

Index

α -chloroacrylate, 346
 α -methylbenzyl phenyl ether, 272
1,1-diphenyl-2-picrylhydrazyl, 256
[2 + 2] cycloaddition, 238
2,2'-azobis(butyronitrile), 283
4,4'-bis(dimethylamino)
 benzophenone, 287
4,4'-diazidobenzalacetone, 246
4,4'-diazidobenzophenone, 246
4-acetoxystyrene, 319
4-hydroxystyrene, 318

A

absorbance, 65
absorption coefficient, 57
acetal resist systems, 75
acid–base interactions, 132
acid–base neutralization reactions,
 103
acridine amine, 95
acridinium dyes, 290
acriflavin, 290
acrylate, 7
acrylonitrile, 346
action spectrum, 217
activation energy, 75
acylsilanes, 248
addition polymerization, 405
aerial image, 50
aerial image formation, 55
aldehydes, 271
alicyclic polymer, 89
alignment, 49

alkoxymethylmelamine, 249
allyl methacrylate, 257
aluminum, 24
ambipolar diffusion, 125, 188
anionic polymerization, 376
anthracene, 209
anthraquinone, 286
antireflection coating, 26, 55
ArF exciplex laser, 8
aromatic monazines, 95
ascorbic acid, 291
atom transfer
 polymerization, 399
Auger electrons, 66
Avogadro's number, 71
azides, 244

B

Beer–Lambert law, 65
Bejerrum length, 158
benzoyl peroxide, 282
bis-azides, 244
bitumen, 234
bitumen of Judea, 234
bleachable absorbance, 67
block copolymers, 25
Bodenstein pseudo-steady state
 approximation, 72
Bohr atom, 136
Boltzmann constant, 138
Boltzmann distribution, 149
Born repulsion, 136
Brønsted acid, 91, 294

broadband, 54
Byers–Petersen model, 89

C

calixerenes, 270
camera obscura, 234
capillary force, 26
carbanion, 386
Case II diffusion, 109
cationic polymerization, 247, 405
ceiling temperature, 359
chain scissioning, 13, 106
chain transfer, 407
charge density, 153
chemical amplification resist, 7
chemical etchant, 4
chemical potential, 125
chemical vapor deposition, 36
chemo-epitaxy, 26, 366
chromatic aberration, 15
chromophore, 235
Claisen rearrangement, 200, 300, 342
coagulation, 132
coating, 1
cohesive energy density, 183
collisional quenching, 206
colloidal particle, 164
commensurability, 29
complex refractive index, 56
concentration quenching, 207
condensation, 199, 253
condensation imaging mechanism, 270
conjoining pressure, 42
contact angle, 34
contrast, 123
contrast curve, 130
contrast enhancement, 56
copolymer domains, 363
copper, 24
Coriolis force, 38
Coulomb's law, 157

Coulombic charge–charge interaction, 125, 157
Coulombic force, 157
counterion, 132
critical dimension, 49
critical wavenumber, 44
crosslink formation, 106
crosslinkable polystyrene, 27
crosslinkers, 19
crosslinking, 13, 199
crystal-originated pits, 42
cyclized polyisoprene, 101
cycloolefin, 7
cycloolefin/maleic anhydride, 7

D

Debye interaction, 135
Debye length, 156
Debye–Hückel approximation, 156
Debye–Langevin equation, 138
deep-ultraviolet light, 3
deep-ultraviolet spectral region, 199
defectivity, 40
defects, 20
deformation, 449
dendrimers, 270
depolymerization, 200
deprotection, 75, 106, 200
deprotection kinetics, 89
depth of focus, 4
developer solution, 4, 31
development, 1
development rate gradient, 74
development rate models, 111
dewetting, 42
di(α -methylbenzene)ether, 272
diamond, 19
diazo-Meldrum's acid, 307
diazonaphthoquinone/novolac system, 7
diazonaphthoquinones, 305
diazonium ion, 265
diazoquinone, 249
diblock copolymers, 393

- dichromate resists, 241
dielectric constant, 148, 159
dielectric permittivity, 143
diffraction order, 10
diffraction pattern, 52
diffusion coefficients, 187
diffusion length, 85
diffusion point spread function, 78
diffusivity, 83
Dill model, 66
dimedone, 291
dioxycyclopentadiene, 296
dip coating, 36
dipole–dipole interaction, 103
dipole-induced dipole interaction, 135
dipole resonance, 211
discharge-produced plasma, 11
disjoining pressure, 43
dispersion, 103
dispersion forces, 134–135
dissociation constant, 155
dissociative electron attachment, 232
dissolution inhibition, 200, 309
di-*tert*-butyl peroxide, 331
dry ArF lithography, 7
- E**
Einstein's coefficient of absorption, 71
Einstein's relation for absorption, 71
electric field, 26, 56
electrolyte, 153
electromagnetic radiation, 1
electromagnetic spectrum, 143
electron acceptor, 209
electron beam curing, 119
electron beam lithography, 12
electron beams, 66
electron source, 13
electronegative atoms, 132
electronic polarizability, 138
electrophilic substitution, 251, 253
electrostatic double-layer forces, 132
electrostatic double-layer interaction energy, 161
electrostatic double-layer interactions, 131, 158
ellipsometry, 46
embossing/imprinting, 1, 447
emission, 209
energy migration, 214
energy transfer, 203, 210
energy transfer quenching, 207
enhanced kinetic development rate model, 112
enthalpic change, 128
enthalpy of mixing, 182
entropy, 164
esterification, 199, 273
ethylacrylate, 256
excimer-binding energy, 208
excimers, 208
exciplexes, 208
excitation energy, 209
excited complex, 209
excited molecule, 203
exciton, 214
expectation (mean) value, 98
exposure, 1
exposure wavelength, 98
extended source method, 54
extreme ultraviolet lithography, 10
extreme ultraviolet photons, 66
extreme ultraviolet spectral region, 199
- F**
Fick's second law of diffusion, 76
field emission, 14
field-emission sources, 15
finite difference methods, 88
Flory–Huggins entropy of mixing, 181

Flory–Huggins theory, 106, 183
flow fields, 26
fluorescein, 290
fluorescence, 94, 204
fluorescence spectroscopy, 94
fluorophores, 94
Fourier transform, 53
free electron laser, 11
free-radical polymerization, 330
free radicals, 280
Fresnel reflection coefficients, 56
Fresnel transmission coefficients, 56
Fujita–Doolittle equation, 83
functional group transformation, 106

G

g-line lithography, 7
G-value, 258
GaAs, 24
Gaussian function, 77
glass, 19
glass transition temperature, 41
gold, 24
Grahame equation, 154
grapho-epitaxy, 26, 366
ground state, 203
Grun's formula, 120
Guoy–Chapman theory, 149

H

h-line lithography, 7
Hamaker constant, 43, 138
Henry's law, 85
hexamethyldisilazane, 32
Hildebrand's solubility parameters, 128
homolytic cleavage, 91
Hopkins' method, 54
hydration interactions, 132, 164
hydrodynamic volume, 104
hydrogen bonding, 103, 128, 132, 165
hydrolysis, 280

hydrophobic effect, 124
hydrophobic forces, 162
hydrophobic interaction, 124, 132, 163
hydroxymethylmelamine, 249

I

i-line lithography, 7
illumination optics system, 6
imprint lithography, 17
indene carboxylic acid, 70
induction, 103
induction forces, 134–135
information registration medium, 123
inherent radiative lifetime, 206
integrated circuit devices, 1
interaction parameter, 182
interfacial interactions, 26
interference effects, 55
intermolecular forces, 103
internal crossing, 203
intersystem crossing, 204
intramolecular dehydration reaction, 269
intramolecular esterification, 273
intramolecular forces, 103
ion beam lithography, 16
ionization, 228
ionization frequency, 139
IR spectroscopy, 91

J

Jet and Flash Imprint lithography, 21

K

Köhler illumination, 51
Keesom interaction, 135
ketal resist systems, 75
ketene intermediate, 70
ketocoumarins, 288
kinetic development rate model, 112
Kodak thin film resist, 244

L

lanthanum hexaboride, 14
Laplace pressure, 43
laser-produced plasma, 11
latent heat of vaporization, 128
latent image, 75
lens, 51
Lewis acid–base interactions, 132
ligand exchange, 199, 277
light polarization, 55
lipophilic system, 133
lithographic molecular solubility modulation, 129
lithographic resolution, 4
lithographic simulators, 76
living polymerization, 375
London interaction, 135
London–van der Waals interactions, 41
Lorenz–Lorentz equation, 142
low-energy secondary electrons, 231
low thermal expansion material, 11
lumped parameter model, 112

M

main-chain scissioning, 200
maleic anhydride, 273
manufacturability, 40
mask, 2, 31
master, 445
Maxwell's equations, 54
mercury (Hg) arc lamp, 7
metacresol, 307
metal-ion-free developers, 101
metal oxide sulfate, 242
methacrylic acid, 327
methyl methacrylate, 327
methylene blue, 290
methylolated phenolic, 271
Michler's ketone, 287
mid-ultraviolet spectral region, 199
Mo/Si multilayer, 11
molecular orbit, 203
molecular self-assembly, 1

molecular weight, 45
Monte Carlo simulation, 174
multiplicity, 203

N

N-(9-acridinyl) acetamide, 95
N-hydroxynaphthalimide triflate, 279
N-methoxymethylated melamine, 251
nanotechnology, 25
negative-tone resist, 4, 131
neutral layer lift-off, 28
Newtonian fluid, 37, 449
nickel, 19
nitromethane, 331
nonbleachable absorbance, 67
nonparaxial scaling equations, 9
nonpolar solvents, 103
norbornene, 273
normal-incidence illumination, 56
normalized image log-slope, 74
Norrish type I degradation, 345
novolac, 249, 307
numerical aperture, 4

O

O-alkylation, 253, 270
o-nitrobenzyl ester, 311
Onsager distance, 189
optical density, 65
order–disorder transition, 364
orientation forces, 134–135
osmotic force, 164
overlay, 50
oxirane, 294
oxycyclohexene, 296
oxygen quenching, 207

P

p-polarized light, 59
p-toluenesulfonic acid, 311
partial coherence, 54
PEB delay stability issues, 76

- PEB sensitivity, 76
pellicle, 6
perfluoropolyether, 19
permanent dipole moment, 138
permanent dipoles, 135
peroxo complexing agent, 242
phase, 52
phase separation, 25
phenol, 307
phenylene diacrylates, 239
phenylsilanediol, 273
phosphorescence, 205
photoacid generator, 3
photoactive compound, 3
photochemical imaging
 mechanisms, 199
photochemistry, 200
photocurable oligomers, 19
photodimerization, 238
photoelectrons, 66, 230
photo-Fries rearrangement, 200,
 300, 342
photoimprint lithography, 17,
 441
photoinsolubilization, 234
photoisomerization, 248
photolithography, 5
photolysis, 71, 199
photomask, 6
photon shot noise, 97
photophysics, 200
photopolymerization, 443
photoresist, 3
pinacol–pinacolone rearrangement,
 267
pinacol rearrangement, 199, 268
pinholes, 42
pinhole camera, 101
planarization, 49
Planck's constant, 71
plasma (dry) etch, 4
platinum, 24
Poisson distribution, 97
Poisson's ratio, 19
polarity switching, 199
polarizability, 138
poly(3-methyl-4-hydroxy styrene),
 46
poly(4-hydroxy- α -methylstyrene),
 321
poly(4-hydroxyl styrene-*co-t*-
 butoxycarbonyloxystyrene), 79
poly(4-hydroxystyrene sulfone), 321
poly(4-hydroxystyrene-*co-4*-
 polyhydroxystyrene-*tert*-butyl
 ester), 324
poly(4-hydroxystyrene-*co-tert*-butyl
 acrylate), 326
poly(4-*tert*-
 butoxycarbonyloxystyrene
 sulfone), 321
poly(4-vinylbenzoic acid), 325
poly(acrylate), 101
polycarbonates, 357
poly(chloro-acrylate-*co- α* -
 methylstyrene), 355
poly(chloromethyl styrene), 259
poly(chloromethyl styrene-*co-2*-
 vinyl naphthalene), 259
poly(*cis*-isoprene), 245
poly(cycloolefin), 101
poly(dimethyl siloxane), 19, 444
poly(diphenyl siloxane), 260
polydispersity index, 368
polyelectrolyte, 132
polyelectrolyte effects, 175
poly(ethylene terephthalate), 22
poly(glycidyl methacrylate), 256,
 347
polymer, 3
polymer–polymer attractive forces,
 103
polymerization, 199
polymer-relaxation-controlled mass
 transfer, 109
poly(methacrylic acid), 325
poly(methyl isopropenyl ketone),
 351

- poly(methyl methacrylate), 327, 343
polynorbornene, 441
poly(olefin sulfones), 352
poly(phthaldehyde), 356
poly(*p*-styrene sulfonate), 260
poly(*p*-*tert*-butoxycarbonyl oxystyrene), 315
polystyrene, 46, 441
poly(styrene-co-maleimide), 321
poly(styrene-co-N-(4-hydroxyphenyl)maleimide), 321
poly(styrene-*r*-methyl methacrylate), 26
poly(tetrafluoro ethylene), 441
poly(tetrahydrofuran-co-novolac), 314
polyurethane, 441
poly(vinyl alcohol), 242
poly(vinyl benzyl chloride), 101
poly(vinyl butyral), 242
poly(vinyl cinnamate), 217
poly(vinyl cinnamylidene acetate), 238
poly(vinyl phenol), 343
poly(vinyl pyridine), 249, 260
poly(vinyl pyrrolidone), 242
positive-tone resist, 4, 131
positron annihilation lifetime spectroscopy, 46
post-apply bake, 47
post-exposure bake, 1
post-exposure stabilization, 1
potential gradient, 155
prebake, 47
primary electrons, 230
printing, 20
projection system, 51
PROLITH, 75
propagation constant, 56
propargyl methacrylate, 257
propylene glycol monomethyl ether acetate, 28
pupil-fill, 10
- Q**
quantum mechanics, 70
quantum yield, 96, 206
quartz, 19
quenchers, 87
quenching process, 206
quenching sphere, 214
- R**
radiative migration (self-quenching), 207
radical initiators, 19
radiochemical imaging mechanisms, 199
radiolysis, 199
radius of gyration, 45
rearrangement, 106
reflective imaging system, 10
reflective mask, 10
relative dielectric constant, 187
residual layer, 453
resist, 2, 123
resist bleaching, 55
resist contrast, 130
resist image, 66
resist trim and neutral brush, 27
reticle, 6, 31
riboflavin, 290
ring-opening metathesis polymerization, 330
roll-to-roll photoimprint lithography (R2R-PIL), 22–24
rose bengal, 290
rotational velocity, 38
roughness, 19
- S**
s-polarized light, 58
scalar model, 55
scission yield, 225
secondary electrons, 119, 203
self-assembled monolayer, 24
self-assembly, 363

- self-condensation, 273
self-consistent mean-field theory, 418
semiconductor lithography, 2, 31
sensitizers, 209
sessile drop technique, 34
shear stress, 449
silesquioxanes, 273
silicon, 19
silicon nitride, 19
silicon wafer, 3
siloxycarbenes, 248
silver, 24
simple harmonic oscillator model, 139
single-wafer puddle process, 102
singlet, 203
singlet–triplet splitting, 219
sinusoidal aerial image, 64
SiO₂, 24
soft bake, 47
soft lithography, 20
solubility parameter, 103
solubility, degree of, 128
solvent annealing, 366, 430
solvent evaporation, 26
spatial frequency, 10, 53–54
spectral sensitization, 216
speed of light, 71
spin coating, 36
spinodal decomposition, 43
spray coating, 36
stable free-radical polymerization, 399, 401
stamp, 445
standing waves, 55
static dielectric constant, 187
step-and-scan architecture, 11
steric interactions, 132
Stern–Volmer equation, 207
Stirling’s approximation, 179
styrylpyridine, 240
sulfonium salt, 91
super-hydrophobic surfaces, 24
superacid, 87
supercritical CO₂, 275
surface energy, 20
surface potential, 161
surface tension, 43
swelling, 4
synchrotron, 11
- T**
T-top forms, 84
template, 445
tert-butyl methacrylate, 327
tetracene, 209
tetrahydrofuran, 286
tetrahydropyranal methacrylate, 275
tetramethylammonium hydroxide, 101
thermal depolymerization, 357
thermal fields, 26
thermal imprint lithography, 17, 441
thermionic emission, 14
thermodynamics, 125
thermoplastic polymer, 19
thiazines, 290
thionine, 290
thoriated tungsten, 14
titanium, 24
transesterification, 275
transistor, 5
transmittance, 65
transverse electric, 58
transverse magnetic, 58
triazines, 285
triblock copolymers, 394
triphenyl sulfonium
 hexafluoroantimonate, 299
triphenyl sulfonium triflate, 79
triplet, 203
triplet sensitization, 217
truxillate, 236

truxinate, 236
tungsten, 14

U

ultrathin resist, 40
universal gas constant, 187
UV radiation curing, 117

V

van der Waals dispersion forces, 124
van der Waals interactions, 105, 132
van der Waals radii, 208
vector model, 55
velocity profile, 37
vinyl addition polymerization, 330
viscosity, 451
viscosity-dependent (dynamic)
 quenching, 206
viscosity-independent (static)
 quenching, 206
viscous forces, 37
visible spectral region, 199

W

wafer, 31
water-immersion ArF lithography,
 8
wetting, 26
Williams–Landel–Ferry equation,
 451

X

xanthenes, 290
x-ray photons, 66
x-ray reflectometry, 46
x-ray spectral region, 199
xylene, 269

Y

Young–Dupré equation, 35
Young’s equation, 34
Young’s modulus, 19

Z

zirconium, 24



Uzodinma Okoroanyanwu is a research scientist and founder and chief executive officer of ALLNANO LLC, a company that develops and produces printed electronic devices and nanostructured materials used in applications in energy transduction and storage, sensing, display, and wearable electronics. He worked previously at Advanced Micro Devices, where he spent 12 years conducting research on advanced lithography and organic polymer memories, and at GLOBALFOUNDRIES, where he spent 4 years conducting research on advanced lithography. He has published extensively on lithography science and technology and on electronic applications of polymers. His previous book is *Chemistry and Lithography* (SPIE Press, 2010).

A holder of 36 U.S. patents, Okoroanyanwu was educated at The University of Texas at Austin, where he earned the following degrees: Ph.D. in physical chemistry (1997), M.S. in chemical engineering (1995), M.A. in physical chemistry (1994), and B.S. in chemistry and chemical engineering (1991).