

## Index

### **a**

- acetylcholine (Ach) 61, 136, 322–327, 332
- acetylcholinesterase (AChE) 61, 136, 137, 323–326, 328, 332
- affinity biosensors 45, 61–63
- 3-amino-benzylamine (ABA) monomers 137, 318–332
- aminophenylboronic acid (APBA) 136
- aniline (ANI) 247, 319, 325
- anti-BNP antibody 305, 306, 309
- aptamers 61, 63, 80, 82, 150, 191, 198, 219, 223, 225, 252, 356, 363, 364, 374, 409
- aptasensor 61, 91, 117, 118
- atomic force microscopy (AFM) 32, 33, 104, 189, 193, 194, 209, 210, 213, 214, 221, 222, 351, 375, 376
- Avian influenza virus infection 374

### **b**

- baseline drift 374, 387–398
- bilayer graphene (BLG) 107, 155, 169–181, 221
- bioanalytical tools 251
- biocompatibility 26, 59, 60, 88, 126, 127, 138, 141, 160, 162–163, 285, 286, 303, 340, 367, 406

bioelectronic noses 106, 107

bioelectronics

- using bioprobe-modified

- graphene 112–116

- wearable 358, 360

biological recognition element (BRE) 339

biosensors

- classification 339

- for environmental component monitoring 116–120

biostability 160, 162–163

blood glucose biosensors 71

bottom-up syntheses 105

bovine serum albumin (BSA) 35, 36, 82, 128, 130, 131, 305, 309, 376, 390–393

B-type natriuretic peptide 301

### **c**

carbon-based nanomaterials 103

carbon nanotube

- (CNT) 214–215, 231–233

cation doping 388–390

cellulosome complex 198

charge carrier mobility 36, 75, 159, 169, 174, 215, 216, 238–240, 272, 320, 347

charge neutrality point (CNP/V<sub>CNP</sub>) 58, 73–75, 78, 83, 177, 178, 192, 195, 343, 344, 346, 375

- chemical vapor deposition (CVD) 2, 43, 76, 105, 125, 207  
 carrier mobility 208  
 diazonium 217  
 for FET 214–224  
 growth 210  
 pyrene chemistry 220–224  
 clustered regularly interspaced short palindromic repeats (CRISPR) 62, 79, 83, 115, 116, 253, 254  
 computer chips 154  
 conducting polymer nanotubes (CPNTs) 111  
 conducting polymers (CPs)  
     films 186, 317–333  
 conductivity, BLG 178  
 continuous glucose monitor (CGM) 150, 161  
 coronavirus disease 2019 (COVID-19) 62, 80, 87, 114, 128, 142, 150, 301, 302, 360  
 cortisol 162, 342, 343, 354, 355, 364  
 cut-off frequency 11, 14, 16  
 cutting-edge technologies 374, 393
- d**
- Debye–Hückel model 252  
 Debye length 251, 380  
     GFET 81–82  
     screening 63–64  
 Debye screening 384  
     effect 87, 362–364  
     length ( $\lambda_D$ ) 64, 81, 254, 354, 362, 364–365, 367  
 deep-learning-based optical inspection 393–398  
 density functional theory (DFT) 196–198, 200–202, 209  
 deoxyribonucleic acid (DNA)  
     biosensors 83–85  
     methylation 84  
 device fabrication, GFET  
     biosensors 349–350  
 device-to-device variability 362, 366, 367  
 diabetes mellitus 327  
 1,5-diaminonaphthalene (DAN) 107, 110  
 diazonium chemistry 217–220  
 Dice coefficient 395  
 Dirac point, graphene 173–174  
 Dirac voltage ( $V_{\text{Dirac}}$ ) 11, 188, 189, 344, 346, 347, 350, 351, 353, 354, 358–360, 363, 365  
 Donnan equilibrium 253, 254, 257  
 Donnan potential 253–255, 257, 265  
 dopamine (DA) 51, 78, 82, 135, 138, 151, 152, 209, 260, 325, 342, 355, 356  
 Duchenne muscular dystrophy (DMD) 83
- e**
- elaborate theoretical model 245  
 electrical double layer (EDL/EDL1) 6, 44, 73, 127, 154, 174, 218, 232, 251, 346, 363  
 electroactive molecule 151  
 electrochemical double-layer (EDL) 216  
 electrochemical techniques 51  
 electrolyte-gated FETs 44, 72, 232  
 electrolyte-gated gFETs (EG-gFETs)  
     biomolecule sensing 251  
     characterization 73  
     principle 72–75  
 electron beam (E-beam) evaporator 105  
 electronic biosensors 71–93  
     disease diagnosis 71  
 electronic sensors 43, 106, 125, 285  
 electrosynthesized polymer 318  
 enable nearfield communication (NFC) 162  
 enzymatic cascades 293, 294, 297  
 enzyme immobilization 293, 297, 322, 323  
 enzyme-linked immunosorbent assay (ELISA) 71, 113, 254, 302, 381–383, 406  
 exosomes (EXOs) 61, 406, 410–411  
 extracellular vesicles (EVs) 405  
     clinical significance 406  
     description of 405–6

**f**

fabrication process  
 developments 78  
 of G-FET sensor 304  
 graphene transfer over substrates 76–77  
 synthesis 75–76  
 Faradaic effect 243–245  
 fatigue biosensors 353–357  
 Fe(III) meso-tetra(4-carboxyphenyl) porphyrin (FeTCP) 138  
 Fermi energy 177, 178, 289  
 field-effect transistors (FETs) 9, 339  
 biosensors 373–398  
 graphene 43, 72, 151–152, 185  
 figures of merit (FOMs) 5, 14  
 fitness trackers 149, 161  
 flexible electronics 11, 53, 340  
 fluid-sensor interface 160  
 fluorescence microscopy 189, 190  
 fluorescent dyes 189  
 food safety 106, 118, 285  
 full width half maximum (FWHM)  
 175

**g**

gas detection 125, 138–140, 276  
 gas sensing technology 271  
 graphene 272, 274–275  
 graphene FET 272, 274–275  
 hybrid graphene FET 277–280  
 glassy carbon (GCE) 51, 152  
 glucose detection 80, 90, 136, 327–332  
 glucose oxidase (GOx) 80,  
 327–328, 330–333  
 Grahame equation 252  
 Grand Canonical MC (GCMC)  
 method 201  
 graphene 2, 343  
 capacitors 9  
 characterize molecular functionalization 186–196  
 frequency multipliers 18  
 functionalization 350–353  
 Hall structures 156–159

inductors 5  
 membranes 159  
 mixers 18  
 oscillators 19  
 production 348–349  
 quantum capacitance 8  
 synthesis 104  
 transistors 153  
 tunable capacitor 7–8  
 graphene-based field effect  
 biosensors (GFET)  
 fabrication of 170–173  
 fundamental sensing  
 parameters 173–174  
 with pyrene derivatives 174–176  
 quadratic fit analysis 177–181  
 graphene-based field effect transistors  
 (gFETs) 10, 186, 251, 285, 286  
 graphene binding peptides  
 (GrBP) 189, 191  
 graphene field-effect transistor (GFET)  
 antibody-antigen interactions  
 85–87  
 biosensor 411–412  
 biosensor fabrication 348–353  
 challenges 92–93  
 Debye length 81–82  
 enzymatic biosensors 87–90  
 functionalization and  
 passivation 78–83  
 nucleic acids 83–85  
 platform 106  
 probe molecules 80–81  
 sensing mechanism 346–348  
 of small ions 90–92  
 structure 345–346  
 graphene field-effect transistor (G-FET)  
 biosensors  
 deep-learning-based optical  
 inspection 393–398  
 drift suppression and compensation of  
 cation doping 388–390  
 state-space models (SSMs)  
 390–393  
 influenza viruses 374

- graphene field-effect transistor (G-FET)  
**biosensors (Continued)**  
 mimicking cell surfaces 374–377  
 real-time measurement, enzyme reaction in microdroplets  
*Helicobacter pylori* (*H. pylori*, [HP]) 384–385  
 measurement mechanism and model measurement system 385–387  
 sialoglycan 374  
 sialoglycan-functionalized evaluation of 375–377 fabrication 375  
 signal enhancement, G-FETs 377–387  
 graphene oxide (GO) 25  
 biosensors 25–26, 34–38  
 chemical reduction 48–49  
 cyclic voltammograms 52  
 dispersion 46  
 electrochemical reduction 51–52  
 modified Hummers method 27–29  
 production cost 47–52  
 properties 45  
 reduced growth 29–34  
 structure 46  
 synthesis 26, 47  
 thermal reduction 49–51  
 graphene quantum dots (GQDs) 50  
 graphene topographical quality 212–214  
 graphite, chemical exfoliation 44
- h***  
 Hall effect 103, 156–158, 273  
 Hall-structure-based sensors 152, 156–158  
 health sensing 149–151, 160  
 health sensor 149–163  
 heart failure (HF) 301–312  
*Helicobacter pylori* (*H. pylori*, [HP]) 384  
 human immunoglobulin E (IgE) 378  
 human olfactory receptor 2AG1 (hOR2AG1) 107
- human umbilical vein endothelial cells (HUVECs) 138  
 Hummer's method 26–27, 44, 126  
 hydrocarbon source 29  
 hydrothermal process 49, 50
- i***  
 immobilization process 80, 117, 323  
 implantable biosensors 78  
 inductively coupled plasma mass spectrometry (ICP-MS) 132  
 inflammation 341–343, 360, 406  
 interdigitated electrodes 51, 52, 56, 57, 78, 210, 218, 225  
 interface-focused analytical approaches 375  
 interleukin-6 (IL-6) 35, 254, 342, 343  
 ion-exclusion 253–255  
 ionic etchants 76  
 ionophore membranes 80, 90  
 ion-selective-electrodes (ISEs) 241, 242  
 ion-selective field effect transistor (ISFET) 72, 241, 242, 388
- j***  
 Japan Science and Technology Agency (JST) 374
- k***  
 Kelvin Force Microscopy (KFM) 319  
 kinetic inductance 3–5
- l***  
 lab-on-a-graphene-FET 373  
 Langmuir–Blodgett (LB) method 104, 134  
 Langmuir equation 392  
 L-arginine sensor 293  
 lateral flow assay (LFA) 71, 115  
 Launder's approach 5  
 layer-by-layer (LbL) assembly  
 enzyme-based gFET sensors 287–296  
 of polyethylenimine and urease 288–292

LC tank oscillators 19  
 leachables 162, 163  
 Lerf-Klinowski's GO model 30  
 limit of detection (LOD) 108, 152, 219,  
 297, 325, 331, 360, 376, 409, 411  
**liquid**  
 electrochemical perspective  
 241–245  
 field-effect operation 232–233  
 graphene FET 235–236  
 measurement modes 236–237  
 sensing mechanism 238–240  
 liquid-phase exfoliation (LPE) 2, 104  
 living-cell biosensor 137–138  
 low gate voltages 36, 325

**m**

*Maackia amurensis* (MAM) 375–377  
 magainin I 113, 114, 259  
 material flexibility 358  
 MATLAB 394  
 maximum available power gain 15  
 mechanically exfoliation 125  
 medical imaging compatibility  
 160, 163  
 metal-containing systems 201  
 metal-ion detection 131–134  
 metal-oxide-semiconductor field-  
 effect transistor (MOSFET)  
 72, 126, 232, 354  
 microelectromechanical system  
 (MEMS) 105–107, 115  
 microvesicles (MVs) 406  
 detection 408–409  
 dual-aptamer modified GFET  
 biosensor 409–410  
 label-free detection 410–411  
 molecular biomarkers 341–343  
 monolayer graphene 72, 76, 91, 105,  
 155, 170, 171, 175–177, 181, 210,  
 213, 221, 340, 350, 366  
 monolayer graphene fabrication  
 technology 105  
 Monte Carlo simulations  
 200, 201, 392

Moore's Law 1  
 multilayer graphene (MLG) inductor  
 3, 76, 214, 220, 348

**n**

nanofluidics 158, 159, 287  
 neuropeptide Y (NPY) sensing 342  
 nucleic acids 246  
 detection 134–135  
 sequences 79

**o**

observation equation 391  
 olfactory receptor-conjugated  
 graphene 106–112  
 open-sandwich immunoassay  
 (OS-IA) 374  
 advantages 380–381  
 antibody fragments and device  
 fabrication 381–382  
 BGP-C7 selectively 382  
 in human serum 382–384  
 principle of 380  
 organic thin-film transistors  
 (OFETs) 207

**p**

p-doping 216, 219, 291, 306, 308, 323,  
 328, 344, 347, 388  
 peptide nucleic acids (PNA) 55,  
 79, 83, 135  
 photolithography (PL) 56, 77, 105, 110,  
 172, 304, 350, 354  
 platinum nanoparticles, decoration  
 of 304–305  
 p-n junctions 16  
 poly(3-amino-benzylamine-co-aniline)  
 (PABA) 137  
 functionalization 318–322  
 nanofilms 318–322  
 polyethylene glycol (PEG) 82, 130,  
 253, 408  
 polyethylene terephthalate (PET)  
 film 53, 107, 129, 137  
 polyethylenimine (PEI) 59, 136,  
 288–292

- polymethyl methacrylate (PMMA) 76, 105, 172–173, 210–211, 213–214, 235, 349, 389–390
- polypyrrole (PPy) 111, 135, 186, 318
- potentiometric sensors 241, 303
- projected-to-atoms density of states (PDOS) 200
- pyrenebutanoic acid succinimidyl ester (PASE) 81, 83, 86, 127, 132, 135, 221, 222, 262, 375, 410
- 1-pyrenebutanoic acid succinimidyl ester (PBASE) 127, 221, 262, 375, 377, 410
- pyrene-maleimide 174, 175, 179, 180
- q**
- quantum capacitance 6, 8, 9, 44, 73, 235, 346
- r**
- Raman spectroscopy 50, 175, 181, 189, 190, 209, 212, 213, 217, 351
- reactive-ion etching (RIE)
- processes 105, 110, 172, 349, 354
- reactive signal amplifiers 287, 291, 293
- reduced graphene oxide (rGO) 128
- chemical reduction 48–49
  - field-effect transistors 286–287
  - functional groups 44
  - gas detection 138–140
  - living-cell biosensor 137–138
  - metal-ion detection 131–134
  - nucleic acid detection 134–135
  - production cost 47
  - properties 126
  - protein detection 128–131
  - small biomolecular
    - biosensor 135–137
    - structure 46
    - thermal reduction 49–51
- rGO SG-FET 53
- affinity biosensors 61–62
  - applications 57–64
  - challenges 64–65
  - Debye length screening 63–64
- enzymatic biosensors 60–61
- functionalization 59
- manufacturing strategies 53–57
- ring oscillators 19
- roll-to-roll (R2R) transfer 76, 78
- root-mean-square deviation (RMSD) 198
- s**
- Sambucus sieboldiana* (SSA) 375–377
- scanning electron microscopy (SEM) 27, 30, 189, 209, 211, 212, 288, 306, 319, 350, 351, 365
- scanning tunnelling microscopy (STM) 188, 189
- Scotch tape method 75, 170, 348
- self-assembled monolayer (SAM) 88, 91
- self-assembly 185
- of (bio)molecular films 186
- sensing performance
- advantages, limitations 311–312
  - clinical application 311
  - selectivity 309
  - sensitivity 309–310
  - stability and reproducibility 308–309
- short-channel effects (SCEs) 185
- sialoglycan 374–377
- sialoglycan-functionalized G-FETs 374
- evaluation of 375–377
  - fabrication of 375–376
- sialylglycopeptide (SGP) 375
- signal enhancement, G-FETs
- increasing receptor density
  - case of linkers 377–378
  - of linker-based performance
  - enhancement 378
  - performance enhancement by
  - linkers 378–380
- open-sandwich immunoassay
- advantages 380–381
  - |antibody fragments and device
  - fabrication 381–382
  - BGP-C7 selectively 382
  - in human serum 382–384
  - principle of 380

- sodium borohydride ( $\text{NaBH}_4$ ) 48, 56  
 solution-gated FETs (SG-FETs) 44, 45,  
   52–60, 62–64  
 solution-processable graphene 125, 126  
 sonication 46, 47, 104, 159  
 S parameters 13–15  
 spectroscopic ellipsometry 191  
 stability factor 15  
 state equation 391  
 state-space models (SSMs) 390–393  
 steroid 343  
 “stiction” 186, 187  
 stress, chronic 341–342  
 stress hormone 343, 354  
 surface binding process 192  
 Surface-Enhanced Raman Scattering  
   (SERS) 50, 72, 118  
 surface functionalization 126, 132, 137,  
   141, 187, 196, 287, 305, 333,  
   352, 412  
 surface modification  
   Donnan potential 253–255  
   ion-exclusion 253–255  
   kinetic cost 262–264  
   with lipid layers 258–259  
   with mesoporous materials 260–261  
   with polymer films 255–258
- t**  
 tetrakis(4-carboxyphenyl) porphyrin  
   (TCPP) 377–380  
 thermal reduction methods 49  
 thin-film transistors (TFTs)  
   principle 126–127  
   rGO 128–140
- thioglycolic acid (TGA) 131, 133,  
   134, 305  
 traditional analytical methods 285  
 traditional immobilization  
   techniques 286  
 transition-metal dichalcogenides  
   (TMDs) 2, 3, 142  
 tripodal pyrene binders 221  
 tumor necrosis factor-alpha  
   (TNF- $\alpha$ ) 342, 343
- 2D materials  
   diodes 15–18  
   modelling 17–18  
   p-n junctions 16  
   transistors 9–15
- u**  
 ultrasensitive sensing 292–296
- v**  
 vancomycin 113, 114  
 volatile organic compounds (VOCs) 111,  
   112, 271, 279, 281
- w**  
 wearable bioelectronics 358, 360  
 wearable sensors 53, 149, 160, 358  
 wet transfer technique 76, 105  
 whole blood, immunodetection in 305  
 whole-gene sequencing 115
- x**  
 X-enes 2  
 X-ray photoelectron spectroscopy  
   (XPS) 189, 209, 213, 307, 389









