Index

a

AC/DC dual drive mode QDLED
  advantages 245
  disadvantages 245
  energy band diagram 250
  optimization
    carrier balance 256
    charge injection 255–256
    device structure 255
    electrical and optical properties 256
    QD materials 255
  structure 249, 250
  working mechanism 244
AC-driven QDLEDs, future research directions for 256
AC electroluminescence (ACEL) 237
active matrix QDLED (AM-QDLED) 19, 134, 143, 329
aerogel quantum dot film 343
Ag–Au–Se (AgAuSe) quantum dots 176
aging-induced enhancement 272
aging mechanism in QDLEDs 271–277
all-inorganic QDLED devices 25, 98, 122
allowed bands 37
alloy core–shell quantum dots 64–65
alloyed ZnCdSSe quantum dots 112
alternating current (AC) driven QDLEDs 235
  advantages 235, 246
  double-emission tandem structure mechanism 239–245
  drawbacks 236
  dual dielectric layer structure 236
  luminescence principle 236–239
  optimization strategies
    AC signal optimization 246
    device engineering 245–246
    hybridization with other materials 246
    QD material optimization 245
    structural modification 246
    surface modification 246
  structure and operating mechanisms 236–238
angle-resolved XPS 74
anharmonic oscillator model 74
asymmetric AC QDLEDs 244
atomic force microscopy (AFM) 278, 287, 303
Auger effect 64
Auger recombination 19–21, 270, 271

b

band engineering strategies, in InAs-based QDs 64
Beijing Oriental Electronics Group Co., Ltd (BOE) 347–351
binding rules, nanocrystals *vs.* ligands 66
bis-benzophenone based cross-linkers 314
blue CdSe/ZnS quantum dots 26, 146
blue CdZnSe/ZnSeS/CdZnS core–shell quantum dots 338
blue QDLEDs 141
  bad/poor performance factors of 141, 142

Colloidal Quantum Dot Light Emitting Diodes: Materials and Devices, First Edition. Hong Meng.
© 2024 WILEY-VCH GmbH. Published 2024 by WILEY-VCH GmbH.

blue QDLEDs (*contd.*)
based on AlSb 155
based on Cu 153–155
based on InP 149–151
based on ZnSe 151–153
with cadmium-free quantum dots 149–155
challenges for 167
charge transport layer optimization 155–164
containing cadmium quantum dots 145–149
current density and brightness 147
devices based on cadmium-containing quantum dots
advantages 148
challenges 148–149
device structure 164–166
external quantum efficiency of 144
luminescent materials 143–155
problems of 166–167
stability studies of 260
technology development breakthroughs 144–145
with ZnMgO/Al/HATCN/MoO_3 interconnection layer 147
blue ZnSeTe ternary quantum dot devices, luminescence spectra of 217
bottom-up method, QD preparation 3
Bragg's law 77, 79
Br^- QDLED 127
brush process 47, 48
bulk semiconductor 20
bandgap 16
physical parameters 9
physical properties 8

C

cadmium-based core/shell QDs 63
cadmium-containing yellow light quantum dots 189, 190
cadmium-free blue QDLED 144
cadmium-free InP/ZnSe/ZnS core–shell structured quantum dots 331
cadmium-free QDLEDs
performance parameters of 207
structure and performance of 209
cadmium-free quantum dots
I-III-VI quantum dots 218–222
indium phosphide 208, 215
QDLED performance optimization methods 222
device structure optimization 225–227
ligand engineering 223–225
shell engineering 224–227
ZnSe 215, 217–218
cadmium-free yellow light quantum dots 189–193
cadmium-free $ZnSe_{1-x}Te_x$/ZnSe/ZnS core–shell quantum dots 330
cadmium-free ZnSe/ZnS core–shell quantum dots 151
calixarene $CsPb(Br_xI_{1-x})_3$ quantum dots, high purity yellow light emission from 191
carbon dots 17
carbon-13 NMR 69
carbon quantum dots 17
cation exchange 180
$CdCl_2$-aliphatic amine complexes 59
CdSe bulk material 89
CdSe/CdS-$Cd(RCOO)_2$ quantum dots, photoluminescence and electroluminescence properties of 8
CdSe@CdS dot/sheet core–shell structured quantum dots, UV–Vis absorption/fluorescence emission spectra of 70
CdSe/CdS quantum rods, absorption and emission spectra of 10
CdSe/CdS-RNH_2 quantum dots, photoluminescence and electroluminescence properties of 8
CdSe/CdS/ZnS colloidal quantum dots 51
CdSe/CdS/ZnS core–multishell quantum dots 262

$CdSe/Cd_{1-x}Zn_xSe_{1-y}S_y/ZnS$ alloy quantum dots, chemical composition and energy band structure of 97
$CdSe/Cd_{1-x}Zn_xSe_{1-y}S_y/ZnS$ QDs 13
CdSe nanocrystals
  solubility of 66, 93
  TEM image of 9
  UV–Vis and PL spectra of 52
  XRD patterns of 56, 57
CdSe quantum dot 15
  original ligands for 90
  patterns, by inkjet printing 367
CdSe quantum sheets, absorption and emission spectra of 10
CdSe/ZnS/CdSZnS quantum dots 121
CdSe/ZnS core–shell quantum dots 95, 200
  type I and type II 11, 12
CdSe/ZnSe core/shell structure based QDLEDs 26
CdSe@ZnS light-emitting diodes 312
CdSe/ZnS quantum dots, absorption and emission spectra of 10
CdSe/ZnS thick-shell quantum dots 127
CdSeZnS/ZnS/ZnS quantum dots 118, 122
$CdSe/Zn_{1-x}Cd_xS$ quantum dots
  photoluminescence/electroluminescence performance *vs.* shell thickness 262
CdTe bulk material 89
CdTe/CdSe II QD 178
CdTe quantum dots 15
  for white light-emitting diodes 189
$Cd_{1-x}Zn_xSe$ QDs 112
4-CF3-BA self-assembled monolayer 319
chalcogenide cadmium quantum dots 177–178
chalcogenide lead quantum dots 176–177
chalcopyrite CIS quantum dots 221
charge transport layer
  optimization, blue QDLEDs 155–164
  in QDLED performance 125
charge transport mechanism, in QDLEDs 292–293
charge transport properties, of quantum dot films 94
China Star Optoelectronics Technology (CSOT) 344–347
CIE chromaticity diagram, boundary of 33
CIGS quantum dots 153
CIGS/ZnS QDLEDs 154
CIS quantum dots 221–223
CIS/ZnS/ZnS quantum dots 191
Cl-passivated tungsten phosphate (Cl-TPA) 308
CNPr-TFB hole transport polymers 158
colloidal CdSe/CdS core/shell nanosheets 123
colloidal QDLEDs 33
  color purity 33–34
  solution processability 34
  stability 35–36
colloidal quantum dots 53
  direct heating method 55–56
  future development challenges 80–81
  hot injection method 54–55
  ligating and non-ligating solvents 56–58
  liquid phase methods 53
  nucleation and growth mechanism 58–59
  physical vapor phase epitaxial growth methods 53
  precursor chemistry of 56, 57
  size distribution
    focusing principle 59
    scattering 60
  surface chemistry of
    covalent bond classification method 65–66
    entropic ligands 66
colloidal semiconductor nanocrystals 1
color purity 33–34
color-tunable CIS quantum dots 221
color-tunable QDLEDs 200

composite ZnMgO:ZnO electron transport layers 296
conducting carriers, in semiconductors 38
conduction band 37–39, 62, 91, 95, 120, 241
continuously graded $CdSe/Cd_xZn_{1-x}Se/ZnSe_{0.5}S_{0.5}$ QDs 14
conventional *vs.* inverted QDLEDs 123
core–shell quantum dots 15
  alloy 64–65
  cadmium-free ZnSe/ZnS 151
  non-alloyed 63
  ZCGS/ZnS 222
core–shell structure 8–12
  NIR quantum dot control 180
covalent bond classification (CBC) method 65–66
crystal growth rate *vs.* size, Sugimoto model 59
Cu-based quantum dots 153–155
Cu-doped NiO-based QDLED 317
$CuInS_2$-ZnS/ZnSe/ZnS QD device, fluorescence emission spectra and electroluminescence spectra of 219
current–voltage (IV) measurements 278, 296

d

differential absorption spectroscopy 283–285
1,4-dioxane polar solvent 166
dip coating process 47, 48
direct current (DC) driven QDLEDs 235
  device structure 235, 239, 245, 250
    anode 42
    cathode 42
    electron buffer layer 42
    hole buffer layer 42
    light-emitting layer 42, 43
  luminescence principle 236–239
  structure and operating mechanisms 236, 238
direct heating method 55–56
directional attachment, of nanocrystals 60, 62
displacement current measurement (DCM) technique 285–286
DMATP-QDLED 128
doping 130, 295
  of HTMs 301, 303, 305–309
double heterojunction device, energy level diagram of 179
double-insulated AC-QDLED device 239, 240
double-shell InGaP/ZnSeS/ZnS QDs 151
double-stacked ETMs 297–299

e

efficiency decay mechanism in QDLEDs 268–271
efficiency roll-off, QDLEDs 22, 118, 135, 270, 271, 283, 296
electro-absorption (EA) spectroscopy 281–282
electrohydrodynamic jet (E-jet) printing 368, 369
electrohydrodynamic jet-sprayed process 47, 48
electroluminescence (EL) spectroscopy 278
electroluminescent device 334–335, 341
electroluminescent quantum dot devices (ELQDs) 240
electron communalization movement motion 37
electron diffraction 76
electron injection materials, for QDLED 299
  conductive polymers 300
  conjugated polyelectrolytes 300
  graphene 300
  graphene oxide 300
  lithium fluoride 300
  metal oxides 299–300
  nanoparticles 300
  organic materials 300
  surface dipolar polymers 301

titanium dioxide 300
zinc sulfide 300
electron spectroscopy for chemical analysis (ESCA) 74
electron transport layer (ETL), QDLEDs 161, 164
ageing and degradation 274
energy level alignment 275
interface issues 274
stability 274
electron transport materials (ETMs), QDLEDs 265, 266, 293
composite material design 296
development breakthroughs 297
device performance data 297, 299
double-stacked ETMs 297–299
inorganic organic hybrid ETMs 296–297
metal-doped 293–295
metal salt doped 296
polymer-modified ETMs 296
embryonic nuclei-induced alloying process 145
emission wavelength range, of NIR QDs 174
empty band 37
energy band diagram, of multi-layer QDLED device with poly-TPD 157
energy bands
of an insulator 38
of conductor 37, 38
of semiconductor 38
energy design strategy, $CdSe/Cd_{1-x}Zn_xSe/ZnSe$ quantum dot synthesis 97
energy level
alignment 36, 40, 156, 275, 305, 310, 311, 314
and bands 36, 37
energy level diagram
of common CTLs for InP quantum dots 228
of different electron transport layers 220
of double heterojunction device 179
of molecular, quantum dot and bulk semiconductor materials 1, 2
quantum dots
with different shell layer thickness 221
Ga doping effect on 220
entropic ligands 34, 66, 93
equivalent circuit, of sandwich AC-driven EL device 239
European Union's Restriction of Hazardous Substances (RoHS) rules 207
eutectic indium–gallium (EGaIn) 114, 132
exciton decay 125
exciton formation in QDLEDs 43
external quantum efficiency (EQE) 44, 269
of double-junction green QDLEDs 141

f

Fermi Dirac statistics 39
Fermi distribution function 39
Fermi energy level 4, 5, 39, 268
field-driven AC QDLEDs
dielectric layer optimization 248–250
quantum dot layer optimization 250–251
field-generated AC QDLEDs 240, 241
field-induced AC QDLEDs 247
AC voltage optimization 247
carrier balance control 247
device fabrication and packaging process 247
device structure optimization 247
engineering dielectric layers 247
quantum dot properties, optimization of 247
surface passivation 247
fluorescence electrophoresis 22
fluorescence intermittence 21
fluorescence intermittency 5, 21
fluorescence lifetime 10, 67
of CdSe/ZnS quantum dot film 201

fluorescence lifetime (*contd.*)
of colloidal QDs 68
fluorescence quantum yield 10, 36, 45, 79, 112, 113, 135, 151, 225
fluorescence resonance energy transfer 19, 21–22
fluorescence spectroscopy 66–68
fluorescent carbon nanomaterials 17
forbidden band 37–39, 94, 95
Forster energy transfer 36
Förster resonance energy transfer (FRET) 21, 24, 96, 114, 125, 149, 196, 212, 224
Fourier transform infrared spectroscopy (FTIR) 71, 74
free electrons and holes, in semiconductors 38–39

g

giant quantum dots 12
graphene oxide (GO)/poly(3,4-ethylenedioxythiophene):poly (4-styrenesulfonate)(PEDOT:PSS) bi-layered HIL 319
green QDLEDs
device doping with nickel oxide (NiO_x) 307
device performance improving strategy 132–134
device structure development 122–125
EQE development 114, 118, 119
lifetime and stability of 135
performance affecting factors 125–134
device structure optimization 130–132
QD core/shell structure 129–130
QD ligand effect 126–128
with PFI and Cu–NiO hybrid HTL 309
stability studies of 260
technology development breakthroughs 118, 120
works on 115

h

half-field driven half-injected AC QDLEDs
charge generation layer optimization 254
optimization strategies
device structure optimization 252
driving voltage and frequency 252
electrode materials optimization 252
injection layer optimization 252
quantum dot size and composition 252
P(VDF-TrFE-CFE) dielectric layer 252
tandem structure 254–255
half-field to half-injection (HFHI) AC QDLEDs 242
advantages 242
vs. asymmetric AC QDLEDs 244
device structure 242
disadvantage 242
working mechanism 242
half-life of QDLEDs 164
^{1}H-^{13}C DIPSHIFT results and opening angles 73
hexadecylamine (HDA) 90
high-efficiency orange–yellow QDLEDs 200
high-resolution transmission electron microscopy (HRTEM) 76
^{2}H NMR lineshapes and chain flexibility 72
hole injection materials (HIM), for QDLED 316
hole mobility 135, 167, 229, 263, 276, 296, 301, 303, 305–307, 309, 312, 319
hole transport layer (HTL), QDLED 156–161, 263, 265
ageing and degradation 275–276
hole transport materials (HTMs), for QDLED 301–315
advanced characterization techniques 303
bio-based HTM 311

challenges 304
compositions 309–311
composition strategy 305
conductive polymers 311
copper 311
development breakthroughs 319
device performance data 319
doping 301, 303, 305–309
graphene-based materials 311
interface engineering 301
metal-organic frameworks 304
molecular design 301
molecular self-assembly 303
polymer-based 303
solution-processed HTMs 312
homogeneous transfer 22
hot-electron impact excitation principle 239
hot injection method 54–55
hot injection synthesis method 59
hybrid nanocrystal-organic light-emitting device (NC-OLED) 178
hybrid organic/colloidal QDLEDs 21
hybrid QDLEDs 122, 200, 275
hydroxyl-capped CIS quantum dots 223

i

ICL-ZnMgO/Al/HATCN/MoO_3 tandem QDLED 125
I-III-VI quantum dots 218–222
II–VI semiconductor QDs 16
II_3–V_2 semiconductor QDs 17
InAs/CdSe core/shell QDs 64
InAs QDs 15, 64, 65
indium phosphide (InP) quantum dots 208, 215
InGaN-based blue-emitting chips 195
InGaN LED chips, photoluminescence spectra of 190
injection luminescence principle 42
inkjet printing (IJP) 47, 48, 366–368
inorganic multilayer thin-film QDLEDs 250
inorganic organic hybrid ETMs 296–297
InP quantum dots 207
InP/ZnS core–shell quantum dots 151, 189
InP/ZnSeS/ZnS quantum dots 151, 196, 266
InP/ZnS small core–shell tetrahedral QDs 149
in-situ EL–PL measurement technique 282–283
interfaces energetics 36
interfacial corrosion phenomenon, in tandem QDLEDs 124
internal quantum efficiency (IQE) 44, 102
inverted blue QDLED preparation 166
inverted QDLED 131, 255, 308, 364
vs. conventional 123
current density EQE characteristic curve of 165
device structure 102, 103, 364
ITO/MoO_x/NiO_x/Al_2O_3/QDs/ZnO/Al device 123
ITO/NiO/Al_2O_3/ZnCdSSe/ZnS QDs/ZnO/Al, all-inorganic green QDLEDs of 122
ITO/PEDOT/PSS /TFB/QDs/ZnO/Al 113
ITO/ZnO/CdSe@ZnS/ZnSQDs/PEIE/Poly-TPD/MoO_x/Al device structure 131
ITO/ZnO/PEIE/QDs/CBP/MoO_3/Al inverted device structure 102
IV–VI semiconductor QDs 17

j

Janus quantum dots 15, 16

l

LaMer diagram 53, 58
laser direct writing 368–369
layer printing methods 47
lead chalcogenide IV–VI semiconductor QDs 17
lead oleate 177
lead sulfide (PbS) quantum dots 15, 177, 182

LiF interface layer 162
ligand engineering 262
  cadmium-free quantum dots 223–225
  NIR quantum dot regulation 179–180
ligand-induced surface dipoles 94
ligand selection, in QD conductivity 34
ligating and non-ligating solvents 56–58
light-emitting characteristics, of QDs
  optical property 4–8
  particle size and emission color 3
liquid dispersed quantum-dots ion-beam deposition (LIQUID) 250
liquid-type QDLEDs 193
luminescence spectra 198, 199, 211
  of blue ZnSeTe ternary quantum dot device 217
  of I-III-VI quantum dots 218
luminescent layer materials, in green QDLEDs 120
  alloyed core/shell quantum dots 121
  core/multilayer shell quantum dots 121–122
  discrete core/shell quantum dots 120–121
luminous life, defined 45
luminous lifetime 45–46, 48

m

magic nanoclusters 59, 60
material characterization techniques for quantum dots 66
  Fourier transform infrared spectroscopy 71–74
  nuclear magnetic resonance spectroscopy 69–71
  SAXS 76–77
  transmission electron microscopy 76
  UV–Vis absorption and fluorescence spectroscopy 67–69
  WAXS 76–77
  XAFS spectroscopy 78–79
  X-ray diffractometer 77
  X-ray photoelectron spectroscopy 74–75
mercaptopropionic acid (MPA) 90
3-mercaptopropyl trimethoxysilane (MPTMS) 90
11-mercapto-undecanoic acid (MUA)-modified NiO nanoparticles, as hole transport layer 307
metal-doped ETM 293–295
metal oxide ETLs 272, 275
metal salt doped ETMs 296
metal-sulfide nanocrystals, stoichiometry and ligand exchange of 65
Mg-doped ZnO electron transport materials 296
micro-contact transfer (MCT) 363–366
MicroLED device 346
MicroLED display technology 329
mixed nanocrystal–organic light emitting device, structure and emission spectrum of 179
molar extinction coefficients, of CdX nanocrystals 67
molecular energy calculations 60
molecular orbital energy level diagram 1
monodisperse Ag_2S QDs 55
monodisperse quantum dots 51
MoO_3-doped PEDOT:PSS hole transport layer 306
MoO_3/TFB hole-generating layer 254
multicolor fluorescent LEDs based on cesium-lead halide chalcogenide QDs 191
multilayered QDLED device structure 311
multilayer structure of InP/ZnS QDLED 150

n

Najing Tech 338–344
Nanoco 335–338
nanocrystals
  CdSe (*see* CdSe nanocrystals)
  colloidal semiconductor 1
  crystalline seed-mediated growth 60
  directional attachment growth of 60, 61

semiconductor, 1
silicon 178
two-dimensional 61
ZnOS/ZnO 340
nanostructure engineering 162
Nanosys 330–332
near infrared (NIR) quantum dots
chalcogenide cadmium quantum dots 177–178
chalcogenide lead quantum dots 176–177
classification of 173
control of 180
developments and device performance data 176
light-emitting diodes 27
material optimization 179–182
materials 174
regulation of 179–180
silicon quantum dots 178–179
negative ageing effect, QDLEDs 273, 274
NiO-based QDLED 123
NiO_x–BA–CF3 films 317, 318
non-alloyed core–shell quantum dots 63
non-cadmium quantum dot light-emitting materials and devices 207
characterization and understanding 230
environmental impact studies 230
new material development 229
research directions 229–230
technology development 208
non-coordinating solvents 57
non-metallic inorganic ligands 34
non-passivated S-sites 91
nuclear magnetic resonance (NMR) spectroscopy 69–71
nuclear-shell quantum dots, synthesis methods and band gap regulation engineering of 61–65

o

1-octadecene (ODE) 58, 177
oil-soluble quantum dot 193
OLED technology 259
oleic acid (OA) 177
one-dimensional-quantum wires 2
one-pot colloidal synthesis method, for high-quality CdS nanocrystals 55
one-pot scheme, core/shell QD synthesis 63
orange-yellow QDLEDs 201
organic/inorganic hybrid construction, of V_2O_5/ PVK heterojunctions 309
organic/inorganic hybrid QDLED device structures 122
Osher composite process 224, 227
Ostwald ripening 60
ozone plasma treatment 268

p

passivation of quantum dots 4, 89, 255, 277, 336
patterning techniques, for QDLED 361
electrohydrodynamic jet printing 369
inkjet printing 366–368
laser direct writing 368
micro-contact transfer 363–366
photolithography 361–363
self-assembly methods 369
PbS/CdS quantum dots with core–shell structure 175, 180
PbS quantum dots 15
fine band energy calibration of 94
PbX QDs based on NIR–QDLEDs 175
PEDOT:PSS/V_2O_x-bi-layered-HIL devices 319, 320
perfluorinated inomer (PFI) 308, 310
perovskite QDs 15, 174
phosphine-free method 113
phosphomolybdic acid (PMA) 166, 319
photoconductivity measurements 278
photoexcitation theory 236
photolithography 48, 361–363, 368
photoluminescent device 193, 333
poly(3,4-poly (3,4-ethylenedioxythiophene):poly(styrene-sulfonate) (PEDOT:PSS) 316
poly(9-vinylcarbazole) (PVK) 113, 118, 304

poly-[(9,9-bis(3′-(*N,N*-dimethylamino) propyl)-2,7-fluorene)-*alt*-2,7-(9,9-ioctylfluorene)] (PFN) 301
poly((9,9-dioctylfluorenyl-2,7-diyl)-alt-(9-(2-ethylhexyl)carbazole-3,6-diyl)) copolymer 315
poly(indenofuorene-*co*-triphenylamine) copolymer (PIF-TPA) 312, 313
polyethoxy polyethyleneimine (PEIE) modified conventional ZnO layers 296
polymer-mediated QD assembly strategy 197
polymer-modified ETMs 296
poly [2-methoxy-5-(2′-ethylxyloxy)-1,4-phenyl vinyl] (MEH-PPV) matrix material 181
poly(3,4-ethylenedioxythiophene): poly(styrene sulfonate) (PEDOT:PSS) 305
poly-TPD 146, 156, 157, 211, 215, 304–306
positive aging effect, in QDLED 272–273
precursor chemistry 55, 56
proton NMR 69
PVK/poly-TPD bilayer 309
pyridine-treated CdSe nanocrystals, NMR spectra of 71

q

QDiP structure simulation 182
QDiP system 181, 182
quantum confinement effect 5, 7, 8, 12, 27, 68, 141, 149, 151, 153, 155
quantum dot display industry 328
  chain 329
  patent layout
    BOE 347–351, 354
    CSOT 344–347
    Najing Tech 338–344
    Nanoco 335–338
    Nanosys 330–332
    SAMSUNG Group 332–335
    TCL 351–354
quantum dot-enhanced liquid crystal display (QD-LCD) 143, 327, 329, 330, 351
quantum dot enhancement film (QDEF) 330, 349, 355
quantum dot light-emitting diodes (QDLEDs) 18, 259
  advantages 235
  ageing and degradation, QD layer impact 276–277
  aging mechanism 271–277
  anode-interface regulation layer 267
  basic structure of 18–19
  cathode-interface regulation layer 267
  characterization technologies for 278–286
  charge transport mechanism 292–293
  commercialization challenge 19
  common materials for functional layer 262
  with Cs_2CO_3/Al cathode and MoO_3/Alq_3 anode 267
  current density-voltage and luminous intensity-voltage curves 265
  development, history of 22–27
  device structure
    conventional 99, 102
    inverted 102
    and performance 100
    tandem 102
    Type I 98
    Type II 98
    Type III 98
    Type IV 98–99
  efficiency and stability of 291
  efficiency decay mechanism 268–271
  electronic transport layer 265–267
  EQE-current density curves 265
  factors affecting light emission 19
    Auger recombination 19–21
    fluorescence resonance energy transfer 21–22
    surface traps and field emission burst 22
  hole transport layer 263–265

with InP/ZnSe/ZnS quantum dots 99
performance degradation causes of 125
performance with WO_3 nanoparticles *vs.* PEDOT:PSS as anode interface layer 268, 269
QD light-emitting layer 261–263
stability
factors affecting 261–268
structure 261
types of 235
working mechanism 261
quantum dots (QDs) 51
application on display devices 18–27
classification 111
with direct white light emission 197–200
display technology 327
energy spectroscopy 197
feature of 10
fluorescence quantum yield measurement 79
ink 347
ligand engineering 92
light-emitting characteristics of
continuously gradated core–shell structure 12, 14
core-shell structure 8–12
optical property 4–8
particle size and emission color 3
materials and their properties 14–17
in matrix 181
photoluminescent display products 327
preparation route of 3
QD-OLED 329
for white LEDs 188–200
quantum dots light-emitting diodes (QDLED)
device fabrication process 48
operating parameters
current efficiency 45
luminescence color 45
luminous brightness 44
luminous efficiency 44
luminous lifetime 45–46, 48
power efficiency 45
quantum efficiency 44–45
turn-on voltage 44
structure of 41–43
working principle of
carrier injection 43
carrier transport 43
exciton formation 43–44
radiative recombination of excitons 44
quantum optical properties 6, 8
quantum size effect 1, 4, 5
quantum surface effect 4
quantum tunnelling effect 5, 6

r

red QDLEDs
ageing of 275
alloy core–shell structure 96–97
breakthrough technology developments 87, 88
challenges 103, 104
core–shell structure 94–96
device architecture development 97
with double-hole transport layer 310
external quantum efficiency development 87, 88
fluorescence emission range 89
materials 88–97
PIF-TPA as HTL in 312
stability studies of 260
structure design and optimization range 90–91
surface ligands on 91–94
research directions, QDLED degradation and aging 287
RGB color space parameters 46

S

SAMSUNG Group 332–335
sandwich AC-driven thin film electroluminescent (AC-TFEL) device 239
Scherrer's formula 77

Schottky barrier 39, 40
scintillation phenomenon of quantum dots 21
selected area electron diffraction (SAED) technique 77
self-annihilation of quantum dots 181
self-assembly methods 369
self-quenching 21
semiconductor nanocrystals 1, 51, 57, 188, 332, 335
Se-ZnSe colloidal quantum dots, UV–Vis absorption spectrum of 69
shell engineering 114, 118, 130, 134
  cadmium-free quantum dots 224–227
SILAR (sequential ion layer adsorption and reaction), core/shell QD synthesis 63
silicon nanocrystals 178
silicon quantum dots 15, 17, 178–179
single-layer quantum dot light-emitting device 41
single light-emitting white light devices 188
SiO_2 CQDs in perovskite matrix 181
slow dropping, core/shell QD synthesis 63
small-angle X-ray scattering (SAXS) 67, 76–77
solid-state ligand exchange process 179, 180
solid-state nuclear magnetic resonance (SSNMR) techniques 71
solubility of CdSe nanocrystals 66, 93
solution ligand exchange process 179, 180
solution NMR spectroscopy 70
solution-prepared inverted QDLEDs 122
solution processability 33, 34
  of colloidal quantum dots 66
solution-processed method 48
solution-processed QDLEDs 25, 27, 48, 200, 314
solvent-resistant blended HTL 315
spin-coating process 47, 48
stability 35–36
surface-adsorbed H_2S 91
surface chemistry, of colloidal quantum dots
  covalent bond classification method 65–66
  entropic ligands 66
surface dipolar polymers 301
surface ligand modification 87, 90, 91
surface passivation 61, 176, 201, 247, 287, 328, 336
surface states, of quantum dots 36

t

tandem QDLED device structure 102
tandem WQDLEDs 196
TCL 351–354
TC-SP (thermocyclically coupled single precursor), core/shell QD synthesis 63
ternary I–III–VI_2 chalcopyrite semiconductor QDs 17
tetradecane 57, 58
2,2′,7,7′-tetrakis[*N*-naphthalenyl(phenyl) amino]-9,9-spirobifluorene (spiro-2NPB) 309
TFB-BP polymer synthesis and photocross-linking 314
thermal spin-coating technique 310
thick-shell structured $Zn_{1-x}Cd_xSe$/ZnS core/shell quantum dots 130
thioglycolic acid (TGA) 90, 332
three base color quantum dot composite 193–197
3D cluster-based bcc single supercrystals 78
time-resolved fluorescence spectroscopy 68
time-resolved photoluminescence (TRPL) 278, 287
top-down method, QD preparation 3
transient electroluminescence (EL) 278–281
transient fluorescence spectra 68, 70

transmission electron microscopy (TEM) 7, 67, 76, 278
tricolor QDs@Psi powders 197
tri-*n*-octylphosphine (TOP) 127
tri-*n*-octylphosphine oxide (TOPO) solution 54
trioctylphosphine oxide 56, 90, 339
tris (4-carbazoyl 9-ylphenyl) amine (TCTA) 158
two-dimensional nanocrystals 59, 61
two-dimensional quantum sheets 2
type I and type II CdSe/ZnS core–shell quantum dots 11, 12
type I core–shell structure 95
type II core–shell QDs 95
type II core–shell structure 95

u

ultra HD quantum dot TV sets 51
ultra-thin 1,3,5-tris(1-phenyl-1*H*-benzimidazol-2-yl)benzene (TPBi) interface layer 264
UV–Vis absorption spectroscopy 66–69

v

vacuum evaporation 132, 165
valence band 1, 3, 37–39, 62, 95, 120, 158
V_2O_5/PVK heterojunctions, as hole transport layers 308

w

white LEDs based on quantum dot photoluminescence mechanism 188
white QDLED based on CIS class 222
white quantum dot light-emitting diodes (WQDLEDs) 188, 195, 201–203
wide-angle X-ray scattering (WAXS) 67, 76–77

x

X-ray absorption fine structure (XAFS) spectroscopy 78–79
X-ray diffraction (XRD) 77, 278
X-ray diffractometer 77–78
X-ray diffractometry 77
X-ray photoelectron spectroscopy (XPS) 74–75

y

YAG hybrid phosphors, for white light-emitting diodes 189
yellow–blue composite white light quantum dots 189–193
yellow–green emitting $CuInS_2$ colloidal quantum dots 190

z

ZCGS/ZnS core–shell quantum dots 222
zero-dimensional-quantum dots 2
$Zn_{0.95}Mg_{0.05}O$ as electron transport layer material 295
ZnO as ETM 293
ZnO ETLs fabrication, n-type dopants for 295
$Zn(OA)_2$-QDs based IJP QDLED 368
ZnSe/CdSe/ZnS core-bilayer shell QDs 114
ZnSe quantum dots 215, 217–218
ZnSe/ZnS-based blue QDLEDs 215
ZnS QDs/CBP/MoO_3/Al inverted device 124
ZnS QDs/CBP/MoO_3/Al QDLED 113
ZnS quantum dots with 1-octanethiol ligands 121
$Zn_xCd_{1-x}Se$ alloyed quantum dots 121
$Zn_{1-x}Cd_xSe$/Zn core/shell quantum dots 126
$Zn_{1-x}Cd_xSe$/ZnSe/$ZnSe_xS_{1-x}$/ZnS core/multi-shell QDs 113