Dember effect 358
- photodetection 29, 136

- photodetectors 29–30
 - UV detectors 128
 - X-ray detectors 128–130
 - photoemission electron microscopy (PEEM) 404–405, 456, 469
 - photoexcitation 254, 255, 265, 280, 315, 423, 457
 - photoluminescence (PL) 21–23, 38, 81, 91, 126, 272–274, 309, 337, 358, 382, 423–425, 428–430, 446
 - photoluminescence quantum yield (PLQY) 4, 50, 121, 151
 - photomultiplier tube (PMT) detector 382
 - photothermal induced resonance (PTIR) 309
 - photovoltaic (PV) 1, 4, 6, 7, 32, 33, 35, 37, 38, 49, 50, 67, 103, 118, 123–125, 127, 136, 147, 165, 203, 263–265, 275, 278, 279, 318, 320, 324, 329, 331, 336, 340, 342, 351, 361, 387, 392, 443, 447, 448, 452, 460, 473
 - phthalimide (PTM) 153
 - piezoresponse force microscopy (PFM) 394, 452
 - PL quantum efficiency (PLQE) 459
 - planar EBIC 389
 - polaron formation 266, 268–269, 335
 - poly[bis(4-phenyl)(2,4,6-trimethylphenyl)amine] (PTAA) 157
 - polydimethylsiloxane (PDMS) 35, 39
 - polymethylmethacrylate (PMMA) 81, 125
 - polymorphic networks 225
 - poly(vinyl alcohol) (PVA) 153, 155
 - postdeposition treatments
 - solvent annealing 200–201
 - vacuum-assisted annealing 201
 - post-synthesis defect-recovery 61–62
 - postsynthesis doping 67–69
 - powder X-ray diffraction (PXRD) 90
 - power conversion efficiency (PCE) 5, 37, 103, 115, 124, 147, 165, 263, 264, 275, 276, 278, 281, 299, 459
 - probing beam-sample interaction 435–436
 - projected density of states 235
 - projector augmented wave (PAW) 219
 - pseudocubic lattice parameters 226
 - pulsed laser deposition (PLD) 184–186
 - pulsed mode (PM) 386
 - pump–push–probe (PPP) spectroscopy 274
- q**
- quantum confinement effect
 - nanocubes 57–58
 - nanoplatelets 58–59
 - nanowires 59
 - quantum dots (QDs) 6, 50, 57, 58, 80–81, 101, 103, 279, 280, 283, 336, 342, 363, 365
 - quantum Monte Carlo calculations 220
 - quantum yield (QY) 4, 81, 183, 281, 291–292, 329, 338, 425, 433
 - quasi-Fermi level (qFL) 158, 271, 272, 276, 431, 445
 - quasiparticle (QP) 234, 266, 423
 - quasiparticle self-consistent GW (QPGW) 235
 - quasi-van der Waals epitaxy 351–353, 355, 358
- r**
- radiative emission 272, 335–337
 - random phase approximation (RPA) 235, 241
 - range-separated hybrid (RSH) 221
 - reduced graphene oxide (RGO) 131
 - relative humidity (RH) 131
 - resonant infrared matrix-assisted pulsed laser evaporation (RIR-MAPLE) 185, 186
 - responsivity 29, 103, 127, 128
 - retrograde solubility 19
 - rhombohedral (MA) 88, 89, 117, 149, 236
 - Roosbroeck–Shockley relation 334

- Ruddlesden–Popper (R-P) phase 3, 4,
20, 39, 93, 117, 132, 154, 170, 242
- S**
- scalable growth methods
blade coating 193–195
inkjet printing 199–200
Meniscus-assisted solution printing
197–198
slot-die coating 195–196
spray-coating 196–197
- scanning capacitance microscopy (SCM)
390
- scanning electron diffraction (SED)
404–405, 456, 460
- scanning electron microscopy (SEM)
310, 378, 379, 393, 446
- scanning probe microscopy (SPM)
methods 389
- scanning spreading resistance (SSRM)
390
- scanning transmission electron
microscopy 399, 402, 456, 462,
467
- scanning transmission electron
microscopy energy dispersive
X-ray spectroscopy (STEM-EDX)
456
- scanning X-ray Bragg diffraction
microscopy (SXDM) 456
- Schottky constant 306
- secondary electrons (SE) 380, 381, 465
- secondary-electron SEM 384
- Seebeck coefficient 361, 363
- seed-assisted method 15
- selected area electron diffraction (SAED)
379, 399, 402, 452, 465
- self-trapped exciton (STE) 69, 87, 88, 90,
125
- semiconductor crystals 16
- sequential vapor deposition 191, 192
- shape-controlling reaction
annealing time 63–64
capping-ligand role 64
temperature 63
- Shockley–Read–Hall (SRH) 332
- Shockley–Queisser (SQ) limit 147, 151,
263, 264, 275, 281, 324
- silicon photomultiplier (SiPM) 32
- single crystal structure
all-inorganic perovskite single crystals
13
lead-based perovskite single crystals
10–12
lead free perovskite single crystals 12
- single junction solar cell 263, 264, 275,
277, 280, 281, 398
- single metal $AB^{2+}X_3$ 116
- single-source thermal ablation (SSTA)
184
- single-source thermal evaporation
methods 185
- single-source vapor deposition (SSVD)
184
- singlet fission (SF) 280
- Slater–Koster approach 236
- slot-die coating 195–197
- slow evaporation method 17–19
- slow hot carrier cooling
Auger heating 268
hot phonon bottleneck 266–268
large polaron formation 268–269
spectroscopic signature of 269–274
- solid–solid technique 16
- solid-state grain growth 178, 179
- solution temperature lowering (STL)
method 15–16
- solution-processed halide exchange
59–60
- solvent annealing 166, 200–201
- solvent–solute system 14
- space-charge-limited current (SCLC)
23–26, 321
- spectroscopic signatures
photocurrent-based techniques
294–295
transient absorption spectroscopy
292–294
- spin-coating method 87, 180, 186–190,
192, 196, 360

- spin-orbit coupling (SOC) 120, 236, 366
 - spiro-OMeTAD 34, 35, 128, 157, 197, 251, 258–260, 322
 - spray coating method 196
 - steady-state photoluminescence (SSPL) 274
 - steady-state technique 23
 - stimulated emission depletion (STED) 469
 - strain engineering
 - experimental progresses 363–365
 - theoretical progresses 361–363
 - Stranski–Krastanov model 177
- t**
- tailoring metal halide film morphology 188
 - temperature-dependent XRD 23
 - terahertz spectroscopy 251, 283
 - TFT devices 321–322
 - 3D MHPs 167–168
 - 3D corner-sharing cuboctahedra 10
 - 3D Cs-based perovskites 88
 - 3D cubic perovskite 2
 - thermal evaporation 184, 185, 398, 462
 - thermal relaxation 280
 - thin film and nanostructures
 - epitaxial substrates 353–354
 - experimental progresses 358–360
 - growth and mechanisms 355–357
 - thin film single crystals (TFSC) 34, 38
 - thin-film solar cells 10, 148
 - three-dimensional TPSC 151–153
 - time-of-flight secondary-ion mass spectrometry (ToF-SIMS) 322, 339, 447
 - time-resolved microwave conductivity (TRMC) 251–254, 259, 263
 - time-resolved PEEM (TR-PEEM) 457, 469
 - time-resolved photoluminescence (TRPL) 22, 23, 81, 253, 270, 272, 273, 283, 309, 337, 435, 446, 454
 - tin halide perovskite solar cells
 - crystallization regulators 155
 - deoxidizers 156
 - interfaces passivating materials 156
 - tin perovskite properties
 - band structure and oxidation 149–151
 - crystal structure 148–149
 - electrical properties and defects 151
 - TPV 21–23
 - traditional phosphor screen 391, 392
 - transient absorption microscopy (TAM) 456, 459, 469
 - transient absorption spectroscopy (TAS) 264, 270–272, 292–294, 337, 338
 - transient photocurrent (TPC) 294
 - transmission electron microscopy (TEM) 390–391
 - applications of 402–405
 - beam damage 400–401
 - glass substrates 405–406
 - imaging conditions 398–400
 - sample preparation and transfer 395–398
 - transparent conducting oxide (TCO) 124
 - transverse optical (TO) 267
 - trap density vs. mobility values 26
 - trap-filled limit voltage (V_{TFL}) 24, 321
 - TripleCat films 427
 - twinned crystal 451
 - 2D and quasi-2D perovskite crystals 90–103
 - 2D Dion–Jacobson (DJ) 4, 96
 - 2D MHPs 170–171
 - 2D nanoplatelets 3, 64, 82–83
 - 2D perovskite
 - artificial synapse 42
 - single crystals method 20–21
- u**
- ultrafast photoluminescence techniques 272
 - ultrafast spectroscopy 99, 269
 - Urbach energy 344, 429, 458, 459
 - utilizing hot carriers, halide perovskites 275–280
 - UV detectors 128
 - UV-vis absorption 21–23, 55, 427

V

- vacancy-ordered double perovskite 12, 69, 132–135, 168, 169
- vacancy ordered perovskites
 - $A_2B(II)B_2(III)X_{12}$: B(II), B(III) substitution + vacancies 135
 - $A_2B(IV)X_6$: B(IV) substitution + vacancies 134
 - $A_3B(III)X_9$: B(III) substitution + vacancies 135
- vacuum-assisted annealing 201
- valence band maximum (VBM) 118, 149, 237, 332, 452
- valence electrons 149, 220, 382
- Vallée–Bogani decay channel 266, 267
- van der Waals epitaxy 351–353, 355–359, 363, 365
- van der Waals interactions 90
- vapor-assisted solution process (VASP) 152, 190–191
- vapor-based perovskite thin film deposition 184
- vinylbenzylammonium (VBA) 420
- virtual bright field (vBF) 405, 466
- Volmer–Weber model 177
- voltage–time (V–t) curve 319

W

- Wannier–Mott excitons 423
- Wannier–Mott model 241, 242
- Warburg-like coefficient 26
- white LEDs (WLEDs) 125, 126

X

- X (γ)-ray excited luminescence (XEL) 32
- X-ray detection 30, 129
- X-ray detectors 7, 30, 101, 128–130, 443
- X-ray diffraction (XRD) 10, 11, 94, 117, 223, 225, 310, 358, 390, 413, 415, 420, 450
- X-ray direct detectors 444
- X-ray fluorescence (XRF) 389, 412, 413, 416, 420, 431
- X-ray scattering and fluorescence techniques
 - fundamentals of 412–413
 - grazing incidence wide-angle X-ray scattering 413–415
- in situ GIWAXS
 - crystallization kinetics and A-site doping 416–418
 - 2D/3D interface formation 420–423
 - X-ray fluorescence 416
- X-ray sources 435, 450
- X-ray spectroscopy (EDS) 340, 378, 381, 460

Z

- Zeldovich factor 18, 97
- 0D Cs-based perovskites 88
- 0D perovskites
 - cesium lead halides 87–88
 - synthesis and properties of 83–87
 - synthesis methods for 86
- 0D quantum dots 80–81

