

Contents

1	Introduction	1
1.1	Mature Physics and New Development	1
1.2	Phase Effect of a Laser Pulse Propagating in an Optical Medium	3
1.3	Multiphoton and Tunnel Ionization	4
1.4	Optical Breakdown	6
1.5	Intense Femtosecond Laser Beam Attenuation	8
2	Filamentation Physics	11
2.1	Some Experimental Observations	11
2.2	Experimental Definition of a Filament by Burn Paper	15
2.3	Single Filamentation Physics	16
2.3.1	Slice-by-Slice Self-Focusing	16
2.3.2	Intensity Clamping	21
2.3.3	Is There Optical Breakdown During Filamentation?	23
2.3.4	Effect of External Focusing	25
2.3.5	Background Energy Reservoir	26
2.3.6	Self-Spatial Mode Filtering	31
2.3.7	Self-Phase Modulation, Self-Steepening and White Light Laser (Supercontinuum)	32
2.3.8	Conical Emission	36
2.3.9	Ring Structure at the Pump Wavelength	38
2.3.10	Self-Pulse Compression	38
2.3.11	X-wave	40
2.4	Full Evolution of a Single Filament	40
2.5	Maturity of a Filament	46
2.6	Filamentation Without Ionization	46
2.7	What Is a Filament?	47
3	Theory of Single Filamentation	49
3.1	Introduction	49
3.2	Filamentation in Air	49
3.3	Numerical Solution of Filamentation in Air	51

3.4 Filamentation in Condensed Matter	55	8.1.2 Filament Collaboration	104
3.5 x-Wave and Conical Emission	55	8.1.3 Optimum Wavelength to Produce the Broadest and Strongest White Light	105
4 Multiple Filamentation	61	8.1.4 Filament Control Using a Deformable Mirror	105
4.1 Introduction	61	8.2 Time-Resolved Excitation of Superexcited States of Molecules	106
4.2 Multiple Filamentation: Experimental Observation	61	8.3 Ultrafast Birefringence	109
4.3 Interference and Competition of Multiple Filaments	64	8.3.1 Filament-Induced Birefringence	110
4.4 Theory of Multiple Filamentation	67	8.3.2 Excitation of Molecular Rotational Wave Packets in Air and Polarization Separation	114
4.5 The Challenge of Long Distance Filamentation	68	8.3.3 Just the Beginning of Filament-Induced Birefringence	118
4.6 Long Distance Multiple Filamentation Control	68		
5 Filamentation Nonlinear Optics: General	71	References	119
5.1 Self-Actions	71	Index	125
5.2 Self-Remote Projection in Air	72		
5.3 Self-Pulse Compression	74		
5.4 Exploitations of the Self-Actions	74		
6 Filamentation Nonlinear Optics: Third Harmonic Generation and Four-Wave-Mixing Inside a Filament	77		
6.1 Introduction	77		
6.2 Third Harmonic Generation Inside a Filament in Air (Theoretical Analysis)	77		
6.3 Experiment on THG in Air	83		
6.4 Conical Emission and Superbroadening of the Third Harmonic in Air	85		
6.5 Efficient Tunable Few Cycle Visible Pulse Generation Through Four-Wave-Mixing Inside the Filament Core	85		
6.6 Self-Group-Phase Locking During Four-Wave-Mixing Inside a Filament	88		
6.7 Derivation of Equation (6.1)	89		
7 Remote Sensing Using Filamentation	93		
7.1 Introduction	93		
7.2 Remote Control of Filamentation	94		
7.3 Physical Considerations	96		
7.4 Detection of Chemical and Biological Agents in Air	97		
7.4.1 Molecules in the Gas/Vapor Phase	97		
7.4.2 Biological Targets	99		
7.4.3 Metallic Targets	100		
7.4.4 Water Aerosols Containing Metallic Salts	100		
7.5 Conclusion and Looking Ahead	101		
8 Challenges Ahead	103		
8.1 Multiple Filamentation	104		
8.1.1 Why Does a Large Diameter Beam Diverge Slowly Over Long Distances When There Is Multiple Filamentation?	104		