

Stefan Enoch · Nicolas Bonod
Editors

Plasmonics

From Basics to Advanced Topics

 Springer

Contents

Part I Surface Plasmons Polaritons on Metallic Surfaces

1	Survey of Surface Plasmon Polariton History	3
1.1	Introduction	3
1.2	Plasmonics and Grating Anomalies	4
1.2.1	Discovery of Wood's Anomalies	4
1.2.2	The Early Experimental and Theoretical Contributions	5
1.2.3	The Explanations in Terms of Surface Waves	5
1.2.4	The Experimental and Theoretical Revolutions	6
1.2.5	The Failure of Perfect Conductivity Model in the Grating Theory	7
1.2.6	The Quantitative Phenomenological Approach	9
1.2.7	Other Studies	10
1.2.8	Coherent Thermal Emission	11
1.3	Plasmonics in Nanophotonics	11
1.3.1	Extraordinary Transmission Through Subwavelength Holes	12
1.3.2	Plasmonics and Metamaterials	14
1.3.3	Plasmonics and Near-Field Microscopy	20
1.4	Plasmon Propagation on Randomly Rough Surfaces, Weak and Strong Localization of Light	21
1.4.1	Enhanced Backscattering (Weak Localization)	22
1.4.2	Anderson Localization (Strong Localization)	26
1.5	Conclusion	28
	References	29
2	Theory of Wood's Anomalies	39
2.1	Introduction	39
2.2	Propagation of Surface Plasmon Polaritons on a Metallic Surface	46

2.2.1	Case of the Flat Surface	46
2.2.2	Case of the Diffraction Grating	58
2.3	Phenomenological Study of Wood Anomalies	63
2.3.1	Pole of the Reflection and Transmission Coefficients	63
2.3.2	Zero of the Reflection Coefficient, Phenomenological Formula	64
2.3.3	Verification of the Phenomenological Formula from Numerical Results	65
2.4	Total Absorption of Light by a Diffraction Grating	67
2.4.1	Theoretical Demonstration	67
2.4.2	Experimental Verification	68
2.4.3	Some Applications	70
2.5	Further Properties of Surface Plasmon Polaritons	71
2.5.1	Physical Interpretation and Fundamental Properties of the Zero of the Reflection Coefficient	71
2.5.2	Analogy with Guided Waves in Dielectric Films Deposited on Metallic Surfaces	73
2.6	Conclusion	76
	Appendix 1: Electromagnetic modelling in Two Dimensions. . .	76
	References	80
3	A New Look at Grating Theories Through the Extraordinary Optical Transmission Phenomenon	85
3.1	Introduction	85
3.2	The Initial Microscopic Interpretation of Wood's Anomaly. . . .	87
3.3	Why Question the Initial Plasmonic Interpretation?	89
3.3.1	Modern Grating Theory and Local Surface Waves.	90
3.3.2	Perfectly-Conducting Case	90
3.3.3	The Quasi-Cylindrical Wave	92
3.4	Explaining the EOT with Grating Theories	94
3.5	Microscopic SPP Theory.	97
3.6	The Role of Surface Plasmons in the EOT	99
3.7	Conclusion	101
	References	102
4	Introduction to Surface Plasmon Theory.	105
4.1	Introduction.	105
4.2	Surface and Particle Electron Oscillation Modes: Introductory Examples	106
4.3	Bulk Plasmon	108
4.3.1	Hydrodynamic Model: The Concept of Polariton.	108
4.3.2	Bulk Plasmon: Electromagnetic Model	110

4.4	Surface Electromagnetic Wave	111
4.4.1	Dispersion Relation for the Non-Magnetic Case.	111
4.4.2	Polarization of the Surface Wave.	113
4.4.3	Length Scales of a Surface Wave.	114
4.4.4	Link with Resonances of the Reflection Factor	115
4.4.5	Generation of a Surface Wave.	115
4.5	Surface Plasmon Polariton.	116
4.5.1	Dielectric Constant of a Metal.	116
4.5.2	Dispersion Relation of a SPP.	119
4.5.3	Electrostatic Limit	123
4.6	Surface Phonon Polaritons.	123
4.6.1	Lorentz Model.	123
4.7	A Potpourri of Surfaces Waves: Sommerfeld or Zenneck Modes, Quasicylindrical or Lateral Wave	124
4.7.1	Historical Perspective	125
4.8	Key Properties of SPP	127
4.8.1	Confinement of the Field	127
4.8.2	Surface Plasmons Contribution to the Local Density of States	129
4.8.3	Broad Spectrum and Fast Response	138
4.9	Surface Plasmon Polaritons on Lossy Materials.	139
4.9.1	First Interpretation	139
4.9.2	Representation of the Fields	140
4.9.3	Implications for LDOS	142
4.9.4	Implications for Superresolution and Strong Confinement.	142
4.10	Fourier Optics for SPP	143
4.10.1	General Representation	144
4.10.2	Huygens–Fresnel Principle	145
4.11	Conclusion	146
	References	146

Part II Surface Plasmons Localized on Metallic Particles

5	Localized Surface Plasmons: Basics and Applications in Field-Enhanced Spectroscopy	151
5.1	Localized Plasmons and Optical Antennas	152
5.1.1	Surface Plasmon Polaritons Versus Localized Surface Plasmon Polaritons	152
5.1.2	The Simplest Optical Nanoantenna: A Metallic Nanoparticle	154
5.1.3	Higher-Order Modes.	157

5.1.4	Retardation	159
5.1.5	Influence of Particle Shape in Plasmon Response	161
5.1.6	Field Enhancement by Plasmon Coupling	163
5.1.7	Optical Antennas: From Radiowaves to Visible Light	166
5.2	Field-Enhanced Vibrational Spectroscopy	168
5.2.1	Concept	169
5.2.2	SERS	169
5.2.3	SEIRA	172
5.2.4	Localized Plasmons in Other Applications	173
	References	174
6	Plasmons on Separated Particles: Homogenization and Applications	177
6.1	Introduction	177
6.2	Electromagnetic Waves in Structured Systems	178
6.3	Effective Permittivities and Permeabilities	180
6.4	Plasmon Resonances in Particle Clusters	188
6.5	Application of Plasmonic Resonances in Solar Energy Absorbers	190
6.6	Coated Cylinders and Plasmonic Cloaking	193
6.7	The Spaser: Cutting our Losses	196
6.8	Envoi	198
	References	198
7	Plasmon Nano-Optics: Designing Novel Nano-Tools for Biology and Medicine	201
7.1	Optical and Thermal Properties of Plasmonic Metallic Nanoparticles	201
7.1.1	Nanoscale Light Concentration in MNP	202
7.1.2	Nanoscale Heat Generation in MNP	202
7.2	MNP as Nano Light-Sources: Application to Biosensing and Optical Trapping	208
7.2.1	Enhanced Sensitivity LSP-Based Biosensing	208
7.2.2	Plasmon-Based Optical Trapping	211
7.3	MNP as Nano Heat-Sources for Photothermal Cancer Therapy	218
7.3.1	Toxicity	219
7.3.2	Cancer Cell Targeting and Latest Advances in Hyperthermia	219
7.4	Conclusion	220
	References	220

Part III Imaging and Nanofabrication

8	Imaging Surface Plasmons	225
8.1	Introduction	225
8.2	Optical Near-Field Imaging	227
8.2.1	Near-Field Imaging of Propagative Surface Plasmons	227
8.2.2	Near-Field Imaging of Localized Surface Plasmons	230
8.3	Photochemical Mapping	232
8.4	Leakage Radiation Microscopy	235
8.4.1	Leaky Mode Properties	235
8.4.2	Leakage Radiation Microscopy	240
8.4.3	Leakage Radiation Microscopy of Surface Plasmon Coupled Emission	242
8.5	Fluorescent Probes	244
8.6	Dark-Field Microscopy	245
8.7	Confocal Laser Microscopy	248
8.8	SPP Imaging with Electrons	251
8.8.1	Electron-Matter Interaction	252
8.8.2	Spatially Resolved Electron Energy-Loss Spectroscopy	255
8.8.3	Cathodoluminescence Microscopy	259
8.8.4	Photoemission Electron Microscopy	261
8.8.5	Photon-Induced Electron Microscopy: Highly Resolved Electron Energy-Loss/Gain Spectroscopy Imaging	262
	References	265
9	Nanofabrication for Plasmonics	269
9.1	Introduction	269
9.2	Methods of Nanofabrication and Related Techniques	270
9.2.1	Lithography: Evolution and Resolution Issue	271
9.2.2	Electron-Beam Lithography	273
9.2.3	Complementary and Alternative Lithographic Techniques	278
9.2.4	Lift-off	282
9.2.5	Direct Writing	284
9.2.6	Surface Functionalization	285
9.3	Structures Fabrication	289
9.3.1	Metallic Nanostructuring on Planar Surfaces	290
9.3.2	Metallic Structures Fabrication on a NonPlanar Surface	300
9.3.3	Metallic Structure Surface Functionalization	303
9.3.4	Hybrid Nanostructures Fabrication	304

9.4	Alternative Techniques and Emerging Issues	306
9.4.1	Localized Photochemical Combined Synthesis and Patterning	307
9.4.2	Material Issues.	307
9.4.3	Large-Scale Nanostructuring: Toward Plasmonic Materials (Effective Properties) and Metamaterials.	310
9.4.4	Plasmonic Integration	312
9.5	Summary	314
	References	315
	Index	317