

Contents

Preface	ix
How to read this book	xi
Chapter 1 History of Near-field Optics	1
1.1 Notion of imaging system	1
1.2 Bases of imaging	4
1.2.1 Vision	4
1.2.2 Image	5
1.2.3 Far-field imaging systems	6
1.2.4 Notion of superresolution	7
1.2.5 Near-field imaging systems	9
1.3 History of near-field microscopy	12
1.3.1 Synge's speculation	12
1.3.2 J. O'Keefe's letter	12
1.3.3 E. Ash and G. Nicholls realization	13
1.3.4 Superresolution in imaging systems	13
1.3.5 Scanning tunnelling microscopy	14
1.3.6 Early optical near-field microscopes	14
Chapter 2 Non-radiating Sources & Non-propagating Fields	17
2.1 Introduction	17
2.1.1 A few words of terminology	18
2.2 Various non-radiating sources	18
2.3 Non-radiating classical distributions	18

2.4	Non-radiating sources by destructive interference	21
2.5	Extension of the notion of non-radiating source	23
2.5.1	Evanescent fields	24
2.5.2	Evanescent field generated by total internal reflection	24
2.5.3	Destructive-interference device	25
2.5.4	Resonant evanescent fields	26
2.5.5	Resonant spherical devices	29
Chapter 3 Evanescent Optics		31
3.1	Theory of Fresnel evanescent waves	32
3.1.1	Reflection and refraction laws	32
3.1.2	Total internal reflection	34
3.1.3	Energy flow and Poynting vector	37
3.1.4	Goos-Hänchen and transversal shifts	38
3.1.4.1	Goos-Hänchen shift	38
3.1.4.2	Transverse shift: Imbert's shift	41
3.2	Evanescent fields generated by sub-wavelength diffraction	42
3.3	Light beam propagation	43
3.4	A particular case of evanescent waves: the plasmons	48
3.4.1	Definition of a plasmon	48
3.4.2	Theory	49
3.4.3	Scanning plasmon optical microscopy	51
Chapter 4 Theories and Modellings		57
4.1	Early works	57
4.2	Recent works	58
4.3	Different ways of approaching the theory of near-field optics	59
4.3.1	Physical approach	59
4.3.1.1	Depending on the dimensional relationship between the sample and the wavelength	59
4.3.1.2	Depending on the mathematical field description	60
4.3.2	Model space	60
4.3.3	Global or non-global approach	60
4.4	Tip description	61
4.4.1	Description in a non-global scheme	61
4.4.1.1	Geometrical approach	62
4.4.1.2	Tip collector as a polarisable dipole centre	62

4.4.1.3	Tip collector as a small sphere	63
4.4.1.4	The aperture case	64
4.4.1.5	The apertureless collector concept	65
4.4.2	Description in a global scheme	68
4.4.2.1	Non-retarded electrostatic model	68
4.4.2.2	Finite-difference time-domain model	68
4.4.2.3	Rigorous theory of gratings	68
4.4.2.4	Perturbative method	69
4.4.2.5	Multiple multipole technique	69
4.5	Light-sample interaction	69
4.5.1	Rigorous grating theory	69
4.5.1.1	Differential methods	70
4.5.2	The reciprocal-space perturbative method (<i>RSPM</i>)	73
4.5.2.1	Diffraction in term of angular spectrum expansion	73
(a)	Rayleigh's hypothesis	75
(b)	Perturbative approach	76
4.5.3	Direct-space-global approaches	77
4.5.3.1	Finite-difference time-domain method (<i>FDTD</i>)	77
(c)	Principle	78
4.5.3.2	Direct-space integral equation method (<i>DSIEM</i>)	79
(d)	Perturbative approximation	84
4.5.3.3	Variant of the dipolar approach: the Green's dyadic technique	84
(e)	Propagators or Green's dyadic	85
(f)	Huygens-Fresnel principle	86
(g)	Resolution of the Lippmann-Schwinger equation	87
(h)	Alternative derivation of the Lippmann-Schwinger equation	87
4.5.3.4	Comparison between <i>RSPM</i> and <i>DSIEM</i>	88
4.5.3.5	The Multiple Multipole technique (<i>MMP</i>)	90
Chapter 5 Inverse Problem and Apparatus Function		93
5.1	Introduction	93
5.2	Inverse problem solution in band-limited far-field imaging	97

5.3	Inverse propagator and reciprocity theorem	98
5.3.1	Reciprocity theorem	98
5.4	Inverse problem solution in near-field imaging	100
5.5	Apparatus functions	100
5.5.1	Impulse response	101
5.5.2	Transfer function	101
Chapter 6 Criteria of Quality, Noise and Artifacts		103
6.1	Degrees of freedom of an optical system	103
6.1.1	Generalization of Lukosz's approach	104
6.1.2	Far-field case	105
6.1.3	Near-field case	106
6.1.4	Information capacity for noisy coherent signals	107
6.2	Noise in optical systems	107
6.2.1	Optical noises	108
6.2.1.1	Shot noise	108
6.2.1.2	Thermal (incoherent) light	109
6.2.1.3	Dark current	109
6.2.1.4	Practical case	110
6.2.2	External noises	111
6.3	Artifacts	112
6.3.1	Scanning modes in near-field microscopy	112
6.3.2	Notion of artifact	112
6.3.2.1	Straightforward artifacts	114
6.3.2.2	Indirect artifacts	114
6.4	Comparison between the three scanning mode behaviours	115
6.4.1	Input parameters of the simulation	115
6.4.2	Constant distance mode	117
6.4.3	Constant height mode	118
6.4.4	Constant intensity mode	119
6.5	Notion of resolution	123
6.5.1	Detection	123
6.5.2	Localization	124
6.5.3	Resolution	125
6.5.4	The two-point criterion	126
6.5.5	Other estimates of resolution	127
6.5.5.1	Full-width-at-half-maximum measurement of the point spread function	127

6.5.5.2	Step slope measurement	128
6.5.5.3	Fourier spectrum extension estimate	129
6.5.6	Optical transfer function <i>OTF</i>	130
6.5.7	<i>OTF</i> in near-field optics	131
6.5.8	Experimental <i>OTF</i> in near-field optics	132
6.5.8.1	Measurement of fringe visibility	132
6.5.8.2	Statistical properties of a random distribution of sources	132
6.5.8.3	Ratio of object and image spectra	132
6.5.9	Contrast	133
6.5.9.1	Noiseless images	133
6.5.9.2	Noisy images	134
6.5.10	New criteria of quality	136
Chapter 7	Nano-collectors and Nano-emitters	139
7.1	Precursors	139
7.2	Near-field collection and emission	140
7.2.1	Principle	140
7.2.2	Distance of collection/emission	141
7.2.3	Shape of nano-collectors/emitters	141
7.2.3.1	Conical shapes	142
7.2.3.2	Large cone angles versus small ones	142
7.2.3.3	Pseudo-paraboloidal, compound tips	143
7.2.3.4	Other shapes	144
7.3	Various technologies	145
7.4	Bare tapers	148
7.4.1	Shaping techniques	148
7.4.2	Etching techniques	148
7.4.3	Effect of parameters	149
7.4.4	More sophisticated procedures	150
7.4.5	High aperture angle conical tips	151
7.4.6	Hot stretching techniques	151
7.4.7	Advantages and drawbacks of the two techniques	153
7.4.8	Tapered metal wire and silicon AFM tips	154
7.4.9	Pyramidal tips	155
7.5	Coated materials	157
7.5.1	Flat nano-apertures	158
7.5.2	Tapered nano-apertures	162

7.5.2.1	Tapered quartz rod	162
7.5.2.2	Micro-pipette coating	162
7.5.3	Tapered/cleaved fibres	164
7.5.4	Efficiency of tapered metal coated fibres	166
7.5.5	Laser damages	166
7.5.6	Realization of the aperture by other techniques	167
7.5.6.1	Rubbing technique	167
7.5.6.2	Solid electrolysis	169
7.6	Nano-antenna used as a near-field perturbing system	170
7.7	Variant of tapered fibres	171
7.8	Chemical sensors used as fluorescent tips	171
Chapter 8 Instrumentation		175
8.1	Basic structure of near-field optical microscopes	175
8.2	Mechanical part	176
8.2.1	Translation stage	176
8.2.1.1	<i>PZT</i> material	176
8.2.1.2	Piezo-electric tubes	178
8.2.2	Practical case	179
8.2.3	Techniques for machining the piezo-electric tube	179
8.2.3.1	Mechanical etching	179
8.2.3.2	Chemical etching	180
8.2.4	Compensation of the thermal drift	181
8.2.5	Connection of the wires on the electrodes	182
8.3	Holding of the nano-collector/emitter	182
8.3.1	Fibre as a nano-collector/emitter	182
8.3.2	Other collector/emitters	184
8.4	Anti-vibration devices	184
8.4.1	Distance control	185
8.4.1.1	Optical control	186
8.4.1.2	Electron tunnelling control	189
8.4.1.3	Force controls	189
8.4.1.4	Shear-force control	189
8.4.1.5	Methods of measurement	191
8.5	Optical part	192
8.5.1	Source	192
8.5.2	Detector	194
8.5.3	Usual optical and opto-electronic components	195

8.6	Electronic stages	195
8.6.1	Synchronous detection	196
8.6.2	Distance control: the <i>P.I.D.</i> device	196
8.6.2.1	New regulation concept	198
Chapter 9 Main Near-field Microscope Configurations		201
9.1	Transmission microscopes	202
9.2	Reflection microscopy	204
9.3	Tunnelling microscopy	206
9.4	Optical tunnelling microscopy	208
9.4.0.2	Guerra's configuration	208
9.4.0.3	Scanning tunnelling optical microscopy STOM ^{††} or PSTM [†]	208
9.4.0.4	Inverse STOM/PSTM: the ISTOM or TNOM	210
9.5	Plasmon microscopy	212
9.6	Hybrid techniques	213
9.6.1	Near-field microscopy with shear-force control	213
9.6.2	Contact near-field optical microscopy	214
Chapter 10 Near-field Image Processing		215
10.1	Generalities	215
10.1.1	Linear distortions	215
10.1.2	Non-linear distortions	216
10.2	Correction of distortions	218
10.2.1	Correction of linear distortions	218
10.2.2	Correction of non-linear distortions	220
10.2.3	Correction of tip-sample sticking	220
10.3	Filtering process	220
10.3.1	Direct or local filtering	220
10.3.1.1	Linear filtering: convolution filtering	220
10.3.1.2	Non-linear filtering	223
10.3.1.3	Normalization procedures	227
10.3.2	Fourier or reciprocal filtering	227
10.4	Karhunen-Loève transform and information extraction	229
Chapter 11 Applications of Near-field Microscopy		235
11.1	Introduction	235
11.1.1	First attempts: topography measurements	236

11.1.2	Local index variation measurement	236
11.1.2.1	First case: sub-wavelength spatial variations	237
11.1.2.2	Second case: very low index variations	237
11.1.2.3	Spatially resolved spectroscopy	238
11.1.2.4	Superresolution fluorescence SNOM	241
11.1.2.5	Biological applications	241
11.2	Light trapping	242
11.3	Concept of nano-optics	243
11.4	A simple case: the frustrated reflection by a sphere or a tip	244
11.5	A second example: the resonant tunnelling effect	244
11.6	A more sophisticated example: a sub-wavelength periodic structure	245
11.7	Photonic transfer through segmented optical waveguides	246
Appendix A Basis of Optics		249
A.0.1	Unit Systems	249
A.1	Basic functions and operators in optics	250
A.1.1	Reminder on vectorial calculus	250
A.1.1.1	Nabla operator	250
A.1.1.2	Gradient of scalar V	250
A.1.1.3	Divergence of vector \mathbf{U}	251
A.1.1.4	Rotational of vector \mathbf{U}	251
A.1.1.5	Scalar laplacian of scalar V	251
A.1.1.6	Vectorial laplacian of vector \mathbf{U}	251
A.1.2	Relations connecting gradient, divergence and rotational	252
A.1.3	Dyadic analysis	252
A.2	Maxwell's equations	253
A.2.1	Material equations	254
A.2.2	Maxwell's equation in the dyadic scheme	254
A.3	Wave equation	255
A.3.1	There is no charges or currents ($\rho = 0$ and $\mathbf{j} = 0$)	255
A.3.2	The medium is homogeneous, (μ and ϵ space-independent)	255
A.3.3	The medium is homogeneous and there is no charges or currents	256
A.3.4	Case of harmonic fields	256
A.4	Scalar and vector potentials	256
A.5	Static regimes	257

A.5.1	Poisson's and Laplace's equations	257
A.5.2	Field generated by a single charge	257
A.5.3	Flux of an electric field through a surface element	258
A.5.4	Gauss' theorem	258
A.6	Green's functions and Green's theorem	260
A.6.1	Green's functions in classical potential theory	260
A.6.2	Time dependent fields: the Helmholtz equation	261
A.6.3	Green's theorem	261
A.6.4	Green's dyadic	262
A.7	Expansion of a field in term of a set of plane waves	262
A.7.1	Basis	263
A.7.2	Angular spectrum expansion (<i>A.S.E.</i>)	263
A.8	Propagation of light using <i>A.S.E.</i>	265
A.9	Analysis of the results	266
	Nomenclature	269
	List of Acronyms	271
	Glossary	275
	Index	279
	Author Index	289
	Bibliography	297