Contents

Part I Laser–Matter Interaction Phenomena

1 Ultrafast Laser Induced Confined Microexplosion: A New Route to Form Super-Dense Material Phases .......... 3
Ludovic Rapp, Bianca Haberl, Jodie E. Bradby, Eugene G. Gamaly, Jim S. Williams and Andrei V. Rode
1.1 Introduction ..................................................... 4
1.2 Energy Density in Confined Ultra-Short Laser Interaction with Solids ................................................. 5
1.2.1 Absorbed Energy Density .................................. 5
1.2.2 Ionisation Processes ....................................... 7
1.2.3 Increase in the Absorbed Energy Density Due to Modification of Optical Properties ................. 10
1.2.4 Energy Transfer From Electrons to Ions: Relaxation Processes After the Pulse ................. 11
1.3 Shock Wave Propagation and Void Formation ............ 13
1.3.1 Shock Wave Generation and Propagation .......... 13
1.3.2 Shock Wave Dissipation ................................. 14
1.3.3 Rarefaction Wave: Formation of Void .......... 15
1.4 Density and Temperature in the Shock-Wave and Heat-Wave Affected Solid ................................. 16
1.4.1 Two Characteristic Areas in Confined Microexplosion ................................................. 16
1.4.2 Upper Limit for the Pressure Achievable in Confined Interaction ................................................. 17
1.4.3 Ionisation Wave Propagation Towards the Laser Beam ................................................. 18
1.4.4 Modelling of Macroscopic Explosions by Micro-Explosion ................................................. 20
1.5 Formation of Void at Si/SiO₂ Interface ......................... 21
1.6 Summary ......................................................... 24
References .......................................................... 25
2 Molecular Dynamics Simulations of Laser-Materials Interactions: General and Material-Specific Mechanisms of Material Removal and Generation of Crystal Defects ........ 27
Eaman T. Karim, Chengping Wu and Leonid V. Zhigilei
2.1 Introduction ..................................................... 27
2.2 Physical Regimes of Laser-Material Interactions ............ 30
2.3 Generation of Crystal Defects Below the Spallation Threshold ........................................ 36
2.4 Evolution of Voids in Photomechanical Spallation ............ 39
2.5 The Visual Picture of Phase Explosion .......................... 41
2.6 Conclusions ....................................................... 44
References ........................................................... 45

3 Laser Nanocrystallization of Metals .............................. 51
Irina N. Zavestovskaya
3.1 Introduction ....................................................... 51
3.1.1 Laser Matter Interaction ..................................... 52
3.1.2 Direct Surface Material Nanostructuring ...................... 53
3.2 Peculiarities of Laser Nano- and Microstructuring of Metal Surfaces: Experimental Results ............... 54
3.2.1 Properties of Nanocrystalline Materials ...................... 54
3.2.2 Laser Glassing .................................................. 55
3.2.3 The Role of Laser Pulse Duration ............................. 56
3.2.4 Metal Surface Nanostructuring with Femtosecond Laser Pulses ......................................... 57
3.2.5 Micro- and Nano-Structuring with Nanosecond Laser Pulses ............................................. 60
3.3 Theoretical Modeling of Laser-Induced Nanocrystallization Processes ........................................... 62
3.3.1 Melting Processes .............................................. 62
3.3.2 Laser Processing of Porous Metal Films .................... 63
3.3.3 Nanocrystallization Kinetics ................................. 65
3.3.4 Volume of the Phase Crystalline and Average Number of Nuclei Particles ............................. 69
3.3.5 Criterion for Laser Amorphisation ......................... 71
3.4 Conclusions ....................................................... 72
References ........................................................... 72

4 Optical Breakdown in Ambient Gas and Its Role in Material Processing by Short-Pulsed Lasers ............... 77
Sergey M. Klimentov and Vitaly I. Konov
4.1 Introduction: Origin of Plasma Near Exposed Surface ...... 77
4.2 Effect of Charged Ablated Nanoparticles Long-Residing in the Ambient Gas...

4.2.1 Observation of Low-Threshold Air Breakdown...

4.2.2 Locations of Plasma and the Resulting Crater Morphology...

4.2.3 Dimensions, Lifetime and Electrical Properties of Nanoparticles...

4.2.4 Removal of Charged Particles by Application of Electric Field...

4.2.5 Relaxation of Plasma in Atmospheric Air and Its Role in High Repetition Rate Micromachining...

4.3 Self-Scattering of Focused Ultrashort Pulses...

4.3.1 Threshold Conditions...

4.3.2 Contributing Mechanisms...

4.3.3 Optimization of Exposure Conditions to Eliminate the Scattering...

4.4 Discussion and Conclusions...

References...

---

**Part II Nanoparticles Related Technologies and Problems**

5 Laser Generation and Printing of Nanoparticles...


5.1 Introduction...

5.2 Laser Printing of Nanoparticles and Nanoparticle Arrays...

5.2.1 Laser Printing of Nanoparticles...

5.2.2 Laser Fabrication of Large-Scale Nanoparticle Arrays...

5.3 Resonant Electric and Magnetic Response of Silicon Nanoparticles...

5.4 Generation of Silicon Nanoparticles from Bulk Silicon...

5.5 Microreplication of Laser-Transferred Gold Nanoparticles/Nanomolding...

5.6 Laser-Based Synthesis of Nanoparticles and Surface Modified Nanoconjugates...

5.6.1 Ultrapure Nanoparticles by Pulsed Laser Ablation in Liquids...

5.6.2 Surface-Functionalized Nano(Bio)Conjugates...

5.7 Novel Laser-Based Conjugation Concepts...

5.8 Conclusion...

References...
6 Light Scattering by Small Particles and Their Light Heating:
New Aspects of the Old Problems ........................ 125
Michael I. Tribelsky and Boris S. Luk’yanchuk
6.1 Introduction ........................................ 125
6.2 Anomalous Light Scattering. ......................... 127
   6.2.1 General Principles ................................ 127
   6.2.2 Near Field Effects ............................... 132
6.3 Anomalous Absorption ............................... 136
6.4 Optimization of Laser Energy Release in Real
   Plasmonic Nanoparticles ............................... 138
6.5 Laser Heating of Particles in Liquid ................. 140
6.6 Conclusion ........................................ 143
References ............................................ 145

Part III Surface and Thin Films Phenomena and Applications

7 Laser-Induced Local Oxidation of Thin Metal Films:
Physical Fundamentals and Applications ................. 149
Vadim P. Veiko and Alexander G. Poleshchuk
7.1 Introduction ........................................ 149
7.2 Physics of Heterogeneous Laser Oxidation: Diffusion,
   Adsorption and Chemical Kinetics ...................... 151
   7.2.1 Laser Oxidation of Metals ...................... 152
   7.2.2 Laser Oxidation at Short Pulse Width .......... 153
   7.2.3 Laser Oxidation with Exposure at a High
       Pulse Repetition Rate ............................ 154
7.3 Oxidation Lithography: Principles, Accuracy
   and Resolution ...................................... 154
7.4 Applications of Oxidation Lithography: Thermochemical DOE Writing .................. 156
   7.4.1 Circular Laser Writing System for Direct
       DOE Fabrication .................................. 156
   7.4.2 Direct Thermochemical DOE Writing, DOE
       Writing Modes .................................... 157
   7.4.3 Application of DOE for Aspheric Optics Testing .... 159
7.5 Super Resolution at the Thermochemical Writing .... 162
   7.5.1 Thermochemical “Peaking” ...................... 162
   7.5.2 Positive Feedback at the Thermochemical Action .... 163
   7.5.3 Effect of Short Pulse Lasers: Oxidation
       Plus Structural Modification ..................... 164
7.6 Conclusion ........................................ 169
References ............................................ 170
8 Photophysics of Nanostructured Metal and Metal-Contained Composite Films .......................................................... 173
Nathalie Destouches, Frank Hubenthal and Tigran Vartanyan
8.1 Introduction ................................................................. 173
8.2 Optical Properties of Noble Metal Nanoparticles .......... 175
  8.2.1 Damping of Plasmon Excitations Localized in Metal Nanoparticles ........................................ 176
  8.2.2 Optical Properties of Nanostructured Noble Metal Nanoparticles on Substrates .............. 178
  8.2.3 Reflection and Transmission of Supported Metal Nanostructures ........................................ 179
  8.2.4 Mutual Modification of Silver Nanoparticle Plasmon Resonances and Absorptive Properties of Polymethine Dye Molecular Layers on a Sapphire Surface ........................................ 180
8.3 Preparation and Defined Manipulation of Metal and Metal Contained Film ..................................................... 182
  8.3.1 Physical Vapour Deposition ........................................ 182
  8.3.2 Laser-Induced Growth of Metal Nanoparticles in Glassy Matrix ........................................ 184
  8.3.3 Laser-Induced Transformations of Supported and Embedded Metal Nanoparticles Ensembles .... 185
  8.3.4 Reversibly Tuning the Size of Nanoparticles with Lasers ......................................................... 189
  8.3.5 Optical Methods of Forming Metallic Nanostructures on the Surface of Insulating Materials .................. 191
8.4 Applications ................................................................. 192
  8.4.1 Metal Nanoparticles as SERS Substrates ................. 192
  8.4.2 Exploiting Near Fields of Gold Nanoparticles for Surface Nanostructuring .................... 193
  8.4.3 Improvement of the Thermal Stability of Silver Films via UV Illumination ....................... 194
  8.4.4 Reversible or Permanent Laser-Induced Color Marking ......................................................... 195
8.5 Conclusion ..................................................................... 196
References .......................................................................... 197

9 Selective Ablation of Thin Films by Pulsed Laser .......... 201
Andreas Ostendorf, Evgeny L. Gurevich and Xiao Shizhou
9.1 Introduction ................................................................. 201
9.2 Thermal Penetration Depth in Laser Ablation of Films .... 203
9.3 Front- and Rear-Side Laser Ablation of Films ............... 206
### Part IV Bulk Micro Structuring of Transparent Materials

#### 10 Reversible Laser-Induced Transformations in Chalcogenide- and Silicate-Based Optical Materials

Alexander V. Kolobov, Junji Tominaga and Vadim P. Veiko

10.1 Chalcogenide Glasses and Phase-Change Alloys

10.1.1 Reversible Photostructural Changes and Photo-Induced Anisotropy

10.1.2 Photocrystallisation of Selenium

10.1.3 Photo-Induced Loss of Long-Range Order

10.2 Silicate Phase-Changing Materials

10.2.1 Glasses and Glass-Ceramics: Different Sides of the Same Coin

10.2.2 Physical Processes of Laser-Induced Phase-Structure Modifications of Oxide Glass-Ceramics

10.2.3 Conclusions

10.3 Applications of Laser-Induced Transformations

10.3.1 Chalcogenides

10.3.2 Silicates

References

#### 11 Fs Laser Induced Reversible and Irreversible Processes in Transparent Bulk Material

V. V. Kononenko and V. I. Konov

11.1 Introduction

11.2 Experimental Techniques

11.2.1 Laser Bulk Treatment Conditions: Sample Scanning and Focusing

11.2.2 Interferometric Control of Laser-Induced Processes in by the Bulk of a Solid

11.3 Transient Changes in Matter

11.3.1 Kerr Non-linearity, Non-linear Ionization and Wave Packet Control

11.3.2 Non-linear Transformation of an Fs Beam and Radiation Losses in a Highly Non-linear Material

11.3.3 Self-Triggered Exciton (STE) Formation

11.3.4 Bulk Heating

References
Part V  Laser-Induced Modification of Polymers

12  A Decade of Advances in Femtosecond Laser Fabrication of Polymers: Mechanisms and Applications  
Mangirdas Malinauskas and Saulius Juodkazis

12.1 3D Direct Laser Writing in Polymers at Nanoscale  
12.1.1 Tight Focusing of Ultrashort Pulses: Multi-Photon and Avalanche Ionization Polymerization  
12.1.2 Laser 3D Nanopolymerization Setup  

12.2 Instrumentation  
12.2.1 Laser Sources and Surface Tracking  
12.2.2 Spatial Resolution and Feature Precision  
12.2.3 Fabrication Strategies, Throughput and Scaling  
12.2.4 Wet Developing  

12.3 Materials for Laser Nanopolymerization  
12.3.1 Structuring with and Without Photo-Initiators  
12.3.2 Organic Photopolymers  
12.3.3 SU-8  
12.3.4 Novel Hybrid Materials  
12.3.5 Biopolymers and Elastomers  

12.4 Applications  
12.4.1 Micro-Optics: Integrated and Multi-Functional Components  
12.4.2 2D and 3D Photonics  
12.4.3 Biomedicine and Microfluidics  

12.5 Future Outlook  

References  

13 Laser Nanostructuring of Polymers  
Nikita M. Bityurin

13.1 Introduction  

13.2 Surface Nanostructuring  
13.2.1 Colloidal Particle Lens Arrays and Interference Lithography  
13.2.2 Nanoablation and Nanoswelling  

References
Fundamentals of Laser-Assisted Micro- and Nanotechnologies
Veiko, V.p.; Konov, V.I. (Eds.)
2014, XVII, 322 p. 145 illus., 49 illus. in color., Hardcover
ISBN: 978-3-319-05986-0