Index

а

all-in-one self-driven monitor patch 32, 101-124, 194 all-laser-engraved multimodal sensing platform 160 all-laser-engraved process 161–164 amperometric sensor 135 analog-to-digital converter (ADC) 146, 177 Apple Watch 2 application-specific integrated circuit (ASIC) 196 areal capacitance 53, 58, 59, 93, 115, 116 arrayed self-driven monitor patch matrix 122 assembled solid-state supercapacitors 72.194 assisted precision therapy 22, 26–28 auxetic foams 20

b

battery-free electronics 43 binary random composite material 105 biocompatible, high-aspect ratio nanomaterial 24 biofeedback-enabled prosthetic development 26 biofluids 22, 137, 142, 159, 179 biofuel cells 127 bionic flexible stretchable TENG with supercapacitor 18 12-bit ADC 179 BLE PSoC module 145, 146 Bluetooth low energy (BLE) 4, 128, 130, 154, 155 bottom wrinkled PDMS layer 79

С

capacitive sensors 13, 20 carbon-based materials 11, 57, 72, 115, 171 carbon materials 118 carbon nanotube-polydimethylsiloxane (CNT-PDMS) conductive elastomer 39, 101 carbon nanotube-polydimethylsiloxane (CNT-PDMS) conductive sponge 39 C_4H_8 plasma treatment 82 charge-discharge current function 93, 115 checker-like interdigital electrode based TENG 8 chemical analysis technology 3 closed-loop smart micro-systems 4, 28, 30. 39. 196 CNT-cotton fabric electrodes 51, 52 CNT-nanofibers interdigital fingers 60 CNT-paper composite 84, 85 CNT–PDMS sponge electrodes 61–65 coefficient factor 113 compressing time (CT) 118 COMSOL Multiphysics software 132

Integrated Smart Micro-Systems Towards Personalized Healthcare, First Edition. Yu Song, Wei Gao, and Haixia Zhang. © 2022 WILEY-VCH GmbH. Published 2022 by WILEY-VCH GmbH. conductive elastomer 32, 68, 105–107, 116 conductive fabric 40, 43, 44 conductive sponge-based piezoresistive sensor 61–67 contact angle measurement system 62. 107 contact-mode TENG strain sensor 20 contact-separation TENG 79, 96 core units of smart micro-systems piezoresistive sensors for function sensing 61–72 supercapacitors for energy storage 50 - 59triboelectric nanogenerator for energy harvesting 39-50 cotton fabric electrode 40 CNT-cotton fabric electrode 51, 52 cube sugar 61, 62 current–voltage (I-V) characteristics 66 cyclic voltammetry (CV) 51, 92, 114, 140, 166, 167 cycling stability measurements 115

d

differential pulse voltammetry (DPV) method 165 digitalized self-powered strain gauge 20 dimethyl formamide (DMF)/acetone mixture 55 dimethyl sulfoxide (DMSO) 55, 95 dodecyl benzene sulfonate sodium (SDBS) 86 drop-coating active materials 67 drop-drying method 31, 50, 51, 55, 85–87 dynamic closed-loop health management 30 dynamic stretchable fabric system 18 dynamic sweat analysis 151–155

е

effective medium theory 105, 106 elastic collapse stress 103 elastomeric honeycomb 103 electrical double layer solid-state supercapacitor 11 electrical double-layer supercapacitors 9.11 electrocardiogram 2, 4, 12 electrochemical double-layer capacitor 10 electrochemical sensors 5, 15, 127, 128, 135, 136, 138-144, 146, 149-152, 155 electrochromic device (ECD) 95-96 electroencephalogram 12 electroless nickel/immersion gold (ENIG) 130 electrolyte-transferring method 101, 108.124 electromagnetic energy harvester 6, 7 electromagnetic generator 5 electromagnetic induction 6 electrooculogram 12 electrospinning process 19, 55 energy harvesting unit 1, 4, 5, 16, 29, 31, 39, 145, 193 see also triboelectric nanogenerator (TENG) energy storage units 1, 4, 5, 9–12, 29 epidermal drug delivery 26, 27 epidermally programmable virtual reality system 24 Euler buckling load 103

f

fabric-based pressure sensor array 14 fabric-based self-charging power unit 16 fabric-based TENG 41 Faraday constant 137 fast Fourier transform (FFT) 175.183 fiber-shaped supercapacitors 11, 16, 19 finite element analysis (FEA) 133 fixed-point nerve injury repair 28 flexible and durable wood-based TENG 20 flexible bioelectronics technology 4 flexible bioelectronics technology 4 flexible CNT-cotton electrode 51 flexible CNT-paper electrodes 85, 87 flexible cotton fabric 51 flexible fabrication process 3 flexible paper electrode-based supercapacitor 83-88 flexible printed circuit board (FPCB) fabrication process 44 flexible sensing unit 149–151 flexible solid-state supercapacitors 11 foaming method 61 freestanding-mode TENG (FTENG) 127 freestanding triboelectric nanogenerator (FTENG) 44 characteristics 133-136 structural design 130-133 working principle 130–133 fully integrated self-powered sweat sensing platform 32, 127–149 applications of 149–155 fully integrated sweat sensor platform 32

g

galvanostatic charge–discharge (GCD) curves 92, 114–115 Gauge factor (*GF*) 113, 175 Gauss theorem 79 general effective media (GEM) equation 105 general-purpose input/output (GPIO) pin 146 grating-shaped TENG 20 grating slider 44, 46, 72, 132, 134

h

healthcare monitoring 4, 195 hexagonal honeycomb model 103 hexagonal MnO₂ nanosheet ink 12 high-performance electromagnetic energy harvester 6 high-performance flexible fiber-shaped supercapacitor 19 high-performance liquid chromatography (HPLC) test 179, 181, 182, 186, 187 high performance, wearable sensors 24 hospital-centered diagnosis method 1 human-machine interaction 14, 20, 22, 28, 29 multifunctional 24–26, personalized 118–120 hybridized self-charging power unit 18

i

ideal honeycomb cell model 103 impedance sensor 136 implantable nerve regeneration 26, 27 indium tin oxide (ITO) layer 78 induced charge 80 inductively coupled plasma (ICP) etcher 82 industrial weaving method 16 inhomogeneous effective medium theory 105 in-planar omni-directional mechanical energy 8-9 in-planar supercapacitor 12 in-plane supercapacitor 11 in-situ self-driven patch 101 integrated design 1, 30 integrated health monitoring system all-laser-engraved process 161-164 multimodal real-time continuous in situ measurement 183-184 non-invasive gout management 184-188 structural design 160-161 sweat analysis 181-183 integrated smart micro-systems all-in-one self-driven monitor patch 32 assisted precision therapy 26-28 core units 31 exploration of integration methods 15 fully integrated sweat sensor platform 32 healthcare monitoring 4, 5 health monitoring approach 1, 2 integrated design 30 lavout of 31 multifunctional human-machine interaction 24-26

202 Index

integrated smart micro-systems (contd.) multimodal sensing integrated health monitoring system 32 progress of 2-3 real-time health monitoring 22 - 24sandwiched self-charging power unit 32 scope of the 29, 30 self-charging power units 16–18 self-driven monitor patches 18-20 self-powered sensing platform 20-22 solid-state supercapacitors 9–12 strain sensors 12-15 triboelectric nanogenerator 5–9 intercalation pseudo-capacitor 9, 10 interdigital electrode-based stator 44 iontronic sensors 12.13 ITO coated polyethylene terephthalate (PET) film 82

l

large-scale printable energy storage devices 12 laser-enabled multimodal sensing platform 161 laser-engraved graphene-based chemical sensor (LEG-CS) 159 calibration of 180 characteristics 165-168 HPLC analysis 181 mechanical stability of 168 reliability 168-170 selectivity 168-170 laser-engraved graphene-based physical sensor 159 microfluidic structural design 173-177 temperature 171–173 laser-engraved graphene electrode (LEGE) 12, 166-168 laser-engraving method 12, 32, 161–164, 171 laser-engraving modes 162, 163

laser-patterning process 55, 56, 60, 72, 101, 108, 124, 139 light-emitting diodes (LEDs) 60, 65, 94 linear buckling theory 81 liquid capsule-based sensing platform 14 liquid crystal display (LCD) 60, 94, 95 long-term cycling stability 135, 143

m

machine-learning method 24 machine-washable TENG 7 mask-assisted method 14 Maxwell's equation 105 mechanical energy-based nanogenerator 6 mechanical-related physiological signals 101 microfluidics 138–139, 160, 161 micro-supercapacitor (MSC) 19, 54-57, 59, 60, 101, 109, 110, 114-117, 123, 124, 194 miniaturized multimodal biosensors 4 miniaturized supercapacitor 54 motion-driven self-activated electrical stimulation device 28 multifunctional electronic skin 26 multifunctional human-machine interaction 24, 25 multifunctional self-driven electronic skin 19 multi-layer composite sensor design 26 multimodal physical-chemical information sensing 23 multimodal real-time continuous in situ measurement 183, 184 multimodal sensing integrated health monitoring system 32 multimodal sensing platform 29, 160, 161, 171, 175, 179, 181, 189, 194 multiple-pixel patch matrix 122 multiplexed sensor array 22, 137, 139

multiplexed sweat chemical signal detection 23 multi-walled carbon nanotube (MWCNT) 12, 140

n

nanomembrane hybrid electronics 24 Na⁺ sensor 141–144, 150, 151 negative Possion-ratio auxetic materials 20 Nernstian equation 137 network body physical indicator monitoring 23 non-drug effective therapy 28 non-invasive gout management personalized 185188 purine-rich diets 185 non-invasive sweat glucose monitoring 26 nylon 40

0

obstructive sleep apnea hypopnea syndrome (OSAHS) 2 one-dimensional (1D) carbon nanotubes 11 one-dimensional (1D) conductive materials 84 one-dimensional (1D) fiber 11, 83 one-dimensional flexible supercapacitor 11 open-circuit voltage 9, 40, 41, 46, 80, 133

р

paper-based electrodes 77 paper-based supercapacitors 11, 12 parallel plate capacitor model 79 parallel TENGs 89–91 patient-centered medical health model 2 "P" character-shape PMMA plate 121 PDMS-based TENG 193 Pearson correlation coefficient 181 percolation coefficient 105 percolation theory 77, 84-86, 88, 97, 105, 106, 112, 193 percolation threshold 84, 85, 105–107, 112.113 peripheral nerve injury 26 personalized human-machine interaction 118 - 120PET-indium tin oxide (ITO) film 65 photovoltaic cell 7 photovoltaic effect 6, 7 pH sensor 130, 138, 141-144, 150, 152 physical-chemical hybrid patch 22 physiological signal monitoring 22, 24, 28, 29, 31, 32 piezoelectric effect 6, 7 piezoelectric energy harvesters 6, 7 piezoelectric generator 5 piezoelectric nanogenerators 5, 127 piezoelectric sensors 13 piezoresistive sensors (PRSs) 13-15, 31, 32, 39, 101, 127, 135, 174, 193, 194 for function sensing 61–72 PKUAW 120 planar micro-supercapacitor 54-60 Poisson's ratio 20, 81, 82, 104, 112, 113 polyaniline (PANI) 138 polydimethylsiloxane (PDMS) layer 78, 139 poly 3,4-ethylenedioxythiophene : polystyrene sulfonic (PEDOT : PSS) 138-140, polyethylene terephthalate (PET) 139, 161 polyethylene terephthalate (PET) substrate 55, 139 polyimide (PI) film 44, 161 polyimide (PI) substrate 161 poly(methyl methacrylate) (PMMA) mold 108 polytetrafluoroethylene (PTFE) 40 polyvinyl alcohol (PVA) powder 108 polyvinyl butyral (PVB) 95, 139 polyvinylidene fluoride (PVDF) 55

pore-creating agent 62 porous CNT-PDMS conductive elastomer 68-70, 73, 104, 106, 108-110, 114, 123.124 porous CNT-PDMS conductive sponge 65, 67, 71 porous CNT-PDMS elastomer 68, 102, 108, 111, 114, 124 porous conductive elastomer-based piezoresistive sensor 67 porous conductive elastomers 103, 104, 107 porous PRS 61 portable health monitoring methods 3 potentiometric electrochemical sensing unit characteristics 141–143 fabrication process 139–141 microfluidic structural design 138-139 working principle 136–138 potentiometric electrochemical sensors 127, 135–143 potentiometric method 128, 130, 165 potentiometric sensor 128, 135–137 power management integrated circuit (PMIC) 130, 145 power management module (PMM) 32, 47, 50, 72, 127, 128, 155, 194, 195 power supply for low-power electronics 94-95 pressure sensors 12, 102 pressure-tolerant capability 117, 124 programmed system on a chip (PSoC) module 130, 146 prosthesis-assisted monitoring 26 pseudo-capacitor 9, 10, 50 purine-rich diets 185-189 PVA/H_3PO_4 gel electrolyte 51, 60, 88, 124 pyroelectric effect 6 pyroelectric effect-based generator 7 pyroelectric generator 6

r

random ellipsoidal model distribution 105 real-time health monitoring 22–24, 118, 127, 155, 169, 181, 182 rechargeable ion battery 9, 10 relative permittivity of dielectric layer 80 releasing time (RT) 118 resistance response (RR) 13, 65–67, 69–72, 102, 112–114, 118, 119, 122, 171, 174, 175, 179 respiration rate (RR) 4, 12, 24, 101, 159, 175, 194

S

sacrificial method 61 sandwiched SC 79, 88 sandwiched SCPU 78, 79, 88, 94, 97 sandwiched self-charging power unit 31, 32, 77-97 sandwiched supercapacitor 54 Seebeck coefficient 7 Seebeck effect 7 self-activated electrical stimulation 26 - 28self-charging energy unit 18, 193 self-charging performance 93–94 self-charging power cloth 16 self-charging power unit (SCPU) 16 flexible paper electrode-based supercapacitor 83-88 power supply for low-power electronics 94-95 SC evaluation 92–93 self-charging performance 93–94 smart display of electrochromic device 95-96 TENG by surface optimization 81–83 TENG evaluation 88–91 theoretical analysis 79-80 working principle 78–79 self-driven 3D touch 119 self-driven monitor patch 15, 18 evaluation of MSC 114-117 evaluation of PRS 110-114

integrated fabrication 108-110 modulation of parameters and morphologies 106-108 personalized human-machine interaction 118-120 real-time health monitoring 118 solution-evaporation method 105-106 static pressure distribution and dynamic tactile trajectory 120 - 123theoretical analysis 103-104 working principle 102 self-powered sensing platform 15, 20–22 serial-switch design 47 short circuit current 41, 46, 80, 89, 133, 134 silicon-based rigid materials 3 silicone encapsulation layer 24 simulation of stick model 77 single arch-shape TENG 89 single-electrode TENG 8, 20, 40–44 single flexible printed circuit board (FPCB) platform 127 single-step fluorocarbon (C_4F_8) plasma processing method 81, 96 skin-interfaced virtual reality 24 smart display of electrochromic device 95-96 smart lifestyle 1 smart textiles 14 sodium dodecylbenzenesulfonate (SDBS) 51.86 sodium dodecyl sulfate (SDS) 86 solar cell 6.7 solid gel electrolyte 9 solid-state supercapacitors 9–12, 51 solution-evaporation method 68, 73, 101.105-106 specific security communication process 120.121 spin-coating PDMS 82 strain sensors 12–15 stretchable humidity sensor 26 stretchable materials 28 stretchable sensors 24

structural design 128, 130 freestanding triboelectric nanogenerator 130-133 integrated health monitoring system 160-161 microfluidic 138–139, 173–177 supercapacitors (SCs) 11, 39, 77 for energy storage 50-60 evaluation 92-93 surface triboelectric charge polarities 6 surfactants 86, 106 system-level circuity module design and block diagram 176-179 signal processing and validation 179-181 system-level integrated circuit module characteristics 146, 148-149 operation flow analysis 145-146

t

TENG see triboelectric nanogenerator (TENG) **TENGoendash SCoendash TENG** sandwich-shaped structure 89 TENG-SC-TENG design 77 thermal energy-based nanogenerator 7 thermoelectric effect 6 thermoelectric generator 6 thermoelectric nanogenerator 7 three-dimensional (3D) columnar graphene 11 three-dimensional (3D) interconnected porous CNT-PDMS conductive elastomers 106 three-dimensional (3D) PMMA character 121 three-dimensional (3D) soft lithography 106 three-dimensional (3D) sponge structure 83 toluene 68, 106 transimpedance amplifier (TIA) 177 triboelectric charge density 7 triboelectric current 7 triboelectric effect 6

206 Index

triboelectric nanogenerator (TENG) 5, 77, 127, 193 assembly 82 for energy harvesting 39 evaluation 88–91 PDMS-based 193–194 triboelectric pairs 80 triboelectric potential 7 triboelectrification effect 131 two-dimensional (2D) graphene 11 tyrosine (Tyr) detection 165–168

u

ultrathin silicon nanobelt 26 uric acid (UR) detection 165–168 US Federal Drug Administration (FDA) 2

V

vacuum permittivity 7 virtual reality with dynamic feedback 24, 25 voltammetric sensor 136

W

watch crystal oscillator (WCO) 146
wearable all-printed, nanomembrane hybrid electronics 24
wearable health field 2
wearable supercapacitors 50–53
whole-body network monitoring 24
Wi-Fi wireless chip 4
wrinkled arch-shaped TENG 88
wrinkled rDMS-based TENGs 89
wrinkle structure development 82
wrinkle structure formation 81
wrinkle structure wavelength 81

y

Young's modulus 3, 81, 82, 102–105, 111–114, 123, 127

Ζ

zero-dimensional (0D) nanoparticles 11