

## Index

### a

adiabatic expansion 31–33  
aerodynamics  
  lenses 142–144, 310  
  size 311  
Ag–Au nanoalloy clusters 72  
aggregation enhancement, NPs  
  buffer gas, pulsed delivery  
    cluster growth 218–221  
    experiment of 217–218  
  experiment 204–205  
  gas dynamic system 221–233  
  kinetic phenomena, cluster growth  
    cluster charge 211–212  
    clusters drift of 206–207  
    cluster velocity 209–211  
    orifice 207  
    temperature dependence of  
      207–209  
    thermalization 205–206  
  metal target pulsed sputtering  
    DC vs. DC pulsed magnetron  
      213–214  
    duty cycle effect 215–216  
  NPs 203–204  
Al-doped  $\text{Pb}_n^+$  clusters 70  
alloyed nanoparticles 109–110  
altocumulus lenticularis 3  
Antoine equation 161  
arcing problem methods  
  bipolar pulsed magnetron sputtering  
    252–254  
  substoichiometric targets 254  
  unipolar pulsed magnetron sputtering  
    252

Arrhenius's law 28  
atomic force microscopy (AFM) 140  
  cluster growth 208, 218  
  deposited nanoparticles 259, 369  
  multi-magnetron approach 92  
 $\text{Au}_n^+$  clusters 62, 63, 65–67  
auto-gas-aggregation source 5

### b

baffle system 250  
beam aperture  
  AFM 140  
  deposits of nanoparticles 141  
  nanoparticle beam 139  
  nozzle-to-substrate distance 141  
beam shaping 325  
Berg's model 254, 255  
Bernoulli's relationship 31  
bimolecular reaction 26–27  
binary nanoclusters 130–131  
biosensors 377–378  
bipolar pulsed magnetron sputtering  
  252  
Boltzmann constant 176, 210  
Boltzmann distribution 40, 159  
boron nitride (BN) 165  
buffer gas  
  cluster growth 218–221  
  pulsed delivery, experiment of  
    217–218

### c

calutron 303  
carrier gas (CG)  
  pressure 65–66

- carrier gas (CG) (*contd.*)
    - PSV 60–61
  - cathode dark space 7
  - cathode fall 7
  - cathode voltage control 249
  - chemical reaction, *see* wet chemical methods 101
  - chemoresistive sensors 375
  - classical nucleation theory (CNT) 25–26
  - Clausius–Clapeyron equation 161
  - Clausius–Clapeyron relation 161
  - cluster beams 325–327
  - cluster-deposition method 288
  - cluster ion trap 313
  - cluster mass flux 147
  - cluster production
    - binary nanoclusters 130–131
    - magnetron sputtering 131–132
    - simple metal nanoclusters 129–130
  - clusters drift 206–207
  - cluster sources
    - generic aspects design 39
    - high-vacuum free beam sources 39
    - laser ablation source 45
    - PACIS 46
    - PMCS 47
    - SGAS 42
    - SSNS 40
    - TGAS 42
  - cluster-surface interaction 324
  - cluster velocity 209–211
  - coating, NPs
    - core-shell NPs 272
    - crystallization mechanism 282
    - dielectric barrier discharge (DBD) 273
    - HRTEM 278
    - magnetron sputtering 274
    - molecular dynamics (MD) 280
    - NPs 271
    - TEM 277
    - transmission electron microscopy (TEM) 277
  - cobalt nitride (CoN) 243, 261
  - conductimetric sensors 375
  - continuous DC supply *vs.* pulsed DC power supply 263
  - core–shell nanoparticles
    - atomic resolution of 113, 115
    - chemical method 273
    - economic/environmental design 273
    - EELS 117
    - fabrication method 113
    - MICS 112, 113
    - physical and chemical property 272
    - protection from aging 273
    - STEM 113, 114
    - surface passivation 272
    - synthesis of 110
  - critical nucleus 25
  - critical temperature, nucleation 24–25
  - crystal structures
    - cluster-deposition method 288
    - dielectric oxide NPs 291
    - magnetic NPs 293
    - NPs high-anisotropy 289
    - post-growth annealing 290
  - cyclic voltammetry (CV) 93
  - cylindrical magnetron
    - characterization of 126–128
    - cluster production
      - binary nanoclusters 130–131
      - magnetron sputtering 131–132
      - simple metal nanoclusters 129–130
    - implementation of 124–126
- d**
- DC *vs.* DC pulsed magnetron 213–214
  - Debye–Scherrer rings 341
  - density functional theory (DFT)
    - cluster geometries 343
    - multi-magnetron approach 94
    - stability patterns of 70
  - deposited nanoparticle properties 259
  - dielectric barrier discharge (DBD) 273
  - dielectric nanocomposites 295
  - dielectric oxide NPs 291
  - direct current (DC) 244
    - cluster-deposition method 288
    - coating 273

- magnetron sputtering 149
  - NPs 81
  - sputtering 147
- double-laser ablation source
  - Ag–Au nanoalloy clusters 72
  - Al-doped  $Pb_n^+$  clusters 70
  - carrier gas pressure 65
  - gold (Au) clusters 66
  - laser energy density 62
  - laser, gas pulse timings 63
  - metal-doped (Si) clusters 72
  - target position source 66
- dual-target dual-laser source design 60, 61
- dusty plasma 9
- duty cycle 215–216
- e**
- e-beam evaporation, *see* electron beam epitaxy (EBE) 166–167
- electrochemical devices 378
- electromagnetic mass filter 303
- electron affinity (EA) 347
- electron beam epitaxy (EBE) 155, 166–167
- electron-dispersive spectroscopy (EDS)
  - alloyed NPs 110
  - multi-target single-magnetron 82
- electron energy loss spectroscopy (EELS) 89
- electron spectroscopy chemical analysis (ESCA) 168
- electron temperatures 233
- electron-to-ion temperature 232, 234
- electrostatic quadrupole 310
- empirical relationship 30
- energetic cluster impact (ECI) 9
- energy-dispersive X-ray (EDX) 82
- exchange-coupled magnets 296–298
- f**
- fabrication method 113
- face-centered cubic (FCC) 291
- finite element method magnetics (FEMM) 125, 126
- floating potential in plasma 232
- fluorescence textit hybridization (FISH) 377
- Fourier transform algorithm 345
- Fourier-transform ion cyclotron resonance (FT-ICR) 356
- Free-Electron Lasers for Infrared eXperiments (FELIX) 72
- Fritz Haber Institute of the Max Planck Society 61, 62
- functional and length-scale integration (FLSI)
  - CMOS 367
  - textit-selected nanoparticle deposition 369
  - FLSI 367
  - gas-phase synthesis 368
  - manipulate NPs 368
  - NPs 368
  - SCBD
    - biosensors 377
    - electrochemical devices 378
    - FlameBeam source 374
    - gas microsensors 375
    - neutral NPs 370
    - NPs deposition process 372
    - PMCS 375
    - seeded beams 371
    - supersonic cluster beam 373
- g**
- GAS, *see* gas aggregation sources (GAS) 257
- gas aggregation sources (GAS)
  - cloud formation 4
  - continuous DC supply *vs.* pulsed DC power supply 263
  - deposited nanoparticles 259
  - deposition machine 9
  - experimental questions 11
  - future development 17
  - kinetic energy 14
  - magnetron cluster source 6
  - magnetron power 263
  - mass spectra 9
  - process parameters 263
  - reactive gas sputtering 257, 259
  - reactive sputtering 243

- gas aggregation sources (GAS) (*contd.*)
    - types of 5, 6
    - UHV 257
  - gas aggregation synthesis
    - adiabatic expansion 31–32
    - kinetic nucleation theory
      - bimolecular reaction 26–27
      - RRKM theory 27–29
      - Weisskopf's model 29–30
    - landscape 23–24
    - nucleation
      - CNT 25–26
      - critical temperature 24–25
      - metal and covalent bonding 26
    - real gases clusters 30–31
    - size distribution
      - coagulation 35–36
      - general case 33–34
      - perfect sticking 34–35
      - Von Smoluchowski 34–36
    - supersonic beam, buffer gas 33
  - gas dynamic system 221–223
  - gas flow
    - aerodynamic lenses 142–144
    - beam aperture 139–142
    - gas pulses 144–146
    - oxygen-assisted synthesis 146–148
  - gas magnetron sputtering
    - arcing problem methods
      - bipolar pulsed magnetron sputtering 252
      - substoichiometric targets 254
      - unipolar pulsed magnetron sputtering 252
    - deposition of 251
  - GAS
    - continuous DC supply vs. pulsed DC power supply 263
    - deposited nanoparticles 259
    - magnetron power 263
    - process parameters 263
    - reactive gas 259
  - hysteresis effect in 244
  - hysteresis methods
    - baffle system 250
    - cathode voltage control 249
    - gas flow 250
    - pumping speed 246
    - reactive gas 247
    - target–substrate distance 249
  - modeling of
    - substrate surface, steady-state condition 255
    - target surface, steady-state condition 254
    - types of 244
  - gas microsensors 375
  - gas-phase grown clusters 323
  - gas pulses 144–146
  - generic aspects, design 39
  - Gibbs–Thomson relationship 25
  - glassy carbon (GC) 92
  - gold (Au) clusters 66
- ## h
- heat balance equation 209
  - heterogeneous nanoparticles 107
  - heterojunction bipolar transistor (HBT)
    - Knudsen cells 165
    - MBE 163
    - RF 163
    - RHEED 163
  - high-angle annular dark field (HAADF)
    - EDS 298
    - multi-magnetron approach 88, 103
  - high-anisotropy structures 289
  - high-flux DC magnetron sputtering
    - gas flow
      - aerodynamic lenses 142–144
      - beam aperture 139–142
      - gas pulses 144–146
      - oxygen-assisted synthesis 146–148
    - ion beams
      - focusing of 151–152
      - ion collection 148–151
  - highly oriented pyrolytic graphite (HOPG)
    - kinetic energies 330
    - multi-magnetron approach 92
  - high-power impulse magnetron sputtering (HiPIMS) 45, 227–230
  - high-power pulsed plasmas

HiPIMS 227–230  
 NPs growth 233–234  
   charging of 231–233  
   pulsed plasma 234–239  
 high-resolution transmission electron  
 microscopy (HRTEM)  
   alloyed NPs 110  
   coating 278  
   high-anisotropy 290  
 high vacuum (HV) 102  
 homogeneous nanoparticles 106  
 hysteresis curve 245  
 hysteresis effect, reactive sputtering  
 244

***i***

ion beams  
   focusing of 151–152  
   ion collection 148–151  
 ionized cluster beam (ICB) 6  
 ion velocity distribution functions  
 (IVDFs) 210

***j***

Jahn–Teller distortion 343

***k***

kinetic energy 14, 330–331  
 kinetic nucleation theory  
   bimolecular reaction 26–27  
   RRKM theory 27–29  
 kinetic phenomena  
   cluster charge 211–212  
   cluster growth temperature  
     207–209  
   clusters drift of 206–207  
   cluster velocity 209–211  
   orifice of 207  
   thermalization 205–206  
 Knudsen cell 42, 155, 157, 165

***l***

Langmuir equation 162  
 Langmuir free evaporation 155  
 laser ablation source 45  
 laser and gas pulse 63  
 laser energy density 62

liquid drop model 204  
 lognormal distribution 9

***m***

magnetic deflection experiments  
   avoided crossing model 353, 354  
   Co, Gd clusters 352  
   Nps 353  
   Stern–Gerlach experiment 305, 350,  
     355  
   3D metals 353  
   TOF 353  
 magnetic hysteresis (M-H) 86  
 magnetic NPs orientation/alignment  
 293  
 magnetic sector 312  
 magnetron cluster source 6  
 magnetron power influence 263  
 magnetron-sputter  
   core/shell NPs 274  
   cylindrical geometries for 131–132  
   head of 10  
   reactive sputter 244  
   shell-coating device 274–275  
 mass-filter, NPs  
   aerodynamic lenses 310  
   applications of 315  
   beam shaping 325  
   cluster beams 325–327  
   cluster ion trap 313  
   clusters 323  
   comparison of 314  
   in-flight processing 326–327  
   kinetic energies 330–331  
   magnetic deflection 305  
   magnetic sector 312  
   mass filtering 325–326  
   matter-wave interferometry 313  
   phenomena 327–330  
   postdeposition treatment 331–333  
   quadrupole 308  
   reflectron of 308  
   TOF 306  
   Wien mass filter 312  
 mass spectrometry 236  
 mass spectrum 9  
 matter-wave interferometry 313

- MBE, *see* molecular beam epitaxy (MBE) 40, 163
- MBE-Komponenten 165, 166
- metal-doped (Si) clusters 72
- metal nanoclusters 129–130
- metal nanoparticle (MENAPA) 169
- metal target pulsed sputtering  
 DC vs. DC pulsed magnetron 213–214  
 duty cycle effect 215–216
- metal vapor cell  
 alumina crucible 157, 158  
 components of 156  
 crucible materials 157  
 EBE 155, 166  
 LUMPS 167  
 MBE 163  
 melting points 156  
 methods and techniques 163  
 microgravity devices 169  
 pressure of 159
- methacrylic acid (MA) 198
- methyl methacrylate (MMA) 198
- microgravity devices 169
- micro-hotplate ( $\mu$ HP) 375
- microsupercapacitor ( $\mu$ SC) 379
- microwave plasma  
 coagulation 179  
 coated NPs 195  
 design of  
 average size 194  
 kitchen frequency 187  
 microwave mode 188  
 operating conditions 189  
 plasma torch 192  
 precursor 191  
 $WS_2$  particles 190  
 energy transfer  
 Boltzmann constant 176  
 collision frequency 177  
 energy depends 176  
 formation of 179  
 iron oxide 175  
 molecular dynamic 180  
 sequence of 179  
 temporal evolution 182
- modulated pulse power (MPP) 229
- molecular beam epitaxy (MBE)  
 defines of 155  
 HBT 163  
 SSNS 40
- molecular dynamics (MD) 341  
 coating 280  
 MPs 88
- molybdenum–lanthanum (ML) 157
- molybdenum–yttrium oxide (MY) 157
- multi magnetron  
 alloyed NPs 109  
 core–shell NPs 110  
 gas aggregation source 104  
 homogeneous NPs 106  
 NPs 86  
 NPs fabrication 106  
 perspectives, applications 117  
 PVP 87  
 total sputtering gas flux 106  
 working parameters of 104, 105
- multiple ion cluster source (MICS) 44, 102
- multi-target single-magnetron  
 M-H 86  
 Nps 82  
 photoelectron spectroscopy 85  
 TEM 82
- n**
- nanoparticles (NPs)  
 aggregation 203–20  
 beams 48  
 DC 81  
 growth 236  
 HiPIMS 231  
 HRTEM 278  
 magnetic deflection experiments 350  
 microwave plasma  
 coated NPs 195  
 design of 187  
 energy transfer 176  
 formation of 179  
 iron oxide 175  
 mixing patterns 79, 80  
 multi-magnetron approach 86, 101  
 multi-target single-magnetron 82

- PES 340, 345
  - techniques for 101
  - XAS 345
  - X-ray absorption spectroscopy (XAS) 339
  - X-ray scattering 340
  - nanosized cluster formation 204
  - nanostructuring orientation, annealing
    - crystal structures
      - cluster-deposition method 288
      - dielectric oxide NPs 291
      - magnetic NPs 293
      - NPs high-anisotropy 289
      - post-growth annealing 290
    - dielectric nanocomposites 295
    - exchange-coupled magnets 296
    - scope of 287
  - neutral metal (M) atoms 11
  - NPs, *see* nanoparticles (NPs)
  - nucleation
    - CNT 25–26
    - critical temperature 24–25
    - metal and covalent bonding 26
- o**
- optical emission spectroscopy (OES) 247, 248
  - orifice 207
  - oxygen-assisted synthesis 146–148
- p**
- Paschen law 7
  - $\text{Pd}_m\text{Au}_n^+$  clusters 63–65
  - photoelectron spectroscopy (PES)
    - DFT 348
    - EA 347
    - LDA theory 349
    - NPs 85, 340
    - Si cluster 72
    - TOF 340, 345, 350
    - XAS 350
  - plasma emission monitoring (PEM) 246, 248
  - polymerization 233
  - polyvinylpyrrolidone (PVP) 87
  - postdeposition treatment, NPs 331–333
  - post-growth annealing, NPs 290–291
  - process parameter influence 263
  - pulsed-arc cluster ion source (PACIS) 46
  - pulsed microplasma cluster source (PMCS) 47
  - pulsed reactive gas flow 250
  - pulsed supersonic valve (PSV) 60
  - pumping speed, hysteresis 246
- q**
- quadrupole electrodes 310
  - quadrupole mass filter (QMF)
    - nanocluster source 205
    - NPs 87
    - schematic diagram of 308–310
- r**
- racetrack shapes 14
  - radial velocity 310
  - radio-frequency (RF) 244
    - cluster-deposition method 288
    - coating 273
    - MBE 163
    - multi magnetron 104
    - NPs 81
  - ray photoelectron spectroscopy (XPS) 111
  - reactive gas
    - influence 259
    - partial pressure 247
  - real gases clusters 30–31
  - reflection high-energy electron diffraction (RHEED) 163
  - reflectron mass filter 308
  - residual gas analyzer (RGA) 169
  - Rice–Ramsperger–Kassel–Marcus (RRKM) theory 27
  - rutherford backscattering spectroscopy (RBS) 73
- s**
- scanning electron microscopy (SEM) 92
  - scanning transmission electron microscope (STEM) 88, 89, 103, 298

- seeded beams 371
  - seeded supersonic nozzle source (SSNS) 40
  - SGAS, *see* sputter gas aggregation source (SGAS) 42
  - shell-coating device
    - magnetron-sputter shell 274, 275
    - nanocluster deposition system 276, 277
    - representation of 275, 276
  - silicon germanium thin-film space-thin-film carbide (SiGe:C) 163
  - Site-selected nanoparticle deposition 369
  - size distribution
    - coagulation 35–36
    - general case 33–34
    - perfect sticking 34–35
    - Von Smoluchowski 34–36
  - sputtered dimers role 13
  - sputtered metal atoms 12
  - sputter gas aggregation source (SGAS)
    - HiPIMS 45
    - MICS 44
    - vaporization technique 42
  - sputtering process 42
  - SSNS, *see* seeded supersonic nozzle source (SSNS) 40
  - standard effusion cell WEZ 165
  - steady-state condition
    - substrate surface 255
    - target surface 254
  - Stern–Gerlach experiment 305, 350
  - sticking coefficient 27
  - stored waveform inverse Fourier transform (SWIFT) 343
  - substoichiometric targets 254
  - supersonic beam 31
  - supersonic cluster beam deposition (SCBD)
    - biosensors 377
    - electrochemical devices 378
    - FlameBeam source 374
    - gas microsensors 375
    - neutral NPs 370
    - NPs deposition process 371
    - PMCS 375
    - seeded beams 371
    - supersonic cluster beam 373
  - supersonic source 5
- t**
- target–substrate distance 249
  - TGAS, *see* thermal gas aggregation source (TGAS) 42
  - thermal gas aggregation source (TGAS)
    - generic aspects 40
    - Knudsen cell 42
  - thermalization 205–206
  - Thermal treatment 331
  - thin-film NPs 230
  - time of flight (TOF)
    - GAS 259
    - geometry of 306
    - laser and gas pulse 64
    - mass filter 306
    - mass spectrometer 129
  - time-of-flight medium energy ion scattering (TOF-MEIS) 93
  - Tolman’s delta 26
  - transmission electron microscopy (TEM)
    - coating 277
    - multi-target single-magnetron 82
    - NPs 103
- u**
- ultra high vacuum (UHV)
    - GAS 102, 257
    - metal vapor cell 155
  - unipolar pulsed magnetron sputtering 252
  - University Mesoscopic Particle Source (LUMPS)
    - ESCA 168
    - GAS 167
    - RGA 169
    - UHV 168
  - unmanned aerial vehicle (UAV) 375
- v**
- van der Waals relationship 24
  - vaporization technique 43
  - vapor pressure



- Antoine equation 161
- Boltzmann distribution 159, 160
- Clausius–Clapeyron equation 161
- curve of 160, 161
- Langmuir equation 162
- NPs deposition 159
- vinylidene fluoride (VDF) 295
- virial coefficient 31
- Von Smoluchowski 34–36
  
- W**
- wet chemical methods 101
- Wien mass filter 312
- Wigner–Seitz radius 210
  
- X**
- X-ray absorption spectroscopy (XAP)
  - DFT 348
  - EA 347
  - LDA theory 349
- PES 350
- TOF 345, 350
- X-ray diffraction (XRD) 289
- X-ray magnetic circular dichroism (XMCD) 355
- X-ray photoelectron spectroscopy (XPS)
  - alloyed NPs 110
  - deposited NPs 259
  - mass spectra 9
  - multi-magnetron approach 93
- X-ray scattering
  - Debye–Scherrer rings 341
  - DFT 343
  - Fourier transform algorithm 343
  - Jahn–Teller distortion 343
  - MD 341
  - NPs 340
  - SWIFT 343
- XRD, *see* X-ray diffraction (XRD) 289

