

TABLE OF CONTENTS

1 INTRODUCTION	14
1.1 Aims and objectives of the study	14
2 RESEARCH METHODOLOGY	15
3 EXECUTIVE SUMMARY	16
3.1 Historical metamaterials market	16
3.2 Recent growth	17
3.3 Global market revenues, current and forecast	17
3.4 Regional analysis	20
3.5 Market opportunity assessment	22
3.6 Investment funding in metamaterials	26
3.7 Market and technology challenges	26
3.8 Industry developments 2020-2022	27
4 METAMATERIALS OVERVIEW	29
4.1 What are metamaterials?	29
4.1.1 Electromagnetic metamaterials	29
4.1.2 Metasurfaces	30
4.1.2.1 Meta-Lens	31
4.1.2.2 Metasurface holograms	32
4.1.2.3 Invisibility cloaking and shielding	33
4.1.2.4 Flexible metasurfaces	33
4.1.2.5 Reconfigurable intelligent surfaces (RIS)	34
4.2 Types of metamaterials	34
4.2.1 Electromagnetic metamaterials	35
4.2.1.1 Double negative (DNG) metamaterials	35
4.2.1.2 Single negative metamaterials	35
4.2.1.3 Electromagnetic bandgap metamaterials (EBG)	35

4.2.1.4	Bi-isotropic and bianisotropic metamaterials	36
4.2.1.5	Chiral metamaterials	36
4.2.1.6	Electromagnetic “Invisibility” cloak.....	37
4.2.2	Terahertz metamaterials	37
4.2.3	Photonic metamaterials.....	38
4.2.4	Tunable metamaterials.....	39
4.2.5	Frequency selective surface (FSS) based metamaterials.....	39
4.2.6	Nonlinear metamaterials	39
4.2.7	Acoustic metamaterials	40
4.2.8	Graphene in metamaterials applications	40
4.3	Technology Readiness Level (TRL)	42

5 MARKETS AND APPLICATIONS FOR METAMATERIALS 44

5.1	Global revenues for metamaterials, by market, 2017-2033 (Millions USD).....	44
5.2	ACOUSTICS.....	46
5.2.1	Market drivers and trends.....	46
5.2.2	Applications.....	47
5.2.2.1	Sound insulation	47
5.2.2.2	Vibration dampers.....	49
5.2.3	Market assessment.....	49
5.2.4	Global revenues 2017-2033	50
5.3	CONSUMER ELECTRONICS AND COMMUNICATIONS.....	52
5.3.1	Market drivers and trends.....	52
5.3.2	Applications.....	52
5.3.2.1	Antennas.....	52
5.3.2.2	5G and 6G Metasurfaces for Wireless Communications	54
5.3.2.3	Thermal management	55
5.3.2.4	Wireless charging.....	56
5.3.3	Market assessment.....	57
5.3.4	Global revenues 2017-2033	59

5.4	AUTOMOTIVE	61
5.4.1	Market drivers and trends.....	61
5.4.2	Applications.....	61
5.4.2.1	Radar and sensors.....	61
5.4.2.2	Autonomous vehicles	63
5.4.2.3	Anti-reflective plastics	63
5.4.3	Market assessment.....	64
5.4.4	Global revenues 2017-2033	66
5.5	AEROSPACE, DEFENCE & SECURITY.....	68
5.5.1	Market drivers and trends.....	68
5.5.2	Applications.....	68
5.5.2.1	Stealth technology.....	68
5.5.2.2	Radar	69
5.5.2.3	Optical sensors	70
5.5.2.4	Security screening.....	71
5.5.2.5	Composites.....	71
5.5.2.6	Windscreen films.....	72
5.5.2.7	Protective eyewear for pilots	73
5.5.2.8	Electromagnetic shielding	73
5.5.2.9	Thermal management	73
5.5.3	Market assessment.....	73
5.5.4	Global revenues 2017-2033	75
5.6	COATINGS AND FILMS	77
5.6.1	Market drivers and trends.....	77
5.6.2	Applications.....	77
5.6.2.1	Cooling films	77
5.6.2.2	Anti-reflection surfaces.....	78
5.6.2.3	Optical solar reflection coatings.....	78
5.6.3	Market assessment.....	78

5.6.4	Global revenues 2017-2033	80
5.7	SOLAR.....	82
5.7.1	Market drivers and trends.....	82
5.7.2	Applications.....	82
5.7.2.1	Solar-thermal absorber	82
5.7.2.2	Coatings.....	82
5.7.3	Global revenues 2017-2033	83
5.8	MEDICAL IMAGING.....	85
5.8.1	Market drivers and trends.....	85
5.8.2	Applications.....	85
5.8.2.1	MRI imaging.....	85
5.8.3	Global revenues 2017-2033	86
5.9	DISPLAYS	88
5.9.1	Market drivers and trends.....	88
5.9.2	Applications.....	88
5.9.2.1	Superlenses for cameras, smartphones and VR headsets	88
5.9.2.2	Stretchable displays	88
5.9.2.3	Soft materials	89
5.9.2.4	Anti-reflection coatings.....	91
6	COMPANY PROFILES	92
6.1	.....	92
6.2	.....	93
6.3	.....	93
6.4	.....	94
6.5	.....	95
6.6	.....	96
6.7	.....	97
6.8	.....	99
6.9	.....	100

6.10	.....	102
6.11	.....	104
6.12	.....	104
6.13	.....	105
6.14	.....	106
6.15	.....	108
6.16	.....	108
6.17	.....	109
6.18	.....	109
6.19	.....	112
6.20	.....	114
6.21	.....	115
6.22	.....	116
6.23	.....	117
6.24	.....	119
6.25	.....	120
6.26	.....	122
6.27	.....	122
6.28	.....	123
6.29	.....	124
6.30	.....	125
6.31	.....	127
6.32	.....	127
6.33	.....	128
6.34	.....	128
6.35	.....	129
6.36	.....	130
6.37	.....	131
6.38	.....	131

6.39	██████████	.....	132
6.40	████████████████████	.....	133
6.41	██████████████	.....	133
6.42	████████████████████	.....	134
6.43	██████████████	.....	134
6.44	██████████████	.....	135
6.45	██████████████	.....	136
6.46	██████████████	.....	137
6.47	██████████████	.....	138
6.48	██████████████	.....	138
6.49	██████████████	.....	139
6.50	██████████████	.....	139
6.51	██████████	.....	140
6.52	██████████	.....	141
6.53	██████████████	.....	142
6.54	██████████████	.....	143
6.55	██████████████	.....	143
6.56	██████████	.....	144
6.57	██████████████	.....	144

7 REFERENCES 146

List of Tables

Table 1. Market summary for metamaterials.....	18
Table 2. Global revenues for metamaterials and metasurfaces, total, 2017-2033 (Millions USD), Conservative estimate.....	19
Table 3. Global revenues for metamaterials and metasurfaces, by region, 2017-2033 (Millions USD).....	21
Table 4. Market opportunity assessment matrix for metamaterials and metasurfaces applications.....	24
Table 5. Investment funding in metamaterials and metasurfaces companies.....	26
Table 6. Market and technology challenges in metamaterials and metasurfaces.....	26

Table 7. Metamaterials and metasurfaces industry developments 2020-2021.	27
Table 8. Technology Readiness Level (TRL) Examples.....	42
Table 9. Global revenues for metamaterials, by market, 2017-2033 (Millions USD).....	44
Table 10. Metamaterials and metasurfaces in sound insulation-market drivers and trends.....	46
Table 11. Market assessment for metamaterials and metasurfaces in acoustics.	49
Table 12. Market opportunity assessment for metamaterials in acoustics.....	50
Table 13. Global revenues for metamaterials and metasurfaces in acoustics, 2017-2033 (Millions USD)...	51
Table 14: Metamaterials and metasurfaces in electronics and communications-market drivers and trends.	52
Table 15. Unmet need, metamaterial solution and markets.	53
Table 16. Market assessment for metamaterials and metasurfaces in communications.	57
Table 17. Market opportunity assessment for metamaterials and metasurfaces in communications.....	58
Table 18. Global revenues for metamaterials and metasurfaces in communications, 2017-2033 (Millions USD).....	59
Table 19. Metamaterials and metasurfaces in the automotive sector-market drivers and trends.....	61
Table 20. Market assessment for metamaterials and metasurfaces in automotive.....	64
Table 21. Market opportunity assessment for metamaterials and metasurfaces in automotive.	65
Table 22. Global revenues for metamaterials and metasurfaces in automotive, 2017-2033 (Millions USD).	66
Table 23. Metamaterials and metasurfaces in aerospace, defence and security-market drivers and trends.	68
Table 24. Market assessment for metamaterials and metasurfaces in aerospace, defence & security.	73
Table 25. Market opportunity assessment for metamaterials and metasurfaces in aerospace, defence & security.	74
Table 26. Global revenues for metamaterials in aerospace, defence & security, 2017-2033 (Millions USD).	76
Table 27. Metamaterials in coatings and films-market drivers and trends.	77
Table 28. Market assessment for metamaterials and metasurfaces in coatings and films.....	78
Table 29. Market opportunity assessment for metamaterials and metasurfaces in coatings and films.	79
Table 30. Global revenues for metamaterials and metasurfaces in coatings and films, 2017-2033 (Millions USD).....	80

Table 31: Metamaterials and metasurfaces in solar-market drivers and trends.....	82
Table 32. Global revenues for metamaterials and metasurfaces in solar, 2017-2033 (Millions USD).....	84
Table 33: Metamaterials and metasurfaces in medical imaging-drivers and trends.....	85
Table 34. Global revenues for metamaterials and metasurfaces in medical imaging, 2017-2033 (Millions USD).....	86
Table 35: Metamaterials and metasurfaces in touch screens and displays-drivers and trends.....	88

List of Figures

Figure 1. Classification of metamaterials based on functionalities.	16
Figure 2. Global revenues for metamaterials and metasurfaces, total, 2017-2033 (Millions USD).	18
Figure 3. Global revenues for metamaterials and metasurfaces, by market, 2017-2033 (Millions USD).	20
Figure 4. Global revenues for metamaterials and metasurfaces, by region, 2017-2033 (Millions USD).	21
Figure 5. Metamaterials example structures.	29
Figure 6. Metamaterial schematic versus conventional materials.	30
Figure 7. Scanning electron microscope (SEM) images of several metalens antenna forms.	32
Figure 8. Transparent and flexible metamaterial film developed by Sekishi Chemical.	33
Figure 9. Electromagnetic metamaterial.	35
Figure 10. Schematic of Electromagnetic Band Gap (EBG) structure.	36
Figure 11. Schematic of chiral metamaterials.	37
Figure 12. Terahertz metamaterials.	38
Figure 13. Nonlinear metamaterials- 400-nm thick nonlinear mirror that reflects frequency-doubled output using input light intensity as small as that of a laser pointer.	40
Figure 14. Properties and applications of graphene metamaterials.....	41
Figure 15. Technology Readiness Level (TRL) for metamaterials and metasurfaces.....	43
Figure 16. Global revenues for metamaterials, by market, 2017-2033 (Millions USD).	45
Figure 17. Prototype metamaterial device used in acoustic sound insulation.....	47
Figure 18. Metamaterials installed in HVAC sound insulation the Hotel Madera Hong Kong.	48
Figure 19. Robotic metamaterial device for seismic-induced vibration mitigation.	49
Figure 20. Global revenues for metamaterials and metasurfaces in acoustics, 2017-2033 (Millions USD)..	51

Figure 21. Flat-panel satellite antenna (top) and antenna mounted on a vehicle (bottom).	54
Figure 22. META Transparent Window Film.	55
Figure 23. Radi-cool metamaterial film.	56
Figure 24. Wireless charging technology prototype.	57
Figure 25. Global revenues for metamaterials and metasurfaces in communications, 2017-2033 (Millions USD).	59
Figure 26. Metamaterials in automotive applications.	62
Figure 27. Lumotive advanced beam steering concept.	62
Figure 28. Illustration of EchoDrive operation.	63
Figure 29. Anti-reflective metamaterials plastic.	64
Figure 30. Global revenues for metamaterials and metasurfaces in automotive, 2017-2033 (Millions USD).	66
Figure 31. Metamaterials invisibility cloak for microwave frequencies.	69
Figure 32. Metamaterials radar antenna.	70
Figure 33. Metamaterials radar array.	70
Figure 34. Evolv Edge visitor screening solution.	71
Figure 35. Lightweight metamaterial microlattice.	72
Figure 36. metaAIR eyewear.	73
Figure 37. Global revenues for metamaterials in aerospace, defence & security, 2017-2033 (Millions USD).	76
Figure 38. Schematic of dry-cooling technology.	78
Figure 39. Global revenues for metamaterials and metasurfaces in coatings and films, 2017-2033 (Millions USD).	80
Figure 40. Metamaterial solar coating.	83
Figure 41. Global revenues for metamaterials and metasurfaces in solar, 2017-2033 (Millions USD).	84
Figure 42. A patient in MRI scan modified by metasurface.	85
Figure 43. Global revenues for metamaterials and metasurfaces in medical imaging, 2017-2033 (Millions USD).	86
Figure 44. Stretchable hologram.	89
Figure 45. Design concepts of soft mechanical metamaterials with large negative swelling ratios and tunable stress-strain curves.	90

Figure 46. Anywaves antenna products. CubeSat S-band antenna, CubeSat X-band antenna and UAV cellular antenna.....	94
Figure 47. Brelyon monitor.	95
Figure 48. RadarZero.	97
Figure 49. Schematic of MESA System.	98
Figure 50. EchoGuard Radar System.	99
Figure 51. Edgohog Advanced Technologies Omnidirectional anti-reflective coating.....	100
Figure 52. Emrod architecture. 1. A transmitting antenna. 2. A relay that is essentially lossless, doesn't require any power, and acts as a lens refocusing the beam extending the travel range. 3. A rectenna that receives and rectifies the beam back to electricity. Metamaterials allow converting wireless energy back into electricity efficiently.	101
Figure 53. Commercial application of Emrod technology.	102
Figure 54. Evolv Edge screening system.	103
Figure 55. FM/R technology.....	106
Figure 56. Metablade antenna.	107
Figure 57. MTenna flat panel antenna.	110
Figure 58. Kymeta u8 antenna installed on a vehicle.	111
Figure 59. LIDAR system for autonomous vehicles.	113
Figure 60. Metamaterials film.....	114
Figure 61. Metaboard wireless charger.....	115
Figure 62. Orion dot pattern projector.	118
Figure 63. A 12-inch wafer made using standard semiconductor processes contains thousands of metasurface optics.	118
Figure 64. metaAIR.	121
Figure 65. Nissan acoustic metamaterial.	130
Figure 66. Metamaterial structure used to control thermal emission.	136