

# Contents

<b>1</b>	<b>General Methods for Obtaining Nanoscale Light Spot</b>	<b>1</b>
1.1	Introduction	1
1.2	Near-Field Scanning Probe Method	2
1.2.1	Aperture-Type Probe	3
1.2.2	Apertureless-Type Metal Probe	4
1.2.3	Tip-on-Aperture-Type Probe	4
1.2.4	C-Aperture Encircled by Surface Corrugations on a Metal Film	5
1.2.5	Nonlinear Self-focusing Probe	7
1.3	Solid Immersion Lens Method	7
1.4	Surface Plasmonic Lens	9
1.5	Stimulated Emission Depletion Fluorescence Microscope Methods	10
	References	12
<b>2</b>	<b>Third-Order Nonlinear Effects</b>	<b>13</b>
2.1	Introduction	13
2.2	Nonlinear Refraction	14
2.3	Nonlinear Absorption	16
	References	18
<b>3</b>	<b>Characterization Methods for Nonlinear Absorption and Refraction Coefficients</b>	<b>19</b>
3.1	Introduction	19
3.2	Theory and Setup of Basic z-scan Method	19
3.2.1	Description of Basic Principle	19
3.2.2	Data Analysis for z-scan Curves	21
3.3	Generation and Elimination of Pseudo-nonlinearity in z-scan Measurement	27
3.3.1	Incident Angle as a Function of z-scan Position	27

3.3.2	Dependence of Transmittance on Incident and Polarization Azimuth Angles . . . . .	29
3.3.3	Incident Angle Change-Induced Pseudo-nonlinear Absorption . . . . .	31
3.3.4	Calculated Pseudo-nonlinear Absorption Curves . . . . .	32
3.3.5	Reduction or Elimination of Pseudo-nonlinear Absorption . . . . .	35
3.4	Eliminating the Influence from Reflection Loss on z-scan Measurement . . . . .	36
3.4.1	Fresnel Reflection Loss in the z-scan Measurement . . . . .	36
3.4.2	The Case of Thin Samples . . . . .	37
3.4.3	The Case of Nanofilm Samples . . . . .	41
3.5	Influence of Feedback Light on z-scan Measurement . . . . .	46
3.5.1	Influence of Feedback Light on Semiconductor Laser Devices . . . . .	47
3.5.2	Elimination of Feedback Light Influence on z-scan Measurement . . . . .	54
	References . . . . .	59
<b>4</b>	<b>Optical Nonlinear Absorption and Refraction of Semiconductor Thin Films . . . . .</b>	<b>61</b>
4.1	Introduction . . . . .	61
4.2	Theoretical Basis . . . . .	61
4.2.1	Two-Band Model for Free-Carriers-Induced Nonlinear Effects . . . . .	61
4.2.2	Three-Band Model for Nonlinear Absorption and Refraction . . . . .	71
4.2.3	Thermally Induced Nonlinear Absorption and Refraction . . . . .	75
4.3	Nonlinear Absorption and Refraction of Semiconductor Thin Films . . . . .	80
4.3.1	Nonlinear Saturation Absorption of c-Sb-Based Phase-Change Thin Films . . . . .	80
4.3.2	Nonlinear Reverse Saturation Absorption and Refraction of c-InSb Thin Films . . . . .	85
4.3.3	Nonlinear Reverse Saturation Absorption of AgInSbTe Thin Films . . . . .	90
4.3.4	Nonlinear Absorption Reversal of c-Ge <sub>2</sub> Sb <sub>2</sub> Te <sub>5</sub> Thin Films . . . . .	93
4.3.5	Nonlinear Saturation Absorption and Refraction of Ag-doped Si Thin Films . . . . .	99
4.4	Summary . . . . .	103
	References . . . . .	104
<b>5</b>	<b>Nanoscale Spot Formation Through Nonlinear Refraction Effect . . . . .</b>	<b>107</b>
5.1	Introduction . . . . .	107
5.2	Interference Manipulation-Induced Nanoscale Spot . . . . .	108

5.2.1	Nonlinear Fabry–Perot Cavity Structure Model . . . . .	108
5.3	Self-focusing Effect-Induced Nanoscale Spot Through “Thick” Samples . . . . .	121
5.3.1	Multilayer Thin Lens Self-focusing Model . . . . .	123
5.3.2	Light Traveling Inside Positive Nonlinear Refraction Samples . . . . .	126
5.3.3	Comparison with Equivalent Converging Lens Model . . . . .	131
5.3.4	Application Schematic Design . . . . .	132
5.4	Summary . . . . .	133
	References . . . . .	133
<b>6</b>	<b>Optical Super-Resolution Effect Through Nonlinear Saturation Absorption . . . . .</b>	<b>135</b>
6.1	Basic Description of Nonlinear Saturation Absorption-Induced Super-Resolution Effect . . . . .	135
6.2	Beer–Lambert Model for Thin (or Weak) Nonlinear Saturation Absorption Sample . . . . .	136
6.2.1	Beer–Lambert Analytical Model . . . . .	136
6.2.2	Experimental Observation of Super-Resolution Spot . . . . .	137
6.3	Multi-layer Model for Thick (or Strong) Nonlinear Saturation Absorption Samples . . . . .	143
6.3.1	Multi-layer Analytical Model for Formation of Pinhole Channel . . . . .	143
6.3.2	Super-Resolution Effect Analysis Using Multi-layer Model . . . . .	144
6.4	Summary . . . . .	150
	References . . . . .	151
<b>7</b>	<b>Resolving Improvement by Combination of Pupil Filters and Nonlinear Thin Films . . . . .</b>	<b>153</b>
7.1	Introduction . . . . .	153
7.2	Super-Resolution with Pupil Filters . . . . .	153
7.2.1	Binary Optical Elements as Pupil Filters: Linearly Polarized Light Illumination . . . . .	153
7.2.2	Ternary Optical Elements as Pupil Filters: Radially or Circularly Polarized Light Illumination . . . . .	158
7.3	Combination of Pupil Filters with Nonlinear Absorption Thin Films . . . . .	165
7.3.1	Combination of Nonlinear Saturation Absorption Thin Films with Three-Zone Annular Binary Phase Filters: Linearly Polarized Light Illumination . . . . .	166
7.3.2	Combination of Nonlinear Reverse Saturation Absorption Thin Films with Five-Zone Binary Pupil Filter: Circularly Polarized Light Illumination . . . . .	171
7.4	Nonlinear Thin Films as Pupil Filters . . . . .	177
7.4.1	Scalar Theoretical Basis . . . . .	177

7.4.2	Super-Resolution Spot Analysis . . . . .	180
	References . . . . .	192
<b>8</b>	<b>Applications of Nonlinear Super-Resolution Thin Films in Nano-optical Data Storage . . . . .</b>	<b>195</b>
8.1	Development Trend for Optical Information Storage . . . . .	195
8.2	Saturation Absorption-Induced High-Density Optical Data Storage . . . . .	196
8.2.1	Read-Only Super-Resolution Optical Disk Storage . . . . .	196
8.2.2	Recordable Super-Resolution Nano-optical Storage . . . . .	202
8.3	Reverse-Saturation Absorption-Induced Super-Resolution Optical Storage . . . . .	215
8.3.1	Recordable Super-Resolution Optical Disks with Nonlinear Reverse-Saturation Absorption . . . . .	215
8.3.2	Read-Only Optical Disk with Reverse-Saturation Absorption Effect . . . . .	216
8.4	Read-Only Super-Resolution Optical Disks with Thermally Induced Reflectance Change Effect . . . . .	219
	References . . . . .	222
<b>9</b>	<b>Applications of Nonlinear Super-Resolution Effects in Nanolithography and High-Resolution Light Imaging . . . . .</b>	<b>225</b>
9.1	Introduction . . . . .	225
9.2	Thermal Threshold Lithography . . . . .	225
9.2.1	Crystallization Threshold Lithography . . . . .	226
9.2.2	Thermal Decomposition Threshold Lithography . . . . .	228
9.2.3	Molten Ablation Threshold Lithography . . . . .	230
9.2.4	Pattern Application: Grayscale Lithography . . . . .	231
9.3	Nanolithography by Combination of Saturation Absorption and Thermal Threshold Effects . . . . .	232
9.3.1	Basic Principle . . . . .	232
9.3.2	Nanoscale Lithography Induced by Si Thin Film with 405-nm Laser Wavelength . . . . .	233
9.4	Nanolithography by Combination of Reverse Saturation Absorption and Thermal Diffusion Manipulation . . . . .	235
9.4.1	Formation of Below-Diffraction-Limited Energy Absorption Spot . . . . .	235
9.4.2	Thermal Diffusion Manipulation by Thermal Conductive Layer . . . . .	242
9.4.3	Experimental Nanolithography Marks . . . . .	245

9.5	Nonlinearity-Induced Super-Resolution Optical Imaging . . . . .	247
9.5.1	Basic Principle Schematics . . . . .	247
9.5.2	Theoretical Description . . . . .	247
9.5.3	Experimental Testing . . . . .	249
9.6	Summary . . . . .	252
	References . . . . .	252
	<b>Remarkings . . . . .</b>	<b>255</b>