

## Index

### a

acene semiconductors *vs.* fused heteroacenes 22

active-matrix liquid-crystal displays (AMLCDs) 232, 238, 240–242, 244, 249

active-matrix organic light-emitting diode (AMOLED)

- Apple Watch 235
- barrier coatings 252–255
- circular polarizer 255
- design 239–241
- display technology 207
- flexible displays 256–258
- future aspects 258
- Galaxy S6 Edge 234
- integrated display drivers 248
- LG G Watch R 235
- pixel design 245–248
- vs.* PMOLED display 239–241
- products 233
- Samsung Galaxy Note Edge 233
- substrates 249–252
- TFT performance 241

addition polymerization process 292

amorphous metal oxide TFTs 245

analogue type resistive touch 102

anode/negative electrode, of LIB 269

applications of 2D-crystal-based inks 165

- energy devices 180–181
- printed electronics 166–178
- printed optoelectronics 178–180
- printed THz devices 181
- sensors and wearable devices 180

### b

backplane 232, 238, 245, 246, 249–251, 253, 258

ball milling 149, 150, 183

bar coating 84, 89, 135. *see also* rod coating

Beer–Lambert law 14, 163

benzothieno[3,2-*b*]benzothiophene (BTBT)  $\pi$ -system 26

bioelectronic devices 289, 292–294, 303, 305

biological sensing 296, 297, 300, 301, 305

2,6-bis(4-methoxyphenyl)naphthalene (BOPNA) 44–46

blade coating 62, 134–135, 158

bottom-gate (BG)/top-contact (TC) OTFTs 20

- hole mobility 45
- on polyethersulfone(PES)/ITO substrate 41
- programmable memory
  - characteristics 43
  - schematic structures 16, 19

bottom-gate (BG)/top-contact (TC) OTFTs organic cell stimulating and sensing transistor fabrication 43

Bragg formula 6

building integrated photovoltaics (BIPV) 52

bulk heterojunction solar cell 54, 55

- charge carrier separation 55
- charge collection 55
- exciton creation 54

- bulk heterojunction solar cell (*contd.*)
  - exciton diffusion 55
  - hopping mechanism 55
  - light absorption 54
  - morphology optimization 55
  - photocurrent 55
  
- C**
- cable-type flexible lithium-ion battery 278
- capacitive touch screens 208, 212
- carbon-based electronics 71, 231
- cathode/positive electrode, of LIB 269
- C8-BTBT 27, 28
- characterization techniques
  - dry film characterization 164
  - electrical characterization of thin films 165
  - ink characterization 163–165
- chemical vapor deposition (CVD)
  - method, of graphene films 97
- clean-lifting transfer (CLT) technique 101
- coating techniques
  - blade coating 134–135, 158
  - inkjet printing 159–163
  - rod coating 135–136, 158
  - spin coating 134, 158
  - spray coating 136–137, 159
- coffee-bag laminates 276
- cohesive energy 145
- condensation polymerization process 292
- conducting inks 131
- conducting polymers 34, 291–293, 301–303
- core-cyanated NDI semiconductors 35
- crack deflection toughening mechanism 109
  
- d**
- DATT  $\pi$ -extended derivatives 27
- DDFTTF-based flexible OFET sensors 297, 298
- density gradient ultracentrifugation (DGU) 154
- 2,7-dialkyl substituted BTBT derivatives 27
- differential ultracentrifugation 154
- diphenyl substituted
  - benzodichalcogenophenes 24
- direct gravure coating 139
- dispersion of SLG flakes 149
- doctor-blading technique 61
- drop on demand (DOD) 63, 141, 142, 146
- dry film characterization 163, 164
- dynamic surface tension 145
  
- e**
- elastomeric conductive composites 1, 7–9
- electrical characterization of thin films 165
- electric double-layer capacitors (EDLC) 266
- electrochemical intercalation 147
- electrochemical power sources
  - classification 266
  - description 266
  - history of 265
- electrocorticography (ECoG) probes, OECT based 300
- electrolytes, for LIB 269
- electronic inks 142
  - functional layered materials, dispersion of 147–148
  - functional material selection 143
  - ink formulation and dispersion 154–157
  - pseudoplastic behavior 143–145
  - rheology 143–146
  - rheology of 155–157
  - shear thickening behavior 144
  - surface chemistry 145
  - viscosity 143
- embedded lithium ion batteries 280, 281
- energy devices 180–181
- e-textiles 290, 291, 294, 303–305
- exfoliation in liquids
  - intercalation-based exfoliation 147
  - LPE

- exfoliation of layered crystals
  - 148–152
  - stabilization of exfoliated flakes
    - 152–154
- exfoliation of layered crystals 148
  - ball milling 150
  - microfluidization 151–152
  - shear exfoliation 150–151
  - ultrasonication 149–150
- f**
- FeCl<sub>3</sub>-intercalated few-layer graphene
  - 220
- fiber-shaped batteries 279
- fill factor (FF), of solar cell 56
- flexible display 16, 105, 137, 207, 208, 210, 219–221, 232, 233, 235, 236, 242, 243, 246, 249–252, 255–258
- flexible energy storage systems
  - design concepts 276–280
  - material concepts 270–276
- flexible graphene-based smartphone
  - 209
- flexible ion-sensitive OFET sensor
  - 296, 297
- flexible lithium-ion-based thin-film batteries 282
- flexible organic bioelectronics 290
  - conducting polymers 292, 293
  - electrodes 300–303
  - e-textiles 303–305
  - organic semiconducting materials
    - 291–293
  - OTFTs 294
- flexible organic electrodes
  - biological sensing 301
  - drug delivery 302
  - neural recording/stimulation 301
- flexible organic solar cell, structure of
  - 53–55
- flexible polymers 209, 231, 238, 242, 246, 248, 302
- flexographic printing 62, 63, 134, 138–139, 141, 145, 146, 155, 180
- fullerenes (C<sub>60</sub>), field-effect mobilities
  - 82
- functional layered materials, dispersion
  - of 147–148
- fused design approach 22
- fused heteroacenes 16, 22–29
- fused  $\pi$ -system dibenzothienobisbenzothiophene 22
- g**
- galvanic cell/element 267, 269
- gel polymer electrolytes (GPEs) 274
- glucose sensors, OECT based 298
- graphene
  - applications 132
  - elastic behavior 95
  - features 95
  - mechanical exfoliation 96
  - metalchloride doping of 213
  - pristine 96
  - properties 132
  - saturable absorbers 181
  - zero-gap behavior 96
- graphene and related material (GRM)
  - inks
    - commercialization 132
    - formulation 133
  - graphene-based flexible applications
    - 101
    - field-effect transistors 113–116
    - nanogenerators (NGs) 120–123
    - organic light-emitting diodes
      - 104–109
    - photovoltaic device 109–113
    - sensors 117–120
    - touch screens/panel 102–104
    - transparent conducting electrodes
      - 101–102
  - graphene-based flexible displays 219
  - graphene/epoxy/PET film 100
  - graphene films
    - chemical vapor deposition method
      - 97–99
    - clean-lifting transfer technique 101
    - poly (methyl methacrylate) carrier
      - 99
    - roll-to-roll transfer method 99, 100
    - transfer process 99–101
    - wet transfer method 99

- graphene films (*contd.*)
- graphene/flexible polymer electrodes  
 mechanical robustness 216–219  
 sheet resistance and transmittance  
 212–216
- graphene/metal oxide composites,  
 structural models of 273
- graphene paper 272, 273
- graphene/PET conducting films-based  
 four-wire touch-screen panel  
 102
- graphite oxide (GO) 3–6, 116, 148,  
 158–160, 166, 180, 211, 220, 231
- gravure cells 140
- gravure printing 62, 63, 88, 89, 134,  
 139–141, 164
- green phosphorescent OLED devices  
 108
- h**
- highest occupied molecular orbital  
 (HOMO) 13, 22, 24, 26, 27, 53,  
 54, 56, 57, 104, 166
- high-frequency organic field-effect  
 transistors
- bar-coating 84
- contact resistance 80, 81
- effective charge mobility,  
 maximization of 82–84
- femtosecond-laser ablation 89
- femtosecond-laser sintering 89
- gravure printing technique 88, 89
- high-charge mobility 80
- high-permittivity materials 87–88
- high-resolution laser processing 88
- long-/short-channel effects 81
- at low bias voltage 87–88
- roll-to-roll compatible fabrication  
 process 88
- self-aligned photolithography 85
- split-gate architecture 85
- three dimensional devices 86
- three-dimensional devices 85
- high-mobility polymer semiconductors  
 84
- high-temperature polysilicon TFTS  
 243
- host matrices 268
- hybrid viscoelastic polymer composites  
 2–7
- i**
- ink characterization 163
- inkjet-printed OPV 63
- inkjet printing 16, 27, 63, 84, 88, 91,  
 134, 141–142, 146, 147, 159–164,  
 180, 181, 213, 237, 290, 292, 295,  
 298
- inorganic solid electrolytes (ISEs) 275
- insulating inks 131
- intercalation-based exfoliation 147
- l**
- lactate sensors, OCET based 298
- laminated compound foils 275
- laminated Parafilm/graphene  
 nanoplatelets film 7, 8
- leadacid-based batteries 267
- light–organic matter interactions 13
- liquid organic electrolytes 269, 274
- liquid-phase exfoliation (LPE)  
 exfoliation of layered crystals  
 148–152  
 stabilization of exfoliated flakes  
 152–154
- liquid-phase inks 132
- lithium cobalt oxide (LiCoO<sub>2</sub>) 269
- lithium ion batteries (LIB) 268
- anode/negative electrode 269
- cathode/positive electrode 269
- cell packages 270
- components of 269–270
- composite electrodes 272
- electrolyte 269
- flexible electrodes 271–274
- gel polymer electrolytes 274
- graphene/LFP composite cathode  
 273
- graphene/LTO composite anode  
 273
- graphene paper 272, 273

- intrinsically flexible stand-alone active materials 272
  - liquid organic electrolytes 274
  - multilayered LTO/LCO electrodes with gel electrolyte 280
  - packaging material 275–276
  - separator 270
  - solid-state electrolytes 274
  - total global cell manufacturing capacity 282
  - working principles, schematic illustration of 268
  - lithium-ion chemistry 268, 270, 271
  - lithium titanate ( $\text{Li}_4\text{Ti}_5\text{O}_{12}$ ) 269
  - low-energy absorption edge 13, 45
  - lowest unoccupied molecular orbital (LUMO) 13, 32, 35–37, 53–58, 104, 166
- m**
- mechanical debonding 251
  - mechanical robustness, of graphene/flexible polymer electrodes 216–219
  - metalchloride doping, of graphene 213
  - metal Oxide TFTs 242, 244–245, 249
  - Meyer's model 75
  - microfluidization 132, 149, 151–152, 154
  - microporous polypropylene (PP), in LIBs 270
- n**
- nanogenerators (NGs), for energy harvesting 120–123
  - naphthalenedicarboximides (NDI) 29–32, 34–37, 46
  - naphthodithiophene (NDT) derivatives 29
  - NDI(2OD)(4tBuPh)-DTYM2 ultrathin films 41, 42
  - NDI3HU-DTYM2 ultrathin films 41, 42
  - negative bias illumination stress (NBIS) 245
  - neural recording/stimulation 301–302
  - $N,N'$ -bis(cyclohexyl)NDI 32
  - $N,N'$ -disubstituted NDI semiconductors 32, 46
- o**
- offset gravure coating 139
  - Ohnesorge number 137
  - oligothiophenes 16, 19–22, 26
  - omni-directionally stretchable and transparent multilayered graphene electrode system 218, 219
  - one-step imidization procedure, for disubstituted NDIs 30
  - on-the-fly-dispensing spin-coating 41
  - open circuit voltage ( $V_{OC}$ ), of solar cell 56
  - optical switch concept 4
  - organic bioelectronics 290–293, 305, 306
  - organic cell stimulating and sensing transistor (O-CSTs) devices 43, 44
  - organic electrochemical transistors (OECTs) 298
    - glucose sensors 298
    - integrated microfluidic sensors 300
    - lactate sensors 298
    - sensors 295, 298
  - organic field-effect transistors (OFETs) sensors 72, 75, 79–91, 295, 296
  - organic light-emitting diode (OLED) displays
    - AMOLED 238
    - color 238
    - electro-optic behavior 238
    - hole and electron transport layers 237
    - lifetime effects 239
    - small-molecule and polymer materials 237
    - structure of 236–239
  - organic light-emitting diodes, graphene-based 104–109
  - organic photovoltaics (OPV) 51
    - cost 52
    - design 51

- organic photovoltaics (OPV) (*contd.*)
    - doctor-blading technique 61
    - drop on demand inkjet technology 63
    - efficiency 51
    - flexible electrodes 59–61
    - flexographic printing technique 63
    - gravure printing technique 63
    - indium tin oxide (ITO) bottom electrode 59
    - industrial scale production 61–63
    - integration into greenhouse 52, 53
    - knife (blade) coating 62
    - lifetime 52
    - magic square 51, 52
    - material requirements 57
    - screen printing technique 63
    - semitransparent flexible electrode materials 60
    - slot-die coating 62
    - solar modules 63–65
    - structure and operating principle 53–55
  - organic semiconducting inks 166
  - organic semiconducting materials 166, 289–293, 295
  - organic semiconductor-based FETs (OFETs)
    - high-frequency 80–90
    - transition frequency 73–80
  - organic solar cell 64
    - building integrated photovoltaics 52
    - current–voltage characteristics 56
    - open circuit voltage 56
    - using PffBT4T-C<sub>9</sub>C<sub>13</sub> active layer 59
  - organic thin-film transistors (OTFTs)
    - applications 295
    - electrically ON/OFF states 295
    - OEFTs 298–300
    - OFET sensors 296–298
    - types 295
- p**
- parafilm, self-sticking properties of 2
  - passive-matrix displays 232
  - Payne effect 7
  - pentacene, field-effect mobilities of 82
  - pentathienoacene 22
  - phenylene–thiophene oligomers 20, 21
  - photonic crystals 2
  - photovoltaic device, graphene-based 109–113
  - $\pi$ -conjugated polymer PSeTPTI
    - amorphous films 39
  - $\pi$ -conjugated polymers, chemical structures of 15
  - $\pi$ -conjugated systems, optical
    - absorption properties of 13
  - plastic crystal electrolytes (PCEs) 61, 275
  - PMOLED display 239, 241
  - poly(3,4-ethylenedioxythiophene) (PEDOT) 293
  - poly(styrene-sulfonate) (PSS) 105, 108–110, 293
  - polyaniline (PANI) 139, 159, 293
  - polyethylene (PE) membranes, in LIBs 270
  - polypyrrole (PPy) 293, 301
  - polysilicon TFTs 242–243, 246, 249, 257
  - polystyrene (PS) latex/graphene oxide/Parafilm composite film 3, 4, 6
  - polythiophenes 14, 293
  - pouch-bag laminates 276
  - power conversion efficiency (PCE), of solar cell 56, 109
  - primary batteries 266, 282
  - primary thin-film cells 282
  - printable conductive inks 131, 159
  - printable electronic inks 131
  - printable inks 132, 145, 154, 166, 182
  - printed electronics 131, 133, 141, 147, 163, 166–178, 180, 182
  - printed optoelectronics 178–180, 183
  - printed THz devices 181
  - printing techniques
    - vs. coating techniques 134
    - flexographic printing 138–139
    - gravure printing 139–141
    - inkjet printing 141–142, 159–163
    - screen printing 137–138, 159

- pristine graphene 96, 110, 148, 166  
 pseudo-capacitors 266  
 pseudoplastic behavior, inks 143–145  
 push–pull strategy 57  
 pyrene-based liquid-crystalline  
   semiconductor 25  
 pyromellitic dicarboximides (PyDI)  
   29, 37, 39  
 pyromellitic dithioimides (PyDTI) 39
- r**
- Ragone plot, of conventional energy  
   storage systems 267  
 rapid thermal chemical vapor  
   deposition (RT-CVD) synthesis  
   104, 211, 212, 220  
 reductive chemical intercalation 147  
 resistive panels 208  
 resistive-type touch screen 102  
 rGO-based OLED devices 105  
 RGO films, micropatterned spin coated  
   158  
 rheology of inks 155–157  
 rod coating 134–136, 145, 158, 178  
 roll-to-roll (R2R) transfer method, of  
   graphene films 99, 100  
 rotor-stator mixer 151
- s**
- Samsung Galaxy Note Edge 233, 234  
 screen printing 62, 63, 102, 131, 134,  
   137–138, 145, 147, 152, 159, 160,  
   178, 182, 292, 295  
 secondary batteries 266, 282  
 sedimentation-based separation (SBS)  
   154  
 self-aligned printing (SAP) technique  
   85  
 semiconducting inks 131, 132, 142,  
   166  
 sensors and wearable devices 180  
 separator role, in LIB 270  
 shear exfoliation 149–151, 183  
 shear thickening behavior, inks 144  
 sheet resistance, of graphene/flexible  
   polymer electrodes 212–216
- short circuit current ( $J_{SC}$ ), of solar cell  
   56  
 silver nanowire (AgNW)–graphene  
   hybrid flexible transparent  
   electrodes 216, 220  
 SLG flakes, dispersion of 149  
 soft color composites 1, 2  
 soft materials 292  
 solar cell characteristics 55–57  
 solar garden lamp 52, 53  
 solar modules 51–53, 62–65  
 solid electrolyte interphase (SEI) 270,  
   274  
 solid polymer electrolytes (SPEs) 113,  
   269, 275, 303  
 solid-state electrolytes 274  
   inorganic solid electrolytes 275  
   SPEs/plastic crystal electrolytes 275  
 solid-state electrolytes drawback 275  
 spin coating r spin 27, 28, 39–41, 61,  
   134, 135, 147, 158, 292, 295  
 spray coating 131, 134, 136–137, 147,  
   159, 182  
 spreading coefficient 146  
 stabilization of exfoliated flakes  
   152–154  
 supercapacitors (SCs) 121, 158, 159,  
   166, 181, 266  
 surface chemistry 143–146, 272,  
   302  
 surface tension 3, 134, 135, 137,  
   141–143, 145, 152, 164  
 surfactants 152–154, 162  
 synchronous inkjet printers 141
- t**
- TFT LCDs 232  
 thiazolothiazole/phenyl oligomers 20  
 thieno-annulation synthesis 26  
 thin films  
   batteries 80, 158, 276, 282  
   coplanar design 277  
   printing techniques 277, 278  
   single-stack/sandwich design  
   276  
 electrical characterization 165  
 solar module 64

- thin-film transistors (TFTs) 16, 294
    - metal oxide TFT 244–245
    - organic TFT 242
    - parameters 19
    - polysilicon TFT 242–243
    - requirements 241
  - 3D interdigitated microbattery
    - architecture 278
  - top-contact staggered OFETs
    - wet-etch patterning method 83
  - top-gate (TG)/bottom-contact (BC) OTFTs
    - schematic structures 16, 19
  - touch screens/panel, graphene-based 102
  - transition frequency  $f_t$ , FETs
    - current gain 73
    - definition 73
    - direct measurement method 75
    - Kirchhoff's law 76
    - modified measuring scheme 76
    - scattering parameters  $S$ -parameters 79
    - transconductance measurement 76
    - $Y$ -parameters (admittance parameters) matrix 77, 78
  - transmittance, of graphene/flexible polymer electrodes 212–216
  - transparent conducting electrodes (TCE), graphene-based
    - organic light-emitting diodes 104–109
    - photovoltaic device 109–113
    - touch screens/panel 102–104
  - transparent conductive film (TCF) 208, 210, 211, 213, 221
  - transparent organic semiconductors 15
    - fused aromatic dicarboximides 29–39
    - fused heteroacenes 22–29
    - oligothiophenes 19–22
    - rylene dicarboximides 29–39
  - triboelectric nanogenerator (TENG) 121, 123
  - turbulent mixing 151
  - 2D-crystal-based inks
    - applications
      - energy devices 180–181
      - printed electronics 166–178
      - printed optoelectronics 178–180
      - printed THz devices 181
      - sensors and wearable devices 180
    - blade coating 158
    - dry film characterization 164
    - electrical characterization of thin films 165
    - ink characterization 163–165
    - inkjet printing 159–163
    - rod coating 158
    - screen printing 159
    - spin coating 158
    - spray coating 159
  - two-dimensional (2D) crystals 132
- U**
- ultracentrifugation
    - density gradient ultracentrifugation 154
    - differential ultracentrifugation 154
  - ultrasonication 132, 148–152
- V**
- viscosity 63, 134, 136–139, 141–146, 153, 156, 157
  - voltaic pile 266
  - V-shaped
    - dinaphtho[2,3-*b*,2';3'-*d*]thiophene (DNT-V)  $\pi$ -core 24
- W**
- white organic light-emitting diode (WOLED) 238, 239
  - wide band gap semiconductors 14, 15
  - wire electrochemical transistors (WECTs) 303
  - wire-wound rod coating 135–136