#### а

absorbing film 170, 171 absorption 42-46 - of carbon black 173 - constant 40, 43, 44 - of electromagnetic radiation 25, 52, 54.57 - inhomogeneous line spreading of absorption spot 41 - Lambert absorption rule 43, 44 - of laser radiation 50, 109-114, 194, 199.217 - of MIR-laser radiation 55-59 - of NIR-laser radiation 49, 50, 54, 63 - of PC 43 - plastics to NIR radiation, adaption of 2 - properties 49 - spectral absorption of Clearweld coating 168 - spectra of natural PMMA, PA6 and PP 55 spectra of thermoplastic resins 54 - surface, in thermoplastic resins 141 additives 35, 36, 42 - absorbing, properties regarding laser welding applications 65 adaptation of NIR-radiation absorption 59 - based on copper phosphates 63 - heat-sensitive LIS agents 194 light-scattering 185 - like inorganic pigments 119 - nano-ITO 66, 173 - organic dyes 217 - silicone-based 192, 193 - use of absorbing additives 172-178 air-bag systems, fabrics for 222 aligned two-mirror beam-guiding system 95

amorphous thermoplastic resins – material properties 10 – polycarbonate 10, 50 – polymethylmethacrylate 10 – polystyrene 5, 10 – polyvinylchloride 4, 6, 10 – temperature conductivity 33 amorphous thermoplastics 10, 12, 19, 21, 23, 27, 28, 32, 33, 46, 126, 134, 185, 188 Arrhenius function 131 asymmetric oscillation 54 automotive components 60, 217 – airbag sensor 218 azo dyes 66

# b

beam diameter 113 beam-guiding systems 88 – glass-fiber systems 88–93 - mirror systems 93, 95 beam parameter product (BPP) - focal length and Rayleigh length 77, 78 - of laser sources for plastic welding 76 beam propagation 74 - BPP as constant quantity for laser 76 - and focusing properties 73 - of TEM<sub>00</sub> mode 75 - in transparent media 90 beam-shaping optics 100, 101 - device 153 beamsplitter 143 Bernoulli's Lemniskate geometries 155 Boltzmann constant 131 BPP. see beam parameter product (BPP) Brown's micromobility 128 butadiene resin (BR) 13

Laser Welding of Plastics, First Edition. Rolf Klein.

© 2011 Wiley-VCH Verlag GmbH & Co. KGaA. Published 2011 by Wiley-VCH Verlag GmbH & Co. KGaA.

butt-joint welding 143 – in analogy to hot-plate welding 143 – with laser 142 – principle of 142 – of thermoplastic components 143

#### С

camshaft sensor 220 carbon black 173, 174 - pigments 59-61 case studies - automotive components 217-222 - consumer goods 223-226 - electronic devices 227-231 - medical devices 232-237 - others 238-241 CCD camera, imaging recording 198 CD players 1 cerumen protectors 235 clamping device advantage of 191 – design of 191 clamping tools, alternatives for 189 Clearweld coating 167, 168 - contour laser-welded PMMA sample 169 - transmission spectra of 167 Clearweld process 172 CO<sub>2</sub>-lasers 1, 35, 85, 86 - beam-bending mirror for 94 principle setup of a waveguide 86 slow-flow, principle setup 85 color-corrected laser-transparent 175 color-corrected opaque samples – using Clearweld LWA 267, 176 communication technology 1 comolding laser welding with absorbing layer by 171 - of plastic components 170 component centering - by clamping device 191 - using adapted component contour shapes 190 computer data storage 1 conformation angle 55 consumer goods 1, 2, 223 contour laser welding - joint design using 183 – principle of 146 copolyamides 17 copolyester elastomers 17 copolymers 15, 16 crystallization temperature 11

# d

decomposition temperature Td 13 diffusion coefficients 130, 131 diffusion process 128 digital imaging - cameras 206 - of contour laser welding PET films 207 - techniques to monitor the laser-welding process 205 diode lasers 35, 74, 78-80 - with direct beam emission 80 - to form weld line 151 - high-power 1 - semiconductor materials and wavelengths of 79 – setup of 79 diode-pumped fiber laser, principle setup 84 dipole momentum 56 down-holder tools 189 dryer fabric, for paper manufacturing machinery 239

# е

Einstein's law 130 elasticity 7 elastomers 8, 13 - copolyester 17 - temperature behavior of mechanical properties 13 - thermoplastic 14, 15-18, 21, 177 -- polyolefin 16 -- polyurethane 17 electromagnetic radiation 59 - distribution in solid body, wave equation 36-42 - and material, interaction 35 - oscillation excitation by absorption of 58 electronic devices, optical sensor 227 electronic excitation, in polymers 41, 50 epoxy resin 13

# f

Fabulase coating, laser-welded LDPE sample 169
Fabulase dispersion 169
Fabulase laser pigments 177
fiber-coupled diode laser 81
fiber lasers 83–85
materials, wavelengths in NIR spectral range 84
finite element method (FEM) computation 122, 123
fixing tie 238 fluid tank, for self-running carpet cleaner 225 focusing elements 97 focusing properties, of laser beam 76, 77 focusing systems 95 - beam-shaping optics 100, 101 - dynamic focusing systems 99, 100 - static focusing systems 95-98 frame oscillations. see oscillations Franck–Condon principle 50 frequency spectrum, for a linear molecule chain 25 fusion process theory 126-135 - crystalline phases mixing 133-135 - interdiffusion process (see reptation model) - macromolecules interchange, by squeeze flow process 132, 133

# g

gap bridging simulation 126 garments made of plain woven fabrics 226 gas measurement device 228 Gauß line spreading 40 Gaussian beam - optics 91 - in TEM<sub>00</sub> mode 76 Gaussian distribution 127 geometrical aberration 76 geometrical optics 89 geometrical translation symmetry 59 glass-fiber beam-delivery system 89 glass-fiber-reinforced PA6, spiral-bound tube of 162 glass-fiber reinforcements 185 glass-fiber system 88-93 - for high laser power 93 - with SMA connector for low laser power 92 glass temperature Tg 11 glass-transition temperature 23 Globo laser welding 156, 184 - of automotive lamp housings 157 - principle of 157

# h

halogen lamps – NIR radiation from 158 – spectral distribution of 159 heat capacity 24–27 heat conduction 20, 27–30 – influence of crystallization level 30 – in thermoplastics 27 – total heat conductivity 29 heat-conduction equation 115, 116 heat dissipation 121 heat transfer 31 heavy-duty instruments, for ship building 240 hydraulic pump, fluid reservoir for 221

#### i

indium tin oxide (ITO) 61, 64, 65 infusion pump 234 injection molding 191 ink cartridge, for large size printer 230 inorganic pigments 61-64, 66 - absorption of NIR radiation 61 integrated laser welding system 107 interaction processes 109 - between laser radiation and macromolecules 109 - within and between molecule chains 26 interdiffusion process 132 - of macromolecule chain segments 131 IR camera 202 IR-hybrid laser welding 184

# j

joint geometry. *see also* laser plastic welding – design of 181–186 – gap bridging 193–195 – obstacles to avoid 191–193 – tolerances/clamping 186–191

## k

Kuhn's sphere model 127

## I

Lambert law 116 larger gap bridging 194 laser absorbers 173, 176 laser-absorbing additives 111, 117, 177. see also additives laser-absorbing coating 186 - liquid coatings 167 - surface coatings 172 - ultrasonic spray device for 166 laser-absorbing component 207 - black coloration of 217 - carbon black 209 laser-absorbing dyes, to optical transparent resins 175 laser-absorbing liquid, joint-interface geometry 185 laser-absorbing materials, Fabulase powder 171 laser-absorbing organic dyes 175

laser-absorbing resin comolding of plastic components 170 - FABULASE NBD-801 194, 195 laser-assisted tape winding 161 - principle of 161 robotic system for 162 using diode laser 162 laser-assisted thermotransfer application 171 laser beam 144 - focusing 147 intensity distribution of 74 laser-beam diameter 114 laser-beam welding - gap bridging 195 - HDPE, gap bridging for 194 laser contour welding, processing parameters 146 laser focusing head - with integrated digital imaging camera 206 - with external thermography camera 204 - with integrated optical reflection measurement 208 with integrated pyrometer 202 laser-induced foaming process 194 laser light scattering 196 laser line energy 146, 149 laser marking, of PC/ABS 178 laser plastic welding 217 - absorption, adaption of 163 -- absorbing additives, uses 172-178 -- special lasers, uses 178–181 -- surface coatings, uses 163-172 - butt-joint welding, principle of 141-143 - contour welding 145-148 - crystalline phases mixing 133-135 - fusion process theory 126-135 - Globo laser welding 156-158 - heat generation and dissipation 109-126 - industrial joining method 217 - interdiffusion process 131, 132 - IR-hybrid laser welding 158, 159 - joint geometry 181-193 - laser energy transfer into process heat 114-118 - laser radiation absorption 109-114 - laying/winding 160-162 - macromolecules interchange by squeeze flow process 132, 133 - mask laser welding 154, 155 - material compatibility 135-138 process heat dissipation 118–121 process simulation, by complex computation 121-126

- quality monitoring, and control methods 195-211 -- digital imaging monitoring 205-207 -- mechanical set-path monitoring 208, 209 -- monitoring techniques 209-211 -- optical reflection monitoring 207, 208 -- before processing 196-199 -- pyrometric monitoring 199-203 -- thermography monitoring 203-205 - quasisimultaneous laser welding 148-150 - simultaneous laser welding 150-154 - through-transmission laser welding (TTLW) 143-145 - TWIST laser welding 155, 156 - typical laser sources for 87 - ultrasonic hybrid laser welding 159, 160 laser quasisimultaneous welding - processing parameters for 148 laser radiation 109-114, 156, 161 - absorption, properties for 218 - direct absorption 109, 110 - hindered absorption by internal scattering 111-114 - indirect absorption 110, 111 - NIR lamp and 158 - properties of 71-73, 76 - reflection of 207 laser sewing system 160 lasers, types of. see CO2-lasers; diode lasers; fiber lasers; Nd:YAG-lasers laser-transparent components 196 - interface 119 - radiation-scattering additives 186 - transmission of 196, 197 laser-transparent resin layer 121 - melting depth 122 laser wavelength 73 laser welding 150 - with absorbing additive 173 - with absorbing layer, by comolding 171 - with absorbing surface layer 172 - applications 181 - concentric laser beam circles 152 - electronic car 174 - gap bridging 174 - geometrical joint tolerance limits 188 - head, IR hybrid 159 - holographic mask as 153 - in industrial applications 2 - integrated temperature radiation measurement during 98 - IR-hybrid, principle of 158

- joint 145 - joint design 184, 185, 187 - joint gaps 193 - joints using laser-absorbing coating 188 - microfluidic mixer device 181 - monitoring and control techniques 195 - natural HDPE samples 176 -- using Fabulase 322 pigments 176 - obstacles for 192 - parallelism limit of 189 – of PC/ABS with PMMA 178 - PET films, digital imaging of 207 - plastic laser welding system, setup 102 - PP resin with carbon black 193 - quality 146 - of SAN without and with temperature control by pyrometer 203 - system, principle setup of 101 - of thermoplastics 141, 179, 199, 200 -- components 2, 143, 163, 180, 196.209 -- fabrics 160 -- monitoring process 210 -- resins 163, 180, 185, 199 - ultrasonic hybrid 160 laser-welding methods, for industrial application 217 laser-welding process 158, 186, 190, 208. see also laser welding - closed-loop control of 201 - coloration 168 - simulation 125 laser welding systems, principle setup of 101-107 - beam-shaping optics, for circular beam pattern 101 - CNC controller 104 integration -- into production chain 106 -- with work piece feeding system 107 - plastic laser welding system, typical setup 102 - pneumatic clamping device 103 - stand-alone laser welding system 105 -- for plastic chairs 106 - work-piece handling systems, basic configurations 102 laser-welding transparent PC, with absorbing PC film layer 170 Lazerflair<sup>®</sup> pigments 61, 62 lens material 95 - used for focusing 97

light amplification 1 liquid-coating application 170 liquid-coating technologies 163 Lorentz line spreading 41 Lorentz–Lorenz law 39 low-volume–low-pressure (LVLP) pneumatic spray valves 165

#### m

macromolecular chain - coupling between atoms 3 – Kuhn's sphere model 128 - with no crosslinks 9 - orientation and length of 20 - oscillation (see vibronic excitation) - reptation model 129 - segments, interdiffusion 131 macromolecules - conformation types 5 - crosslinked 8 - helix type/statistical knotted 57 - interchange of 132, 133 - penetration process 127 - stretching 134 - van der Waals bonding 28 mask laser welding - flexibility of 155 - principle of 155 medical devices 232 melt energy, for semicrystalline thermoplastics 22 melt-flow index (MFI) 136 – values 9 melting process 119 microfluidic device 233 microfluidic disposable cartridge - for DNA and RNA analysis 236 MIR radiation 109 mirror systems, laser systems 93-95 molding process 171 molding tool, injection system 192 molecule groups, of polymer materials 38 monochromatic radiation 59 monomer units 3 multiresin-injecting molding tools 170

# n

nano-ITO pigments 173 natural resins, NIR radiation 114 natural thermoplastic resins 110

Nd:YAG-lasers 1, 35, 74, 76, 80-83, 161, 163 - diode-pumped, principle setup 82 – lamp-pumped, principle setup 81 - laser-assisted tape winding 162 - radiations 53 near-order bonding forces, for crystalline structure 134 needle-tip dispenser, for coating application 164 needle-tip dispensing systems 167 NIR imaging, laser-absorbing coating on joint 199 NIR lamps 158 NIR-laser 35 - absorbing layer 164 - beam-bending mirror for 94 radiation 144 NIR radiation - in polymeric material 54 - spectral wavelength distribution of 158 NIR-radiation absorption by additives, adaptation of 59 - carbon black pigments 59-61 - inorganic pigments 61-64, 66 - organic dyes 66 - properties regarding laser welding application 65 NIR-sensitive cameras 202 NIR-transmission imaging 198

### 0

oil reservoir 241 optical constants 36-42 optical material properties absorption 141 optical penetration depth 174, 175 optical polarization 38 optical properties 35, 36 optical sensor 227, 229 organic dyes 66, 110 - absorption properties of thermoplastic resins 66 dispersion 110 oscillation excitation, by absorption of electromagnetic radiation 58 oscillation frequency 57, 58 – methylene group 57 oscillations around their center positions 24 – C–H group 54, 55 – elastic 27, 29 – frame 56, 58, 110 - induced by acoustic/optical waves 26

- material by stimulating electron 35 - MIR spectrum inducing 35 - optical mode of grid, stimulation 25 - resonance 37 - rotation 24, 57 - side-chain molecules/end-chain molecule 56 - stimulation of dipole 42 - thermal effects 21 - types of atoms and atom groups 57 - vibration 35, 42 oscillation spectrum 25 - density distribution 26 - heat capacity at constant volume 26

PA6 fiber material - absorption spectra 55 - influence of crystallite size 12 - influence of optical penetration depth 46 – monomers - spiral-bound tube of glass-fiberreinforced 162 - temperature course of transmission and 122 transmission, in wavelength range from 53 PA6 resin 113, 117, 118 perionon dyes 66 perylene dyes 66 PET. see polyethylenterephtalate (PET) phase transitions - crystallite melting temperature (T<sub>m</sub>) 20 - flow temperature  $(T_f)$  20 - glass transition ( $T_g$ ) 20 - thermal decomposition  $(T_d)$  21, 22 phenolic resin 13 photometric detector 208 Planck's law 200 plasticization process 170 plastic laser-welding processes, quality-monitoring techniques 211 plastics - basic structure of 3 - bonding partners and chain conformations 4 - classification 8 - composites consist of 9 - conformation types of macromolecules 5 – films 141 - molecular and macroscopic material properties 7

- monomers 4 - phase-transition temperatures 9 - physical and chemical structure of macromolecule 6 - processes for generation 4 – resin 155 - scattering of NIR- and IR-radiation in 46-49 - secondary valence forces 6.7 statistical distribution of macromolecule chain length 6 - types of 7,8 plastic welding 1 - BPP of typical laser sources for 76 PMMA. see polymethylmethacrylate (PMMA) pneumatic clamping device, principle setup 103 pneumatic spray device, with laser absorbing coatings 165 pneumatic valves 165 polarization microscopy, observation of cross section 179 polyaddition 3 polyamide (PA) 10 polycarbonates (PC) 10, 50 - reflection and transmission 43 polycondensation 3 polyester resin 13 polyethylenterephtalate (PET) 50, 161, 194, 195, 204, 206 polymer blends 14, 15 polymer composites 18 - classification 19 polymer compounds 14 polymeric matrix 110, 111 polymer macromolecules - mobility 126 polymethylmethacrylate (PMMA) - absorption spectra 55 - as amorphous thermoplastic resins 10 - contour laser-welded sample 169 - nano-ITO particles, transmission of 63 - phase-transition temperatures 21 - refractive index, temperature dependency of 40 - relative weld strength for 137 - temperature conductivity, average values of 34 polyphenylensulfide (PPS) 50 - material properties 11 - stimulated to oscillation by absorption of CO<sub>2</sub>-laser radiation 58

polypropylene (PP) 10 – monomers 4 polystyrene molecules 5 polyurethane resin 13 printer cartridge 231 PVD coatings, at joint interface 192 pyrometers 202, 208 – detector 97

## q

quasisimultaneous laser welding 150
heating process 149
laser beam 148
melt squeeze flow 149
principle of 148
and simultaneous, quality monitoring 206

### r

radius of gyration 127 red laser radiation 1 reflection 42-46 - materials used for 94 - radiation intensity weakening by 43 relaxation process 133 reptation model 127–132. see also interdiffusion process resins. see also laser-absorbing resin; thermoplastic resins - butadiene 13 - epoxy 13 - heat expansion coefficient 136 - laser-transparent 185 - melt-flow index (MFI) 136 - PA6, 123 - phenolic 13 – PMMA 168 - polyamide 179 - polyester 13 - polyolefin 66, 178 - temperature-dependent thermal 122 - thermoplastic 9, 10, 20, 133, 136, 176, 185.192 ruby laser 1

# S

scanner head 99
basic setup 99
in combination with a fiber-guide system 100

scattering - caused by polymer matrix 48 - constant 111, 112 - of NIR- and IR-radiation in plastics 46-49 - structures in polymers and effect to radiation 49 semicrystalline thermoplastics 10-12, 33.34 - behavior 134 - below the glass temperature 23 - heat capacity of 26 - heat conductivity in 30 - layers, resolidification 135 - melt energy for 22 - resins, temperature behavior 12 - temperature conductivity as function of 34 simultaneous laser welding - beam-shaping optic device 153 - cylindrical components — mirror setup for 154 - principle of 150, 152 specific volume 22-24 – behavior of 23 speedometer 220 squeezing process 120 - microswirls caused by 134 static focusing device, principle setup 98 styrene block copolymers 17 styrene butadiene resin (SBR) 13

#### t

temperature conduction 30-32 temperature-dependent radiation absorption 123 temperature distributions – rule of thumb 118 thermal fusion process 141 thermal models, complex 115 thermal oscillation of atoms 22 thermal process control device 162 thermal properties 19, 20 thermal resin expansion 126 thermal-treatment-induced polymerization 160 thermography camera 203, 206 - controller of 203 - images of laser welding PET films 204 - monitoring 205

thermography imaging, of simultaneous laser-welding process 205 thermoplastic copolymers, conditions of application 15 thermoplastic elastomer (TPE) blends 16 - copolymers 17 – structure 16 - types 16 - uncolored 18 thermoplastic elastomers (TPEs) - physical and chemical properties 136 - types 138 - welding 138 thermoplastic resins 9, 10, 118 - absorption properties 181 - hot-plate welding 133 - laser radiation on 115 - melt-temperature ranges and 22 - optical penetration depth, for laser radiation 46 - phase-transition temperatures for 21 thermoplastics 7, 8. see also plastics - average values of temperature conductivity 34 - macromolecular structure of 10 thermoplastic vulcanization elastomers 16 thermosets 8, 13 - temperature behavior 14 through-transmission laser welding (TTLW) 1, 141, 143, 144, 179, 181 - laser beam focusing optic, schematic setup of 179 - laser welding plastic components 145 - principle joint designs 183 - using absorbing layer 163 - using laser-absorbing coatings 144, 145 transmission 42-46, 53 – of Clearweld<sup>®</sup> A208 and A267 dye 64 - of FABULASE<sup>®</sup> 322, 63 - of Lazerflair<sup>®</sup> 825 in PP 62 - of Lumogen® dyes in PC 64 - measurement, control device for 197 - of nano-ITO particles in PMMA 63 – PA6 film 53 - welding 155 TTLW. see through-transmission laser

welding (TTLW)

TWIST laser welding 155, 156 – principle of 156 – of transparent plastic components 156 two-mirror beam-guiding system 96

# и

ultrasonic hybrid laser welding 160 ultrasonic nozzles 166, 167 – soft spray 167 ultrasonic power 160

# ν

valence angle forces 56 vibronic excitation 51, 52 VIS-NIR spectrometers 197

## w

welding speed 104, 118, 123, 146 weld-quality monitoring 207 work-piece handling systems 102 wrist watch, with heart rate monitoring 224