

Index

a

- aberration-correcting electron optics 51
- aberration correctors 94, 131, 142
- aberration-induced emittance growth 79
- adatoms
 - density of surface sinks for 100
 - effective charge of silicon 113
 - electromigration 115
 - electromigration of 115
 - migration length of 116
 - step bunching and the electromigration 111
- adsorbed atoms, kinetics 99
- aerosol Au particle reaction with disilane 182
- agglomeration 126, 130, 183
- Al(Cu) line, micrographs of 293
- Al₂O₃ particles, secondary electron SEM images 32
- Al sample, stress–strain measurements 246
- Al thin films, mechanical behavior of 269
- aluminum conductor line 288
- ambient environment reaction
 - with various components 154
- ambient gas, interactions 154
- amorphous C 193
- amorphous material, crystallization 151
- analytical TEM 66, 67
- annular dark field (ADF) imaging 91
- annular dark-field STEM (ADF-STEM) 64
 - thickness and temperature dependence 65
- anti-bunch formation 111
- antiferroelectric ceramics 322, 335, 336, 340
- antiferroelectric-to-ferroelectric transition 321, 336, 340
- arbitrary waveform generator (AWG) cathode laser system 80, 81
- Arrhenius dependence 109
- Arrhenius law 130
- astigmatism 11, 12, 50, 51. *See also* spherical aberration
 - influence, schematic drawing 12
- atomic defects 125
 - agglomeration 126, 130, 183
 - in solids 126
- atomic force microscopy (AFM) 100, 230, 258
 - tip 231
- atomic number 23
 - contrast 21
- Au crystal, plastic deformation 137
- Au films
 - deformations 244
 - dislocation nucleation 244
 - electrodes 333
- Auger electrons (AEs) 3, 20, 25, 44, 66, 304
- Auger electron spectroscopy (AES) 205
- Au nanoparticles
 - ETEM image sequence 153, 154

b

- backscattered electron imaging (BEI) 291
- back-scattered electrons (BSEs) 20–22, 27, 32
 - characteristics 20
 - detection efficiency 15
 - efficiency 21, 22, 24
 - emission 13
 - escape depth 22
 - scintillator detectors 16
 - signal from 14
- backscattered-limited resolution 27
- band-to-band transition 305
- BaTiO₃ ceramic, crack formation 330
- Bauschinger effect 246
- BCF theory 116, 117
- beam effects 174
- beam electrons, threshold energy 129
- beam paths 79

- Berkovich conductive diamond indenter 272
- Bethe formula 18
- Black's law 282
- Blech segments 282
- Blech-type structure 285
 - drift rates 298
- body-centered cubic (BCC) 83
- Boltzman's constant 18, 282, 305
- bottom-up design process 211
- bound exciton transitions 305
- Bragg angle 33
- Bragg contrast 109
- Bragg-diffracted beam 48
- Bragg diffraction contrast 102
- Bragg's law 33, 34
- Bremsstrahlung radiation 26
- bright-field (BF) detector 56
- bright-field (BF) electron diffraction 73
- bright-field STEM (BF-STEM) 64
- bright-field TEM images
 - cavities, in glass ligament 330
 - of Cu(100) surfaces 202
 - electric field-induced crack growth behavior 329
 - electric field-induced domain wall fracture 332
 - electric field-induced fracture 327
 - morphology of nanometer-sized ferroelectric domains 325
 - sharp wedge geometry 268
- BSEs. *See* back-scattered electrons (BSEs)
- Burgers circuit 54
- Burgers vector 54, 55, 235, 243
- Burton–Cabrera–Frank (BCF) theory 109

- c**
- calibration
 - of growth environment 173
 - precise
 - high voltage of microscope 63
 - pulse arrival times 74
- carbon nanotubes 126
 - formation 155
 - irradiation 135
- carbon replica grating, bright-field images 77
- catalytic processes 162
- cathode ray tube computer monitor-based system 13
- cathodoluminescence (CL) 36, 303, 305
 - contrast, theories 306
 - monochromatic image 306
 - panchromatic image 306
 - principles of 304
 - CL spectroscopy, characteristic 305, 306
 - detection systems 307
 - electron-hole pairs, generation/recombination 304, 305
 - imaging, and contrast analysis 306
 - spatial resolution 306, 307
 - room-temperature (RT) blue light-emitting diode 308
 - in SEM and TEM 303
 - applications 307–313
 - cavities, in glass ligament 330
 - CBED. *See* convergent electron beam diffraction (CBED)
 - [1 3 3] CBED pattern 289
 - central laser initiation point 87
 - ceria–zirconia mixed oxides 151
 - cerium–zirconium oxides 162
 - channeling contrast 31
 - characterization technique 156
 - charge-coupled device (CCD) cameras 31, 77, 82, 227
 - chemical reactions
 - observation 145–165
 - types 146
 - chemical reaction, types 150–154
 - chemical vapor deposition (CVD) 172
 - Child–Langmuir effect 92
 - chromatic aberrations 11, 94. *See also* Spherical aberration
 - CL. *See* cathodoluminescence (CL)
 - CNT
 - formation 160, 161, 164
 - growth, low-magnification images 155
 - nucleation 160
 - coefficient of emissivity 106
 - complex wave function 46, 54, 58
 - composite TEM image, of anode and cathode ends of Al segment 272
 - compositional contrast 21
 - concentric multi-shell fullerene clusters 134
 - confocal laser microscopy 211
 - consecutive reflection electron microscopy 110
 - contour plot of copper islands after deposition 186
 - contrast mechanisms 28–31
 - channeling contrast 31
 - composition contrast 31
 - topographic contrast 28–30
 - contrast transfer function 49
 - conventional
 - detector 29
 - imaging techniques (*See* conventional TEM)
 - indentation techniques 257
 - nanoindentation techniques 257, 260

- optical microscopy 3
 - scanning electron microscopes 7
 - structuring techniques 133
 - conventional TEM 39, 44, 90, 94, 172
 - of defects in crystals 54, 55
 - straining stage 229, 242
 - convergence angle 49, 62, 63, 65, 91, 93, 94
 - convergent electron beam diffraction (CBED) 61–63, 267, 272, 278, 283, 284, 288, 289, 294, 298
 - characterization of amorphous structures by diffraction 63
 - large-angle convergent beam electron diffraction 63
 - scattering geometry 62
 - copper electromigration, diffusion pathway 288
 - copper grid electrodes 322
 - corrosive gase 164
 - Coulomb field 26
 - Coulomb forces 281
 - coulombic interactions 90
 - Coulomb interaction 281
 - crack growth 326, 328, 331–333, 335
 - crystal growth
 - electrochemical 183
 - experiments 172–175
 - from liquid phase 183, 187
 - reactions 184
 - from vapor phase 183
 - crystallization processes 90, 94
 - crystal surface, evolution 99
 - C_s-corrector 40, 51
 - Cu/ α -Al₂O₃ interface (IF) 239
 - dislocation network 238
 - Cu–Au alloy 202
 - oxidation 158
 - Cu–Au(100) oxidation 199
 - Cu reflections 202
 - Cu–Sn alloys 289
 - drift velocities 289
- d**
- dark-field (DF) electron diffraction 73
 - dark-field (DF) TEM images 197
 - Cu₂O dark-field images 197
 - de Broglie wavelength 40
 - defective carbon nanotube, reconstruction 134
 - deflection system 13
 - deformation
 - behavior 265
 - mechanisms 230
 - dehydroxylation 152, 153
 - deliquescence 153
 - dendritic transition 202
 - denuded zones 116
 - detection quantum efficiency (DQE) 157
 - device fabrication process 153
 - diamond crystal, nucleation 135
 - dielectric breakdown 330
 - differential cryogenic pumping device 105
 - differential Howie–Whelan equations 55
 - differential phase contrast (DPC)
 - imaging 347
 - differentially pumped system, drawback 149
 - differential phase contrast (DPC)
 - technique 56
 - differential pumping device
 - design 105
 - schematic drawing 105
 - differential pumping system, schematic flow-chart 150
 - differential scanning calorimetry (DSC) 88
 - diffraction pattern
 - by adjusting microscope.s projector lens system 59
 - Al film possess 246
 - energy-filtered 60
 - selected area electron diffraction patterns 83
 - by using EBSD detector 31
 - diffractograms 51, 52
 - diffusional processes 244
 - diffusion-induced grain boundary 244
 - diffusion processes 281
 - diffusivity 282
 - digermane (Ge₂H₆) 176
 - 3-D islands 114
 - dislocation mechanisms, controlling plasticity 240
 - dislocation nucleation 244
 - dislocations, TEM images 231
 - dispersive X-ray spectroscopy 34–36
 - displacement threshold 135
 - 2-D negative islands, nucleation 118
 - doped ceria (CeO₂) 162
 - double-walled carbon nanotubes 137
 - 3-D oxide islands, shape dynamics 205
 - 3-D shadowing effect 29
 - DTEM. *See* dynamic transmission electron microscopy (DTEM)
 - dual damascene structure, typical failure features 295
 - dynamical image contrast formation 73, 75
 - dynamical scattering theory 46
 - dynamic transmission electron microscopy (DTEM) 71, 72, 74, 76

- aberration correction 93, 94
 - acquiring high time resolution movies 81, 82
 - applications 82
 - arbitrary waveform generation laser system 80
 - crystallization under far-from-equilibrium conditions 88–90
 - current performance 74, 75
 - diffusionless first-order phase transformations 82–85
 - electron sources and optics 75–80
 - experimental applications 82–88
 - global space charge 90, 91
 - next-generation 91–94
 - novel electron sources 91, 92
 - observing transient phenomena in reactive multilayer foils 85–88
 - pulse compression 93
 - relativistic beams 92, 93
 - single-shot work 72–82
 - space charge effects in single-shot 90, 91
 - stochastic blurring 91
 - time resolution 82
- e**
- edge dislocation core model 49
 - EELS detector 162
 - efflorescence phenomena 153
 - elastically scattered electrons 53
 - elastic contact theory 270
 - elastic deformation 270
 - elastic scattering 16
 - angles 17
 - cross-section 45
 - direction via 304
 - of electrons 42, 44, 66
 - inversely proportional to 18
 - multiple 17
 - electric field-induced
 - antiferroelectric ↔ ferroelectric phase switching 335
 - crack growth 328, 329, 333
 - domain switching 325
 - domain wall fracture, confirmation of 334
 - phase transitions 321
 - relaxor-to-ferroelectric 344
 - electric field *in-situ* TEM experimental set-up 323
 - electrochemical deposition
 - of Cu onto polycrystalline Au electrode 185
 - and polymer growth, from liquid precursors 173
 - electrochemical liquid cells 184
 - electrode configuration 322
 - electromagnetic lenses 5, 9–13
 - electromigration 281. *See also* transmission electron microscopy (TEM)
 - damage 291
 - diffusion paths 296
 - *ex-situ* experiments 283
 - failure mechanisms 290
 - focused ion beam (FIB) 295, 296
 - induced drift rates 282
 - induced material transport 282
 - *in-situ* experiments 283
 - *in-situ* methods 298
 - comparison 284, 297–299
 - parameters 282
 - phenomenon 111
 - process 297, 298
 - scanning probe methods 296, 297
 - testing, mass depletion 290
 - electron backscatter diffraction (EBSD) 31–34, 212, 217, 283, 292, 298
 - scans for determining local crystal orientations 212, 214
 - electron beam 6, 134
 - schematic drawing 4
 - electron beam effects 157
 - electron beam-induced current (EBIC) 36
 - electron beam-induced decomposition (EBID) 160
 - electron beam-induced voltage (EBIV) 36
 - electron beam spot 138
 - electron current density 12
 - electron detectors 13–16
 - Everhart–Thornley detector 13, 14
 - in-lens/through-the-lens detectors 16
 - scintillator detector 15, 16
 - solid-state detector 16
 - electron diffraction 158, 191, 344
 - intensity calculations 115
 - electron-diffraction patterns 161
 - electron diffraction techniques 59–61
 - fundamentals 59–61
 - electron–electron interactions 72
 - electron–electron scattering 127
 - electron energy-loss spectroscopy (EELS) 65, 66, 127, 191, 303
 - electron guns 6–9
 - electron-hole pairs 304, 305
 - electron hologram 45
 - electronic drift compensation 131
 - electron interaction constant 57
 - electron irradiation 131–140, 139
 - electron–matter interaction 16–28, 26
 - electron microscopy

- in electron energy loss spectroscopy (EELS) 65, 66, 127, 191, 303
- electron irradiation 131, 132
- ion irradiation 132
- sample heating, benefits 106
- setup in 131, 132
- electron–optical system 4
- electron penetration range 305
- electron probe 9, 157
- electrons 125, 126
 - beam rays, schematic representation 103
 - energy distribution 21
 - experiments 132–141
 - inelastic electron scattering 128
 - scattering 128, 129
 - setup in electron microscope 131, 132
 - sources, properties 9
 - source, type 6, 7
 - structure factor 45
 - trajectories, Monte Carlo simulation 19
- electron–specimen interaction constant 47
- electrons scattering processes 44
- electron transmission microscopy, advanced 39
- electron-transparent film/polyimide area 242
- electron-transparent windows
 - principle 146, 147
 - schematic representation 147
- electrostatic deflector array 82
- electrostatic potential barrier, schematic drawing 7
- energy-dispersive X-ray spectroscopy (EDS) 9, 34, 65, 66, 127, 145, 193, 283, 303, 326
- energy-filtered diffraction pattern 60
- energy-filtered TEM (EFTEM) images 66
- energy-filtered transmission electron microscopy (EFTEM) imaging 163
- energy loss magnetic dichroism (EMCD) 347
- environmental cells 192, 193
- environmental scanning electron microscopes 6
- environmental transmission electron microscopes (ETEM)s 149, 156, 159
- epitaxial nucleation, of oxide islands 203
- epitaxial silicon carbide 107
- escape depth 20
- Everhart–Thornley (ET) detector 13, 14, 28, 29
- Ewald sphere 60
 - construction diagram 46
 - curvature 47
- excitation error 47, 54, 60
- ex-situ* measurements, on test samples 174
- ex-situ* nanoindentation experiments 272

f

- fabricating devices 90
- face-centered cubic (fcc) metal films 233
- fast Fourier transforms (FFTs) 161
- fcc single crystals 241
- Fermi level 25
- ferroelectric ceramics 321, 322
 - electric field-induced domain switching in 322
 - electric field-induced fracture 328
 - field-induced grain boundary 326
- ferroelectric domains 343
- ferroelectric material, dielectric permittivity of 322
- ferroelectric oxides
 - *in-situ* TEM technique 321, 322
 - antiferroelectric-to-ferroelectric phase transition 335–341
 - domain polarization switching 324–326
 - domain wall fracture 331, 335
 - experiment 323, 324
 - grain boundary cavitation 326, 330
 - relaxor-to-ferroelectric phase transition 341–345
- ferroelectric single crystals 146
- fiber-based electrooptical modulator 80
- field-cooling 341
 - cation-ordered domains, morphological changes 343
 - cation-ordered domains, morphology 344
- field emission gun (FEG) 8, 10, 50, 126
- field emission scanning electron microscopy (FESEM) 264
- field-induced crack growth process 328
- field-induced relaxor-to normal-ferroelectric phase transition 343
- film deposition 231
- fine-grained microstructures 89
- fluctuation electron microscopy (FEM) 63
- fluorescence process 26
- flux divergencies 298
- focused ion beam (FIB) 229, 295
 - cutting 241
 - grain contrast 295
 - milling 214
 - prepared samples 262
 - scanning electron microscope 233
 - single-crystal conductor line 296
 - structuring 133
- foreshortening effect 104
- Foucault imaging mode 56
- Fourier coefficients 44
- Fourier components 45
- Frank–Read dislocation 237

- Frenkel pair 129
 - frequency-tripled laser pulses 74
 - Fresnel contrast 57
 - Fresnel imaging mode 56
 - Fresnel imaging, schematic of 348
 - Fresnel zone plate-based technique 292, 294
 - full-width at half-maximum (FWHM) electron pulse 73, 351
 - fusion reactors 125
- g**
- GaAs-based quantum wells, fabrication 309
 - Ga⁺ ions 176
 - GaN epilayer 308, 309
 - gas-handling system 194, 195
 - gas-injection system 148
 - gas injector, schematic diagram 148, 149
 - gas–solid interactions 148
 - Gatan GIF Quantum series, of imaging energy filters 157
 - Gatan TV system 107
 - Gaussian distribution 12
 - global space charge (GSC) 90
 - gold electrodes 324
 - grain boundaries 282, 333, 342
 - cavities 329
 - crack 329
 - with Cu atoms 293
 - diffusion 282
 - grooving 297
 - motion 244
 - plasticity by motion 244, 245
 - triple junction 327
 - graphite–diamond interface, electron irradiation 140
 - graphitic carbon 134
 - grid/support materials reaction
 - with sample/with each other 154, 155
 - growth rate 174–176, 178, 179
- h**
- hardening 242
 - hardness 222
 - hexagonal close packing (HCP) 83
 - high-angle annular dark-field (HAADF) detector 64
 - high-current pulsed electron probes 72
 - high-energy electron 25, 26
 - higher order Laue zone (HOLZ) lines 62
 - highest spatial frequency 53
 - high oxygen flux 117
 - high-pressure impulse loading 92
 - high-quantum efficiency photocathode 78
 - high-resolution focal series 58
 - high-resolution images 30, 156, 158–161, 229
 - high resolution SEM 8
 - high-resolution TEM (HRTEM) 42, 48–53, 101
 - experimental conditions 43
 - image-formation process 48
 - images 45, 47, 49, 51, 53, 54
 - simplified ray diagram of image 50
 - high spatial resolution 100
 - high-temperature microscopy 131
 - high-voltage accelerator design 92
 - high-voltage electron microscope 93
 - holography 57
 - HOLZ reflections 62
 - Hough transformation 288, 289
 - Howie–Whelan differential equations 48
 - HRTEM. *See* high-resolution TEM (HRTEM)
 - hydroxylation 152, 153
- i**
- image formation process 13
 - InAs dots 310
 - incident wave vector 61
 - incoherent aberrations 53
 - indentation-induced dislocation nucleation 263
 - inelastic scattering 16, 17, 61, 66, 127, 128
 - cross-section 18
 - effects 20
 - electron beam by the oxygen gas 204
 - of ions 129
 - multiple 18
 - processes 18
 - infrared spectroscopy 145
 - in-lens detector system 27, 29, 30
 - advantage 23
 - schematic drawing 15
 - SEM image 30
 - in-lens/through-the-lens detectors 16
 - inline electron holography 57–59
 - inline holograms 58
 - advantages 58
 - in-situ* bending device, with vertically aligned loading axes 215
 - in-situ* 3-D imaging techniques 205
 - in-situ* electron irradiation 141, 142
 - in-situ* imaging 163
 - in situ* ion irradiation experiments 132
 - in-situ* loading samples in tension, compression, and bending
 - of macroscopic samples
 - applications of 216, 217
 - dynamic loading 216
 - static loading 214, 215

- of micron-sized samples 217, 218
 - applications of *in-situ* testing of small-scale samples 220–222
 - *in-situ* microindentation and nanoindentation 222, 223
 - static loading 218–220
 - in-situ* nanoindentation 255, 263
 - experimental methodology 260–263
 - *in-situ* mechanical probing 255, 256
 - nanoindentation 256–260
 - Al thin films, *in-situ* 269–272
 - silicon, *in-situ* 263–269
 - sample 262
 - cross-section of 270
 - in-situ* nanomechanical probing experiments 262
 - in-situ* oxidation
 - effect of electron beam irradiation 195
 - experiments using window environmental cells 193
 - importance of 192
 - study of surface oxidation 192
 - in-situ* Raman spectroscopy 259, 260
 - in-situ* TEM 88
 - growth experiments 173
 - in-situ* TEM straining experiments 227
 - instrumented stages 230–233
 - mechanical straining 229, 230
 - MEMS/NEMS devices 230–233
 - size-dependent dislocation plasticity 239
 - grain size heterogeneities, influences 245–247
 - plasticity by grain boundaries motion 244, 245
 - plasticity in geometrically confined single crystal fcc metals 241–243
 - transitions in dislocation plasticity 243, 244
 - thermally strained metallic films, dislocation mechanisms
 - basic concepts 233–235
 - nucleation and multiplication in thin films 236–239
 - polycrystalline Cu films, diffusion-induced dislocation plasticity 239
 - in single crystalline films 235, 236
 - thermal straining 228, 229
 - in-situ* UHV-REM technique 114, 115
 - in-situ* ultrahigh-vacuum (UHV) environmental transmission electron microscopy (TEM) 191
 - in-situ* visualization, of oxidation processes 203
 - instrumentation, and basic electron optics 40–42
 - interaction energy 114
 - interaction volume 18
 - schematic drawing 20
 - inverse pole figure (IPF) maps, of polycrystalline aluminum sample 217
 - ion-channeling effect 295
 - ion–electron scattering 129
 - ion irradiation 125, 126, 132, 140, 141
 - experiments 127
 - physics 126–129
 - radiation defects in solids 129, 130
 - ion irradiation facility, setup 133
 - ions scattering 129
 - irradiation principles 126
 - island nucleation 116
 - isothermal annealing 113
 - isotropic atomic scattering factors 44
- j**
- JEOL 200 CX transmission electron microscope, *in-situ* nanoindentation stage 261
 - JEOL 2000FX microscope platform 72, 73
 - Johnson–Mehl–Avrami–Kolomogrov (JMAK) semi-empirical formulae 88
- k**
- kinematical approximation 60
 - kinematical scattering theory 46
 - kinetic theory of gases 193
 - Kossel cones 33
 - Kramers relation 35
 - Kratos high-voltage microscope 261
- l**
- large-angle convergent beam electron diffraction (LACBED) technique 42, 63
 - large-bore lens 79
 - latex sphere 59
 - lattice distortion 54
 - lattice imaging 136
 - Laue condition 61
 - Lawrence Livermore National Laboratory (LLNL) 72, 157
 - dynamic transmission electron microscope 73, 75
 - lead zirconate titanate (PZT) ceramic 324
 - bright-field TEM images 325
 - EC65 ceramic 324, 325
 - microcracks development 327
 - nanometer-sized ferroelectric domains, morphology of 325
 - scanning electron microscopy image 326
 - lens system 11

- light elements analysis 34
 - liquid cell biological imaging 94
 - liquid crystal display (LCD) computer monitor-based system 13
 - liquid-phase growth processes 183
 - electrochemical nucleation 184
 - growth in TEM system 184–187
 - observing liquid samples using TEM 183, 184
 - Lomer–Cottrell dislocations 313
 - Lorentz force 10, 55, 56
 - Lorentz lenses 55
 - Lorentz microscopy 55–57, 56, 347–367
 - coils/pole-pieces, magnetizing 352–356
 - domain wall separations 364
 - dynamic randomaccess memory (DRAM) cells 358
 - electromigration, effect of 366
 - electron beam 350, 362
 - Fresnel imaging, schematic of 348
 - in-plane field component, creation 351
 - *in-situ* magnetic fields, generation of 357
 - *in-situ* magnetizing experiments 350, 351
 - magnetic disk 361
 - contrast formation 360
 - schematic of 359, 361
 - magnetic field values 355
 - magnetic rings, remanent states 363
 - magnetic specimen 358
 - magnetic stray field maps 365
 - magnetizing holder 356
 - technical drawing of 354
 - view of 353
 - magnetizing stages without coils
 - oersted magnetic field 356–358
 - self-driven devices 361, 362
 - spin torque applications 358–361
 - objective lens field with specimen tilt, combining 351, 352
 - problems solving 366–367
 - ring structures, demagnetization/magnetization of 362–364
 - stray fields, determination of 365, 366
 - thin Au conductor, light micrograph of 357
 - TWIN lens set-up 349
 - TWINlens configuration 355
 - use of 348
 - wall velocities, determination of 364
 - low-energy electron diffraction (LEED) 100
 - applications 101
 - low-vapor-pressure liquids 6, 173
 - low-voltage scanning electron microscopy (SEM) 101
- m**
- magnesium oxide (MgO) 152
 - mean free path (MFP) 17
 - mechanical annealing 242
 - median time to failure (MTF) 281
 - MEMS/NEMS-based tensile testing
 - of nanocrystalline Al and Au 245
 - MEMS/NEMS devices 231
 - drawbacks 232
 - limitations 233
 - TEM straining stage 231, 232
 - metal-induced crystallization 172
 - metal matrix compound (MMC) 217
 - micro-bending beam 218
 - micro-compression 241
 - microelectromechanical system (MEMS) technology 146, 174, 227
 - actuated tests 255
 - applications 88
 - microindentation 222, 223
 - micro-Laue diffraction 298
 - microscopic x-radiographic techniques 293
 - micro-tensile testing 241
 - micro-x-ray fluorescence 294
 - miniaturization 217
 - minority carriers, diffusion constant 305
 - Mo laser mirror 73
 - molecular beam epitaxy (MBE) 172
 - methods 99
 - molecular dynamics (MD) 63
 - monochromatic light, TEM images of
 - dislocations 312
 - Monte Carlo simulation 19
 - electron trajectory simulations 18
 - Mott formula 44
 - Mott scattering 17
 - movie mode technology 81
 - multi-walled carbon nanotube 139
 - electron irradiation 136
- n**
- nanoampere electron beam 76
 - nanocrystalline Ni films, *ex-situ* TEM studies 145
 - nanocrystalline Ti film, experimental isothermal phase diagram 84
 - nanocrystallites, deformation 135
 - nano-electromechanical systems (NEMS) 227
 - nanoelectronics technology 99
 - nanoindentation 222, 223, 255
 - *ex-situ* experiments 272
 - *in-situ* nanoindenter 219
 - load *vs.* displacement curve 258
 - nanoreactor, schematic cross-section 148

- nanoscale synthesis processes, robust scaling 145
- nanostuctre, growth 153, 154
- nanotechnology 180
- nanowire formation 178
- nanowires, synthesis temperature 158
- National Television System Committee (NTSC) 156
- natural oxide films 107
- Nb-doped lead zirconium titanate (PZT) 151
- negative C_s imaging (NCSI) conditions 51
- neodymium-doped yttrium aluminum garnet (YAG) lasers 74
- Ni micro-compression pillars, stress-strain curves 241
- Ni pillars, *in-situ* TEM compression 242
- NiTi pulsed laser-induced crystallization process 88
- nitridation 152
- nonacarbonyldiiron $[\text{Fe}_2(\text{CO})_9]$
- electron beam-induced decomposition (EBID) 160
- noncrystallographic fracture 268
- nonvanishing excitation error 46
- nucleate phase transformations 268
- nucleation 153, 154
- nucleation barrier energy 84
- nucleation kinetics
- of Ge islands on Si(001) 176
 - in nanostructures 180-183
- nucleation processes 115
- o**
- off-axis and inline electron holography 57-59
- off-axis electron holography 57-59
- off-axis hologram 58
- optical microscopy 26, 333
- disadvantages of 211
 - image 334
- (111)-oriented Al films
- cross-sectional thermal straining experiments of 235
- (100)-oriented Au films, transition 243
- Ostwald ripening 139
- oxidation phenomena 196
- of $\text{Nb}_{12}\text{O}_{29}$ 204
 - nucleation and initial oxide growth 197, 198
 - pathways 203-205
 - surface reconstruction 196
- oxidation reactions 150, 151
- oxidation/reduction cycles 151
- oxide nanostructures
- growth mechanisms for 153
 - oxide nuclei, orientations of 202, 203
 - oxygen pressure 202, 203
- p**
- partial spatial coherence 40
- Pati-Cohen model 84
- $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3$
- dielectric property of 341
 - polar nanoregions 341
 - polycrystalline specimens 341
- PbO-containing amorphous phase 330
- Peierls-Nabarro barrier 267
- phase distortion function 49, 50
- phase shift 50, 51, 57-59, 109
- phase transformations 82, 141, 151, 160, 182, 260, 263, 267, 268, 272
- phosphorescent screen 31
- photocathode source 91
- photomultiplier systems 13-15
- photon energy 305
- photons emission 25, 26
- picosecond-nanometer resolution single-shot imaging 93
- piezo-ceramic actuator 261
- piezo-driven *in-situ* fatigue testing device 216
- piezoelectric coefficients 334
- piezoelectric single crystals 146
- uses 331
- piezoelectric strain 333, 334
- pinning phenomenon 110
- plain excitation error 48
- Planck's constant 25
- plasmonics 287
- plastic deformation 241, 245, 263
- Al grain, time series of 271
- point analysis 35
- polarized cathodoluminescent light, quantitative analyses 311
- polar nanodomains, morphological evolution 342
- polycrystalline Al films 269
- stress values 236
- polycrystalline ceramic, polarization measurements 343
- polycrystalline Cu films 239
- dislocations emission 240
- polycrystalline films 235, 236, 237
- flow stresses 237
- polycrystalline reactant materials 85
- polycrystalline tantalum, back-scattered electron image 33
- polycrystalline thin films, thermal stress measurements of 236
- polyimide, single-crystal Al film 242

- polymerization 151, 152
 - pressure-induced phase transformations 257
 - primary electrons (PEs) 20
 - probe aperture-dependent semi-convergence angle 12
 - projector lens system 42
 - proportionality constant 45
 - protective oxide films 202
 - PSMN8 cation-ordered domains 344
 - PSMN8 ceramic 345
 - pulsed electron diffraction data 86
 - pulsed laser-induced crystallization process 88
 - pump laser 89
 - PZST 45/6/2 ceramic
 - field-induced transition 336
 - incommensurate modulation 337
- q**
- qualitatively imaging 227
 - quantitative *in-situ* TEM
 - nanindentation 272
 - quantum dots (QDs) 309
 - growth kinetics 176, 177
 - quasi-coherent approximation 49, 53
- r**
- radiofrequency (RF)-based photoguns 92
 - Raman peak shift 294
 - Raman spectroscopy 145, 157, 294
 - rapid material processes 81
 - rapid solid-state chemical reactions in reactive multilayer foils (RMLFs) 85
 - reaction front morphology, snap-shot images 87
 - reaction rates (kinetics) 164
 - reciprocal lattice vectors 45, 46, 54, 61, 62
 - recording media 156, 157
 - reduced density function (RDF) 63
 - reduction (redox) reactions 150, 151
 - reflection coefficient 118
 - reflection electron microscopy 99–107
 - consequent set 117
 - epitaxial growth 115, 116
 - extreme sensitivity 104
 - high sensitivity 103
 - images 113
 - images, features 103
 - monatomic steps 109–111
 - silicon substrate preparation 107–109
 - step bunching 111–114
 - stepped silicon images 112
 - surface patterns formation 99–102
 - surface reconstructions 114, 115
 - thermal oxygen etching 116–118
 - reflective high-energy electron diffraction (RHEED) 100–102, 107, 108, 113, 116, 118, 296. *See also* electromigration
 - disappearance 116
 - oscillations 118
 - residual gas analyzer (RGA) detector 195
 - reverse Monte Carlo (RMC) simulations 63
 - reversible switching, using O₂ 181
 - Rose criterion analysis 76, 77
 - rules of momentum conservation 127, 128
 - Rutherford scattering 16–18
- s**
- sample normal vector 22
 - sample temperature 174
 - satellite reflections
 - changes 338
 - electric fields for 340
 - evolution 339
 - satellites electronic, components in 125
 - scanning electron microscopy (SEM) 3, 145, 211, 326
 - auger electrons (AEs) 25
 - backscattered electrons (BSEs) 20–22, 27
 - components 4–16
 - schematic drawing 5
 - contrast mechanisms 28–31
 - deflection system 13
 - dispersive X-ray spectroscopy 34–36
 - electromagnetic lenses 9–13
 - electron backscattered diffraction (EBSD) 31–34
 - electron detectors 13–16
 - electron guns 6–9
 - electron–matter interaction 16–28
 - emission of photons 25, 26
 - emission of X-rays 25, 26
 - images of polycrystalline aluminum sample 213
 - for *in-situ* testing 212
 - interaction volume, and resolution 26–28
 - for microstructural characterization 3
 - other signals 36
 - preparation of specimen 212
 - secondary electrons (SEs) 22–25, 27
 - technical requirements 212–214
 - vs. optical microscopy 212
 - X-rays 27, 28
 - scanning probe microscopy (SPM) 145
 - scanning transmission electron microscopy (STEM) 39–41, 64, 65, 131, 155
 - imaging, advantages 65
 - imaging modes

- annular dark-field STEM (ADF-STEM) 64
- bright-field STEM (BF-STEM) 64
- and Z-contrast 63–66
- scanning tunnel microscopy (STM) 100, 187
- scattering processes 44, 126, 304
- scattering vector, function 83
- Schottky effect 6, 7
- Schottky emitters 9, 10, 41, 53
- Schwoebel effect 111
- scintillator detector 15, 16
- secondary electron imaging (SEI) mode 290, 291
- secondary electron microscopy
 - electron backscatter diffraction (EBSD) 31, 34, 217, 283, 292, 298
 - elemental analysis 291, 292
 - imaging 289–291
- secondary electrons (SEs) 22–25, 27
 - emission 13
- secondary electron yield 24
- selected area (SA) aperture 42
- selected-area electron diffraction (SAED) 73, 77, 152, 159, 202, 203, 284
 - patterns from oxidized surfaces 202
- selected area electron diffraction patterns (SAEDPs) 83
- self-cleaning process 8
- self-organization effects 125
- self-organization processes 130
- semiconductors 173
- semi-quantitative analysis 34, 35, 330
- shadowing effects 28
- shape transition
 - bright-field image of a Cu(110) film oxidized at 201
 - Cu(200) dark-field images 200
 - during oxide growth in alloy oxidation 199–202
- shot noise 76
- signal-to-noise ratios (SNRs) 27, 40, 71, 78, 79, 83
- silicide formation 172
- silicon
 - images 108
 - *in-situ* indentation 267
 - *in-situ* nanoindentation 266
 - nanostructures 313
 - plateau 263
 - surface morphology 114
 - technology 231
 - thermal etching, 2-D mechanism 118
 - wedge samples
 - *in-situ* nanoindentation experiments 264
- scanning electron microscopy images
 - of 264
- Si nanowires 153
- Si nanowires, nucleation and growth of 176
- single pump-probe snapshot 81
- single-shot approach 71, 72
- single-shot bright-field series, change in grain morphologies 85
- single-shot DTEM vs. conventional continuous-wave (CW) TEM 78
- single-shot electron diffraction 86
 - data 83
- single-tilt TEM straining stage, optical image of 230
- single-walled nanotubes 136
 - electron irradiation 138
- SiN thin films 193
- size-dependent dislocation plasticity 239–247
 - Cu film, dislocations emission 240
- solid energy diagram, schematic drawing 17
- solid-phase chemical reactions 145
- solids
 - defects formation 129, 130
 - defects migration 130
 - energetic particles in, scattering 126, 127
 - radiation defects in 129, 130
- solid-state detector 16
- solid-state reactions 164
- spatial coherence 49, 53, 58, 78, 79, 93
- spectroscopic techniques 150, 162
- specula-reflected electron beam
 - temporal dependences of intensity 118
- spherical aberration 11, 50, 51, 55, 94
 - coefficient 50
- split-off beam 74
- sputtering effects 139
- stainless steel sample, single-shot pulsed image 76
- standard pumping system 105
- STEM. *See* scanning transmission electron microscopy (STEM)
- STEM-EELS
 - advantages 67
 - maps 66, 67
- step bunching phenomenon 111–114
- step shape meandering 110
- stochastic blurring 91
- strain relaxation 175
- Stranski–Krastanov mode 310
- stress-driven grain boundary motion
 - in nanocrystalline Al 245
- stress–strain curves 241
- stroboscopic approach, refined to subpicosecond time resolution 71

- structural diagnostic methods 100
 - requirements 100
 - structural modification 158–161
 - surface and environmental conditions 193, 194
 - surface chemistry 173
 - surface defects, on surface oxidation 198, 199
 - surface morphology instability
 - phenomenon 113
 - surface phase transitions 111
 - surface-sensitive techniques 126
- t**
- Ta disk cathodes 78
 - temperature-resolved high-resolution imaging 158, 159
 - temporal coherence 40
 - temporal resolution 164
 - tensile testing 244
 - terraces 109
 - thermal annealing 105
 - thermal conductivity 127
 - thermal cycles 165
 - thermal diffuse scattering (TDS) 64
 - reduction 64
 - thermal dislocation network 237
 - thermal etching, 2-D mechanism 118
 - thermal field emitter (TFE) 8
 - thermally strained metallic films, dislocation mechanisms
 - concepts 233–235
 - nucleation, and multiplication in thin films 236–239
 - polycrystalline Cu films, diffusion-induced dislocation plasticity 239
 - in single crystalline films 235, 236
 - thermal straining experiments 229
 - thermionic cathode 13
 - thermionic electron guns 7, 8
 - thermionic source 6
 - thermogravimetric analysis (TGA) 197
 - thin-film deposition techniques 262
 - thin polyimide layer, causing fracture 242
 - threading dislocation deposition 233, 234
 - three-lens system, demagnification 10
 - time-resolved diffraction 85
 - time-resolved experiments, in dynamic transmission electron microscope 74
 - time-resolved high-resolution images 161
 - time-temperature-transformation (TTT) curve 84
 - topographic contrast contributions 31
 - topographic STM scans, linescans of 297
 - transfer cross-coefficient (TCC) 53
 - transmission electron microscopy (TEM) 3, 39, 45, 50, 59, 125, 127, 145, 172, 227, 321.
 - See also* scanning transmission electron microscopy (STEM)
 - ambient environment reaction with various components 154
 - analytical 66, 67
 - application 101
 - available information under reaction conditions 157–164
 - basics 39
 - chamber 322
 - chemical changes 161–163
 - chemical reactions observation 145–165
 - chemical reaction types suitable for 150–154
 - conventional 39, 44, 90, 94, 172
 - of defects in crystals 54, 55
 - straining stage 229, 242
 - convergent beam electron diffraction (CBED) 61, 63, 283, 288, 289
 - diffraction 288
 - electrochemical nucleation and growth in 184–187
 - electron diffraction 158
 - experimental setup 154–157
 - grid/support materials reaction with the sample/with each other 154, 155
 - high-resolution imaging 158–161
 - hydroxylation and dehydroxylation 152, 153
 - imaging 283–287
 - independent verification of results and electron beam effects 157
 - *in-situ* deformation studies 227
 - instrumentation 146–150
 - limitations and future developments 164
 - nitridation 152
 - nucleation and growth of nanostructure 153, 154
 - observing liquid samples using 183, 184
 - oxidation and reduction (redox) reactions 150, 151
 - phase transformations 151
 - polymerization 151, 152
 - principles 41
 - reaction rates (kinetics) 164
 - recording media 156, 157
 - resolution 184
 - selecting appropriate characterization technique 156
 - spatial resolution 71
 - structural modification 158–161
 - temperature and pressure considerations 155, 156

- transport-of-intensity equation (TIE) 347
tungsten filament, schematic drawings 8
turbomolecular pump (TMP) 149
two-dimensional rocking curves 63
- u**
- ultra-high-vacuum (UHV) 173, 174
– conditions 24, 99, 100
– level 6
– scanning electron microscopes 25
– UHV-REM experiments 119
– UHV-REM system 104
– UHV-REM technique 108, 109
ultrahigh-vacuum reflection electron microscopy (UHVREM) 102, 104
ultra-high vacuum (UHV) TEM systems 149
universal loading device
– placed in scanning electron microscope chamber 213
– for tension, compression/fatigue tests on small samples 220
- v**
- vacuum system 5, 102. *See also* ultra-high-vacuum (UHV)
vapor–liquid–solid growth of nanowires 177–180
vapor-liquid-solid (VLS) mechanism 160
vapor-phase growth processes 175, 176
vapor–solid–solid (VSS) mechanism 160
Vickers diamond indenter 333
video-taped SVTEM images 286
visible light emission 26
- w**
- wavelength-dispersive spectrometer (WDS) 34
– disadvantage 34
weak-beam dark-field (WBDF) TEM 42, 43
weak phase object approximation 47
- wedge-shaped cross-sectional sample 228
Wehnelt cylinder 6, 7
wind force 281
- x**
- Xe crystals 140, 141
– nucleates 141
x-radiography studies 292
– microdiffraction 294, 295
– microscopy, and tomography 292, 293
– spectroscopy 293
– topography 294
x-ray diffraction 145
x-ray emission spectroscopy (XES) 303, 307
x-ray energy-dispersive spectroscopy (EDS) 161
x-ray photoelectron spectroscopy (XPS) 205, 206
x-ray pump-probe techniques 71
x-rays 27, 28
– diffraction 343
– dot images 35
– emission 25, 26
– energies 35
– energy regions 36
– mean free path 27
– source 27
– spectrum 26
- y**
- Young's modulus 222
- z**
- Z-contrast imaging 64
zero-order Laue zone (ZOLZ) 61–63
Ziegler–Natta catalyst 152
ZnO nanowires 311
ZnSe light-emitting devices 312

