

Contents

1	Introduction	1
1.1	What are Metamaterials?	1
1.2	Macroscopic Effective Parameters	5
	References	8
2	Optical Properties of Metal-Dielectric Composites	11
2.1	Optical Materials and Electronic Structures	11
2.2	Optical Properties of Dielectric Materials	13
2.3	Optical Properties of Metals	19
2.4	Metal-Dielectric Composites and Mixing Rules	25
	References	36
3	Experimental Techniques and Data Treatment	39
3.1	Fabrication of Two-Dimensional Optical Metamaterials	39
3.2	Approaching the Third Dimension	43
3.3	Characterization of Spectral Properties	47
3.4	Extraction of Homogenized Optical Parameters	51
	References	56
4	Electric Metamaterials	59
4.1	A Brief Overview of Artificial Dielectrics	59
4.2	Optical Properties of Stratified Metal-Dielectric Composites	60
4.3	Periodic Array of Metallic Wires	64
4.4	Semicontinuous Metal Films	71
	References	74
5	Magnetic Metamaterials	77
5.1	Negligible Optical Magnetism in Nature	77
5.2	Split-Ring Resonators	78
5.3	Optical Magnetic Elements	82
5.4	Magnetism in the Visible Spectrum	88

5.5	Analytical Model of Magnetic Nanostrips	93
5.6	High-Permittivity Route to Artificial Magnetism	96
	References	98
6	Negative-Index Metamaterials	101
6.1	A Brief Historical Review	101
6.2	Reversed Phenomena in Negative-Index Media	103
6.3	Negative Refraction in Microwave Frequencies	105
6.4	The Debut of Optical Negative-Index Materials	107
6.5	General Recipe for Construction	112
6.6	Alternative Approaches	116
	References	120
7	Nonlinear Optics with Metamaterials	123
7.1	Recent Advances of Nonlinear Effects in Metamaterials	123
7.2	Second-Harmonic Generation and the Manley–Rowe Relations in Negative-Index Materials	126
7.3	Optical Parametric Amplifications in Negative-index Materials	131
	References	134
8	Super Resolution with Meta-Lenses	137
8.1	Perfect Lens with Subwavelength Resolution	137
8.2	Near-Field Superlens	140
8.3	“Tunable” Superlens Using Random Composites	142
8.4	Potential Applications of the Composite Lens	148
8.5	Far-Field Imaging with Super-Resolution	149
	References	155
9	Transformation Optics and Electromagnetic Cloak of Invisibility	159
9.1	Invisibility and Transformation Optics: An Overview	159
9.2	Cloaking by Coordinate Transformation	162
9.3	Towards Experimental Demonstrations	167
9.4	Non-magnetic Optical Cloak	171
9.5	Cloaking with High-Order Transformations	176
9.6	Designs for High-Order Optical Cloaking	180
9.7	Alternative Approaches for Optical Cloaking	187
9.8	Concluding Remarks on Transformation Optics	191
	References	193
	Index	197