

T. Kamiya F. Saito O. Wada H. Yajima

Femtosecond Technology

From Basic Research
to Application Prospects

With 294 Figures



Springer

Contents

PART I Introduction

I-1 Femtosecond Technology and Its Industrial Impact 1

Takeshi Kamiya

1. Introduction	1
2. Fundamental Nature of Femtosecond Optics	2
3. Device and Material Research Frontiers	5
4. Ultrafast System Goals	8
5. Summary and Future Tasks	10
References	11

PART II Optoelectronics Technology Roadmap and Industry

II-1 Technology Roadmap for the Japanese Opto-Electronics Industry 12

Michiharu Nakamura

1. Introduction	12
2. Roadmap for Optical Communication Technology.....	15
3. Future Prospects for Optoelectronics Technology in Japan	26
4. Summary and Conclusions	27
Acknowledgment	28
References	28

II-2 Technology Roadmap for Optical Communication - A North American Perspective..... 29

Arpad A. Bergh

1. Introduction	29
2. Socioeconomic Driving Forces	29
3. Anticipated Consumer Needs - Bandwidth Requirements	30

4. Core Network.....	34
5. Access Networks	40
6. LANs and Campus Networks	45
7. Conclusion.....	47
References	48

**II-3 Structural Change in Industry and Reorganization
of R&D Systems in Network-Oriented Societies.....49**

Yoshio Nishimura

1. Introduction	49
2. From Vertical to Horizontal.....	50
3. Outsourcing of Industrial R&D Activities	52
4. From Linear Model to "Konoyubi-Tomare" Model.....	54
5. From Proprietary to Licensing	55
6. Hopes for the Renaissance of Universities	57
7. Concluding Remarks	57
References and Notes	57

**PART III Ultrafast Optoelectronics
for Telecommunications**

**III-1 Femtosecond Semiconductor-Based Optoelectronic Devices
for Optical Communications and Signal-Processing Systems59**

Osamu Wada, Akira Suzuki, Yoh Ogawa and Kazuhito Tajima

1. Introduction	59
2. Semiconductor-Based Femtosecond Devices	62
3. Femtosecond Light Sources.....	63
4. Femtosecond All-Optical Switches.....	66
5. Conclusion	76
Acknowledgment.....	76
References	76

**III-2 Generation, Control and Processing of Ultrafast
Optical Signals by Electrooptic Modulation / Deflection79**

Tetsuro Kobayashi and Akihiro Morimoto

1. Introduction	79
2. Generation of Wide Optical Spectra by Using Electrooptic Modulation.....	80
3. Generation of Ultrashort Optical Pulses by Electrooptic Modulation / Deflection	83
4. Overview of the Future	90
References	90

III-3 Subharmonic Mode-Locking of Semiconductor Lasers Operating at Millimetre-Wave Frequencies	92
Hai-Feng Liu, Ampalavanapillai Nirmalathas, Dalma Novak and Yoh Ogawa	
1. Introduction	92
2. Devices	93
3. Subharmonic Hybrid Mode-Locking.....	93
4. Subharmonic Synchronous Mode-locking	98
5. Comparison between SHML and SSML	103
6. Conclusions	104
Acknowledgement.....	105
References	105
III-4 All-Optical Access Node Technologies.....	107
Mohammed N. Islam	
1. Introduction and Motivation for Ultrafast Systems	107
2. Soliton Ring Network Architecture & Protocols.....	109
3. Integration of Components for Access Node.....	113
4. Q-Parameter Measurements of System Performance	117
5. Summary	120
References	121
III-5 Ultrafast All-Optical Switch Using Low-Temperature-Grown InGaAs/InAlAs Multiple-Quantum Wells.....	122
Hidetoshi Iwamura, Ryo Takahashi and Yutaka Matsuoka	
1. Introduction	122
2. Nonlinear Properties of Multi-Quantum Well Structures	123
3. Operation Principle of a Surface-Reflection All-Optical Switch	124
4. Improvement in Switching Speed.....	125
5. Improvement in Optical Nonlinearity.....	128
6. Application to Optical Communication Systems	131
7. Future Works	133
References	133
III-6 High Bandwidth Photodetectors	134
Chi-Kuang Sun and John E. Bowers	
1. Introduction	134
2. Vertically Illuminated Long-Wavelength p-i-n Photodetectors	135
3. Traveling-Wave Photodetector.....	139
4. Silicon Hetero-Interface Avalanche Photodetector	146
5. Summary	148
Acknowledgment	149
References	149

III-7 Coherent Tunable THz Oscillation by Nonlinear Optics	152
Hiromasa Ito, Kodo Kawase and Jun-ichi Shikata	
1. Introduction	152
2. Calculation of Gain.....	153
3. Unidirectional THz-Wave Coupling.....	155
4. Experiments	156
5. Measurement.....	159
6. Conclusion	161
Acknowledgment.....	162
References	162
III-8 Multi-Gap Photoconductive Switches Fabricated by a Scanning Probe Microscope	164
Taro Itatani, Toyotomo Morita, Kazuhiko Matsumoto, Tadashi Nakagawa, and Moriaki Wakaki	
1. Introduction	164
2. Fabrication Process	165
3. Electrooptic Vector Sampling.....	167
4. Summary.....	172
Acknowledgements.....	173
References	173
PART IV Semiconductor Quantum Structures for Femtosecond Devices	
IV-1 High Speed Quantum Dot Lasers: Phonon Bottleneck Issue in Quantum Dot Lasers	175
Yasuhiko Arakawa	
1. Introduction	175
2. Lifetime of Confined LO Phonons	177
3. Phonon Bottleneck Issue.....	178
4. Conclusion and Discussions	182
References	182
IV-2 Ultrafast Coherent Dynamics of Radiatively Coupled Excitons in Multiple Quantum Wells.....	184
Jürgen Kuhl, Martin Hübner, Dirk Ammerlahn, Bernd Grote, Tineke Stroucken, Stephan Haas, Andreas Knorr, Stephan Koch, Galina Khitrova, Hyatt Gibbs, Rudolf Hey, and Klaus Ploog	
1. Introduction	184
2. Theoretical Model.....	185

3. Experimental Techniques and Samples	187
4. Results and Discussions	188
5. Conclusions	196
Acknowledgement.....	197
References	197

IV-3 Femtosecond Studies of Semiconductor Microcavities and VCSELs .198
Jagdeep Shah

1. Introduction	198
2. Basic Concepts	199
3. Femtosecond Studies of VCSELs and Microcavities	201
4. Summary	208
References	208

IV-4 Quantum Dots and the Expected Role in Femtosecond Devices.....211
Hiroshi Ishikawa

1. Introduction	211
2. State-of-the-Art of Quantum Dots and Quantum Dot Lasers	212
3. Modulation Response of Quantum Dot Lasers.....	215
4. Quantum Dots as a Non-Linear Medium	217
5. Summary and Discussions.....	220
References	220

**IV-5 Ultrafast Interband-Resonant Light Modulation
 by Intersubband-Resonant Light in Quantum Wells.....222**
Susumu Noda

1. Introduction	222
2. Modulation Utilizing n-Doped Quantum Wells	223
3. Shortening of the ISB-T Wavelength and the ISB Energy Relaxation Time.....	229
4. Conclusion.....	232
Acknowledgement.....	232
References	233

**IV-6 Fabrication Technology of Semiconductor Nanometer Structures
 Towards Femtosecond Optoelectronics.....234**
**Tomonori Ishikawa, Shigeru Kohmoto, Kiyoshi Asakawa
 and Yoshifumi Katayama**

1. Introduction	234
2. UHV Multichamber Process-System.....	235
3. <i>In Situ</i> EB Lithography.....	236
4. The Combination of <i>In Situ</i> EB Lithography and Self-Organized Epitaxy	238
5. Site-Control of Quantum Dots by <i>In Situ</i> EB Lithography	241

6. Summary.....	243
References	244

PART V Femtosecond Lasers and Measurement Applications

V-1 Intense Sub-10-fs Laser Pulses:

Pushing the Frontiers of Nonlinear Optics.....	245
Matthias Lenzner, Matthias Schnürer, Christian Spielmann and Ferenc Krausz	

1. Introduction	245
2. Femtosecond Laser System	246
3. Applications.....	249
4. Conclusions and Outlook.....	256
Acknowledgment.....	256
References	257

V-2 Low-Threshold All-Solid-State Femtosecond Lasers	258
G.J. Valentine, D. Burns and W. Sibbett	

1. Introduction	258
2. Factors Affecting the Pump-Power Requirements of Mode-Locked Lasers	259
3. Laser Cavity Designs for Low-Threshold Operation.....	264
4. Low-Threshold Self-Mode-Locked Cr ³⁺ :LiSAF Lasers.....	267
5. Low-Threshold Femtosecond Cr:LiSAF Laser Based on a Semiconductor Saturable-Absorber Mirror (SESAM)	270
6. Summary.....	271
Acknowledgements.....	272
References	272

V-3 All-Solid-State Cr:LiSAF Femtosecond Lasers	274
Shin-ichiro Aoshima, Haruyasu Itoh, Makoto Hosoda and Yutaka Tsuchiya	

1. Introduction	274
2. Transform-Limited 30-fs Pulse Generation from an All-Solid-state Cr:LiSAF Laser	275
3. Compact All-Solid-State Cr:LiSAF Femtosecond Laser.....	279
4. Conclusions	282
Acknowledgments	283
References	283

V-4 Femtosecond Pulse Generation around 1.3μm Employing Semiconductor Saturable Absorber Mirrors (SESAM).....	284
Kenji Torizuka, Zhigang Zhang, Taro Itatani, Katsuyuki Kobayashi, Takeyoshi Sugaya and Tadashi Nakagawa	

1. Introduction	284
2. Designs and Performance of SESAM in the 1.3 μ m Region.....	285
3. KLM and SESAM ML in the Femtosecond Regime.....	287
4. Broadband SESAM for Extremely Short 1.3 μ m Pulse Generation.....	290
5. Summary	291
References	292

V-5 Ultrashort Pulse Application to Dimensional Measurements 293

Kaoru Minoshima

1. Introduction	293
2. Simultaneous 3-D Shape Measurement.....	294
3. <i>In Situ</i> Measurements of Optical Parts Using Femtosecond Two-Color Interferometer.....	299
4. Conclusion.....	302
Acknowledgment	302
References	302

V-6 Femtosecond X-Ray Pulse Generation by Using a Low Emittance Electron Beam and a High Brightness Laser for Measurement Applications 303

Akira Endo

1. Introduction	303
2. Evaluation of LSS Femtosecond X-ray Source	304
3. Component Technologies	307
4. Laser Oscillator Stabilization	308
5. RF Photoinjector.....	311
6. Conclusion.....	311
Acknowledgment	312
References	312

V-7 Femtosecond Quantum Beam Science and New Pump-and-Probe Analysis..... 313

Mitsuru Uesaka, Takahiro Watanabe, Hideki Harano, Kenichi Kinoshita,
Jun Sugahara, T. Ueda, Koji Yoshii, Kazuhisa Nakajima, Atsushi Ogata,
Fumio Sakai, M.Kando, Hideyuki Kotaki, Hideki Dewa and Shuji Kondo

1. Introduction	313
2. Twin Electron Linac System with Laser Photocathode RF Gun	314
3. Femtosecond Electron Pulse Measurement	316
4. Synchronization of Femtosecond Electron Linac and Laser and Applications.....	319
5. Synchronized Femtosecond Quantum Beam Based Pump-and-Probe Analysis	323
6. Conclusion.....	325
Acknowledgement.....	326
References	326

PART VI Materials for Femtosecond Applications

VI-1 Ultrafast Functional Materials for Femtosecond Optoelectronics.....	328
Toshiro Tani, Ryoichi Akimoto, Koji Ando, Hitoshi Kawashima, Takashi Tokizaki, Makoto Furuki, and Taro Nanbu	
1. Objectives	328
2. II-VI Diluted Magnetic Semiconductor MQW Structures	332
3. Femtosecond Scanning Near-Field Optical Microscope.....	336
4. Coherence, Propagation, and Related Fundamentals	340
5. New Materials and Structures.....	345
6. Summary.....	347
Acknowledgment.....	347
References	347
VI-2 Ultrafast Relaxations in One-Dimensional Systems; π-Conjugated Polymers, J-Aggregates, and Metal-Halogen Chain Complexes	350
Takayoshi Kobayashi	
1. Introduction	350
2. Femtosecond Nonlinear Optical Responses in Polydiacetylenes.....	351
3. Dependence of Ultrafast Excitonic Nonlinear Responses in Conjugated Polymers on the Excitonic Transition Energy	353
4. Femtosecond Resonance Raman Gain Spectroscopy of Polydiacetylenes ..	354
5. Optical Stark Shifts of Raman Gain Spectrum in Polydiacetylene	356
6. Dynamics of Confined Soliton Pair in Phenylpolyacetylene Derivatives...	356
7. Ultrafast Nonlinear Response in J-Aggregates	359
8. Femtosecond Spectroscopy of Halogen-Bridged Mixed-Valence Complexes.....	360
Acknowledgement	362
References	363
VI-3 Femtosecond Dynamics of Supramolecular Structures in Condensed Phase	364
Mirjam van Burgel, Alessandro M. Renier and Koos Duppen	
1. Molecular J-Aggregates	364
2. Experimental.....	366
3. Exciton Delocalization Length	366
4. Exciton Annihilation.....	369
5. Conclusion	374
Acknowledgement	374
References	374
VI-4 Femtosecond Molecular Photonics Materials.....	376
Toshihiko Nagamura	

1. Introduction	376
2. Materials and Methods	378
3. Ultrafast Color Changes in 4,4'-Bipyridinium Salts	380
4. Ultrafast Absorption Changes in the Near Infrared Region.....	382
5. Applications of Ultrafast Absorption Changes to Optical Processing.....	384
6. Ultrafast Nonlinear Optical Responses.....	385
7. Conclusion.....	386
Acknowledgment	387
References	387
VI-5 Ultrafast Dynamics of Photochromic Systems	389
Hiroshi Miyasaka and Masahiro Irie	
1. Introduction	389
2. Dynamic Detection of the Photochromic Reactions.....	390
3. Future Prospects	399
References	399
VI-6. Ultrafast Spectroscopy of Glass Materials Containing Metal Nanoparticles	401
Koichiro Tanaka	
1. Introduction	401
2. Optical Properties of Metal Nanoparticles	403
3. Femtosecond Pump and Probe Experiments of Gold Nanoparticles	408
4. Relaxation Processes of Non-Equilibrium Electrons in Gold Nanoparticles.....	413
5. Conclusion.....	418
Acknowledgment	419
References	419
Index.....	421