

Contents

<i>Preface</i>	v
1. Introduction	1
2. Femtosecond Beam Generation	7
2.1 Theory and Operation of Femtosecond Terawatt Lasers . . .	7
2.1.1 Ultrashort pulses: theory and generation	7
2.1.1.1 Principle of mode locking for short pulse generation	7
2.1.1.2 Mode-locking techniques	10
2.1.2 Stretching and compressing laser pulses	15
2.1.2.1 Chirped pulse amplification principle	15
2.1.2.2 Stretcher/compressor operation	16
2.1.2.3 The Offner triplet configuration	17
2.1.2.4 Compressor subsystem	18
2.1.3 Amplification process	18
2.1.3.1 Regenerative amplification	19
2.1.3.2 Multipass amplification	20
2.1.3.3 20-TW laser system	22
2.2 Linear Accelerator	24
2.2.1 Photoinjectors	24
2.2.1.1 RF cavity and laser	24
2.2.1.2 Cathode and quantum efficiency	29
2.2.1.3 Emittance control	31
2.2.2 Magnetic bunch compression	40

2.2.2.1	Analogy with chirped pulse amplification (CPA) for femtosecond lasers	40
2.2.2.2	Theory	41
2.2.2.3	Experiment	46
2.2.2.4	Other subjects	50
2.2.2.5	Effect of CSR force	50
2.2.3	Velocity bunching	53
2.2.3.1	Theory	54
2.2.3.2	Application to the SPARC project	60
2.2.3.3	Experiments	61
2.2.4	Microbunching	63
2.2.4.1	Staged electron laser acceleration (STELLA)	63
2.2.4.2	Future potential issues	70
2.3	Synchrotron	71
2.3.1	Synchrotron	71
2.3.1.1	Bunch length in synchrotron and storage ring	72
2.3.1.2	Small α_p and intrinsic problems	74
2.3.1.3	Intrinsic bunch length in an electron storage ring	77
2.3.1.4	Microwave instability	78
2.3.2	Femtosecond e-beams in storage rings	80
2.3.2.1	Strong longitudinal focusing	80
2.3.2.2	Coherent synchrotron radiation and stability criteria	82
2.3.2.3	Selected results of computer simulations	86
2.3.2.4	Proposed applications of femtosecond electron bunches in storage rings	87
2.4	Laser Plasma Acceleration	90
2.4.1	Electron	90
2.4.1.1	Laser plasma wake field acceleration	90
2.4.1.2	Laser injected laser accelerator concept (LILAC)	95
2.4.1.3	Plasma cathode: colliding pulse optical injection	105
2.4.1.4	Electron injection due to Langmuir wave breaking	117
2.4.1.5	Plasma cathode by self-injection	128
2.4.2	Ion	139
2.4.2.1	Mechanism	139

2.4.2.2	Low intensity laser case	141
2.4.2.3	Moderate intensity laser case	142
2.4.2.4	Ultra-intense laser case	145
2.4.2.5	Ion acceleration in a solitary wave	147
2.4.3	X-ray	150
2.4.3.1	Mechanism of laser plasma short X-ray generation	150
2.4.3.2	Measurement	150
2.4.3.3	Numerical analysis to enhance intensity	153
2.4.3.4	Nonlinear Thomson scattering	155
2.4.4	Terahertz (THz) radiation	158
2.4.4.1	Magnetic field enhancement scheme	158
2.4.4.2	Terawatt laser excitation scheme	163
2.4.5	Neutron	165
2.4.5.1	Cluster science	165
2.4.5.2	Characteristics of laser-cluster interaction	166
2.4.5.3	Neutron generation	166
2.4.5.4	Numerical simulation	169
2.4.5.5	High efficiency neutron source	171
2.4.6	Positron	172
2.4.6.1	Processes of positron production using lasers	172
2.4.6.2	Laser-solid interaction	174
2.4.6.3	Laser-gas-jet interaction	175
2.4.6.4	Radioactive isotopes	176
2.5	Inverse Compton Scattering X-ray Generation	178
2.5.1	Laser synchrotron source and its applications	178
2.5.1.1	Laser synchrotron source	178
2.5.1.2	Fundamental aspects of laser synchrotron source	180
2.5.1.3	Application of LSS: Polarized photon and positron production	185
2.5.2	Intra-cavity Thomson scattering	193
2.5.2.1	Thomson scattering in the Jefferson Lab infrared FEL	193
2.5.2.2	Measurements of intra-cavity Thomson X-ray	196
2.5.2.3	FEL upgrade Thomson X-ray possibilities	198
2.5.2.4	Conclusions and future program	198
2.6	Beam Slicing by Femtosecond Laser	202

2.7	Free Electron Lasers	207
2.7.1	Femtosecond infrared free electron laser	207
2.7.2	Femtosecond X-ray free electron laser	211
2.8	Energy Recovery Linac	214
	<i>Bibliography</i>	221
3.	Diagnosis and Synchronization	239
3.1	Pulse Shape Diagnostics	239
3.1.1	Streak camera	239
3.1.1.1	Principle of the streak camera	240
3.1.1.2	Consistent characteristic impedance matched deflection circuit	240
3.1.1.3	Measurement example	242
3.1.2	Coherent radiation interferometer	245
3.1.2.1	Technique	246
3.1.2.2	Michelson interferometer	249
3.1.2.3	Bunch length measurements with coherent diffraction radiation	255
3.1.2.4	Pulse shape reconstruction procedure	259
3.1.3	Far infrared polychromator	270
3.1.3.1	Single-shot measurement	270
3.1.3.2	10-channel polychromator	271
3.1.3.3	Bunch length measurement	272
3.1.4	Fluctuation	275
3.1.4.1	Theory	275
3.1.4.2	Discussion	277
3.1.4.3	Experiment	279
3.1.4.4	Fluctuation in time domain	280
3.1.5	Overall comparison	284
3.1.5.1	Theoretical discussion	284
3.1.5.2	Experimental discussion	285
3.1.6	New trends	291
3.1.6.1	Electro-optical method	291
3.1.6.2	T-cavity method	293
3.1.7	Low jitter X-ray streak camera	295
3.2	Synchronization	300
3.2.1	Laser vs. linac	301

3.2.1.1	S-band linacs (thermionic and RF gun vs. active-mode-locked Ti:Sapphire laser)	301
3.2.1.2	Upgraded timing system	306
3.2.1.3	Timing jitter source in laser oscillators	307
3.2.1.4	Timing jitter source in a linac	312
3.2.1.5	Overall evaluation	314
3.2.2	Laser vs. synchrotron	318
3.2.2.1	Synchronization scheme and timing monitor	319
3.2.2.2	Performance of the synchronization at SPring-8	321
3.2.2.3	Synchronous mechanical chopper	326
3.2.2.4	Time-resolved measurements using an X-ray streak camera	327
3.2.2.5	Prospects for femtosecond timing control	329
	<i>Bibliography</i>	331
4.	Applications	337
4.1	Radiation Chemistry	337
4.1.1	Subpicosecond pulse radiolysis	337
4.1.1.1	History of picosecond and subpicosecond pulse radiolysis	337
4.1.1.2	Time resolution of pulse radiolysis	341
4.1.1.3	Subpicosecond pulse radiolysis system	343
4.1.1.4	Jitter compensation system for highly time-resolved measurements	345
4.1.1.5	Early processes of radiation chemistry	346
4.1.1.6	Application to materials for nanotechnology	349
4.1.2	Radiolysis by RF gun	351
4.1.2.1	Supercritical xenon chemistry	351
4.1.2.2	Ultrafast water chemistry	356
4.1.3	Supercritical water	361
4.1.3.1	Supercritical water and its importance	361
4.1.3.2	Pulse radiolysis experimental setup for supercritical water	362
4.1.3.3	Examples of pulse radiolysis studies on supercritical water	363
4.1.3.4	Future subjects	364

4.2	Time-Resolved X-ray Diffraction	366
4.2.1	Phonon dynamics in semiconductors	366
4.2.1.1	Ultrafast microscopic dynamics	366
4.2.1.2	Strain wave in crystals	368
4.2.1.3	Experiments	369
4.2.2	Shock wave propagation in semiconductors	375
4.2.2.1	Shock compression science	375
4.2.2.2	X-ray diffraction of shocked solids	376
4.2.2.3	Laser shock	377
4.2.2.4	Laser plasma hard X-ray pulses	378
4.2.2.5	Ultrafast time-resolved X-ray diffraction of shock compressed silicon	380
4.2.2.6	Summary	384
4.2.3	Fast X-ray shutter using laser-induced lattice expansion at SR source	385
4.2.3.1	Optical switching of X-rays using transient expansion of crystal lattice	385
4.2.3.2	X-ray shutter using optical switch	387
4.3	Protein Dynamics	390
4.4	Molecular Dynamics Simulation	399
4.4.1	Ultrafast phenomena and numerical modeling	399
4.4.2	Molecular dynamics simulation including light interactions	401
4.4.3	Quantum molecular dynamics simulation including light interactions	405
	<i>Bibliography</i>	411
	<i>Index</i>	421