Contents

1 Nonlinear Propagation Theory for Few-to-Mono Optical-Cycle Pulses Beyond the Slowly-Varying-Envelope Approximation (SVEA)
N. Karasawa, Y. Mizuta, X. Fang 1
1.1 Wave Equations for Nonlinear Pulse Propagation 1
1.1.1 Introduction 1
1.1.2 Dispersion Terms 5
1.1.3 Nonlinear Terms 6
1.1.4 Induced Phase Modulation 7
1.1.5 Comparison with the Previous Derivation 8
1.2 Different Numerical Methods 9
1.2.1 Split-Step Fourier Method 10
1.2.2 Finite-Difference in the Frequency Domain Method 12
1.2.3 Finite-Difference Time-Domain Method 13
1.2.4 Fourier Direct Method 14
1.3 Comparison between Theoretical and Experimental Results 24
1.3.1 Split-Step Fourier Analysis beyond SVEA 24
1.3.2 Finite-Difference Frequency-Domain Analysis 34
1.3.3 Finite-Difference Time-Domain Analysis 38
1.3.4 Analysis by Fourier Direct Method 41
1.4 Conclusion 60
References 64

2 Generation of Ultrabroadband Optical Pulses
M. Yamashita, N. Karasawa, M. Adachi, X. Fang 67
2.1 Introduction 67
2.2 Conventional Glass Fiber Technique Using IPM 68
2.2.1 Theoretical Prediction 68
2.2.2 Experiment 74
2.3 Gas-Filled Hollow Fiber Technique using IPM 81
2.3.1 Theoretical Prediction 82
2.3.2 Experiment 85
2.3.3 The Oscillatory Spectrum Due to Only IPM 88
2.4 Unconventional Glass Fiber Technique Using SPM 91
2.4.1 Photonic Crystal Fiber 91

2.4.2 Tapered Fiber 94
2.5 Concluding Remarks 98
References 99

3 Active Chirp Compensation for Ultrabroadband Optical Pulses
M. Yamashita, R. Morita, N. Karasawa 103
3.1 Introduction 103
3.2 Principle and Theory: Chirp Compensator with Spatial Light Modulator (SLM) 106
3.3 Programmable Chirp Compensator for Generation of Few-Optical Cycle Pulses 119
3.3.1 Grating-Pair-Formed Compensator with SLM 119
3.3.2 Prism-Pair-Formed Compensator with SLM 141
3.4 Conclusion 147
References 149

4 Amplitude and Phase Characterization of Few-to-Mono Optical-Cycle Pulses
R. Morita, K. Yamane, Z. Zhang 153
4.1 Introduction 153
4.2 Experimental and Theoretical Demonstration of Limitation in Fringe-Resolved Autocorrelation (FRAC) Measurements 156
4.2.1 Equations for FRAC Signals 156
4.2.2 Numerical Analysis: Deviation of Practical FRAC Signal from Ideal FRAC Signal 158
4.2.3 Experiments 162
4.2.4 Comparison between TL-Pulse FRAC Signals Based on Measured and Corresponding Gaussian Spectra 163
4.2.5 Experimental Comparison between Directly-Measured and Modified-SPIDER-Retrieved FRAC Signals 165
4.3 Frequency Resolved Optical Gating (FROG) 166
4.3.1 Principle 166
4.3.2 Apparatus and Characteristcs 171
4.4 Spectral Interferometry for Direct Electric-Field Reconstruction (SPIDER) 176
4.4.1 Principle 176
4.4.2 Apparatus and Characteristics 180
4.5 Modified SPIDER 185
4.5.1 Principle and Effect of Parameter Error 185
4.5.2 Apparatus and Characteristics 186
4.6 Comparison and Characteristics 194
4.7 Conclusion 196
References 197

5 Feedback Field Control for Optical Pulse Generation in the Monocycle Region
M. Yamashita, K. Yamane, Z. Zhang, M. Adachi, R. Morita 199
5.1 Basic Concept: Combination of Spectral Phase Compensation and Characterization 199
5.2 Feedback Spectral-Phase Control Technique 201
5.2.1 Conventional Glass Fiber Experiment 201
5.2.2 Unconventional Glass Fiber Experiment 213
5.2.3 Gas-Filled Hollow Fiber Experiment 224
5.3 Characterization of Monocycle-Like Optical Pulses Based on Wigner Distribution Function 238
5.4 Conclusion 246
References 247

6 Field Manipulation of Ultrabroadband Optical Pulses
R. Morita, Y. Toda 251
6.1 Principle and Theory 251
6.2 Two-Color Beam Generation with Tunable THz-Pulse Trains ... 256
6.3 Three-Color Beam Generation with Tunable THz-Pulse Trains .. 259
6.4 Application for Vibrational Motion Control of Molecules 263
6.4.1 Principle and Theory 263
6.4.2 Experiment 274
6.5 Future Direction 280
References 282

7 Fundamental of Laser-Assisted Scanning Tunneling Microscopy (STM)
O. Takeuchi, H. Shigekawa 285
7.1 Introduction 285
7.2 Potentialities of Laser Combined STM 286
7.3 Fundamental of Scanning Probe Microscopy 289
7.3.1 How to Visualize the Nanoscopic World 289
7.3.2 Tunnel Current as a Probe Signal 292
7.3.3 Scanning Tunneling Spectroscopy 294
7.3.4 Characteristic of the STM Measurement System 295
7.4 Previous STM Studies in Various Fields 299
7.5 Development of Laser-Assisted STM 307
7.5.1 Performance of Optical Measurements 307
7.5.2 Combination of STM with Optical Methods 308
7.5.3 How to Combine the Two Techniques? 309
7.5.4 Specific Issues in Combining Light Irradiation and STM . 312
References 315

8 Spatially-Resolved Surface Photovoltage Measurement
O. Takeuchi, H. Shigekawa 317
8.1 Background 317
8.2 Surface Photovoltage (SPV) 318
8.3 Macroscopic Measurement of SPV 321
8.4 Photovoltage and Photocurrent Measurement by STM 322
8.5 Light-Modulated Scanning Tunneling Spectroscopy 327
8.6 Point Spectroscopy 329
8.7 Nanoscale Spatial Variation of SPV 331
8.8 Conclusion 333
References 334

9 Atomic-Level Surface Phenomena Controlled by Femtosecond Optical Pulses
D.N. Futaba 335
9.1 Introduction 335
9.2 Femtosecond Pulse Pair Controlled Phenomena at Surfaces 336
9.2.1 Experiment: Site-Selective Silicon Adatom Desorption Using Femtosecond Laser Pulse Pairs and STM 338
9.2.2 Interpretation 342
9.3 Future Directions 345
References 345

10 Femtosecond-Time-Resolved Scanning Tunneling Microscopy
O. Takeuchi, H. Shigekawa 349
10.1 Femtosecond-Ångstrom Technology 349
10.2 Previous Studies in This Field 350
10.3 Fundamentals of the Pulse-Pair-Excited STM 353
10.4 Design of the Measurement System 356
10.5 Shaker Method 358
10.6 Performance of the System 359
10.6.1 Discussion of the Interference Effect 361
10.7 Time-Resolved STM Experiment on GaNAs 363
10.7.1 Sample Preparation 363
10.7.2 Analysis by the Optical Pump-Probe Technique 365
10.7.3 Results Obtained by the SPPX-STM 366
10.7.4 Localized Sensitivity of Time-Resolved Tunnel Current Signal 368
10.7.5 Relative Intensity of Pump and Probe Pulses 369
10.7.6 Accurate Fitting Procedure of Time-Resolved Current Signal 372
10.8 Conclusion 376
References 377

11 Outlook
M. Yamashita, H. Shigekawa, R. Morita 379
References 382

Index 385