

Table of contents

1	INTRODUCTION	9
1.1	What are thermal interface materials (TIMs)?	10
1.2	Properties	12
1.2.1	Thermal conductivity	13
1.3	Comparative properties of TIMs	14
1.4	Advantages and disadvantages of TIMs, by type.	16
1.5	Prices	17
2	MATERIALS	19
2.1	Thermal Pads/Insulators	20
2.2	Thermally Conductive Adhesives	21
2.3	Thermal Compounds or Greases	22
2.4	Thermally Conductive Epoxy/Adhesives	24
2.5	Phase Change Materials	25
2.5.1	Properties of Phase Change Materials (PCMs)	26
2.5.2	Types	27
2.5.2.1	Organic/biobased phase change materials	29
2.5.2.1.1	Advantages and disadvantages	29
2.5.2.1.2	Paraffin wax	29
2.5.2.1.3	Non-Paraffins/Bio-based	30
2.5.2.2	Inorganic phase change materials	31
2.5.2.2.1	Salt hydrates	31
2.5.2.2.1.1	Advantages and disadvantages	32
2.5.2.2.2	Metal and metal alloy PCMs (High-temperature)	32
2.5.2.3	Eutectic mixtures	33
2.5.2.4	Encapsulation of PCMs	33
2.5.2.4.1	Macroencapsulation	33
2.5.2.4.2	Micro/nanoencapsulation	33
2.5.2.5	Nanomaterial phase change materials	34
2.5.3	Thermal energy storage (TES)	34
2.5.3.1	Sensible heat storage	35
2.5.3.2	Latent heat storage	35
2.5.4	Application in TIMs	36
2.6	Metal-based TIMs	38
2.6.1	Solders and low melting temperature alloy TIMs	38
2.6.2	Liquid metals	40
2.6.3	Solid liquid hybrid (SLH) metals	41
2.7	Carbon-based TIMs	42
2.7.1	Multi-walled nanotubes (MWCNT)	43
2.7.1.1	Properties	44
2.7.1.2	Application as thermal interface materials	45

2.7.2	Single-walled carbon nanotubes (SWCNTs)	46
2.7.2.1	Properties	46
2.7.2.2	Application as thermal interface materials	47
2.7.3	Vertically aligned CNTs (VACNTs)	47
2.7.3.1	Properties	48
2.7.3.2	Application as thermal interface materials	49
2.7.4	BN nanotubes (BNNT) and nanosheets (BNNS)	50
2.7.4.1	Properties	50
2.7.4.2	Application as thermal interface materials	51
2.7.5	Graphene	51
2.7.5.1	Properties	52
2.7.5.2	Application as thermal interface materials	53
2.7.6	Nanodiamonds	53
2.7.6.1	Properties	54
2.7.6.2	Application as thermal interface materials	55
2.7.7	Graphite flakes	56
2.7.7.1	Properties	56
2.7.7.2	Application as thermal interface materials	57
3	MARKETS FOR THERMAL INTERFACE MATERIALS (TIMs)	60
3.1	Consumer electronics	60
3.1.1	Overview	62
3.1.2	Applications	63
3.2	EV Batteries	65
3.2.1	Overview	65
3.2.2	Applications	66
3.3	Data Centers	70
3.3.1	Overview	71
3.3.2	Applications	73
3.4	ADAS Sensors	76
3.4.1	Overview	76
3.4.2	Applications	79
3.5	EMI shielding	85
3.5.1	Overview	85
3.6	5G	90
3.6.1	Overview	90
3.6.2	Applications	94
3.7	Global revenues for TIMs 2018-2033, by market	95
3.8	Future market prospects	98
4	COMPANY PROFILES	99
4.1	██████████	99
4.2	████████████████████	100
4.3	████████████████████	101

4.4	██████████	102
4.5	██████████	103
4.6	██████████	104
4.7	██████████	105
4.8	██████████	106
4.9	██████████	107
4.10	██████████	108
4.11	██████████	109
4.12	██████████	110
4.13	██████████	111
4.14	██████████	112
4.15	██████████	113
4.16	██████████	114
4.17	██████████	115
4.18	██████████	116
4.19	██████████	117
4.20	██████████	118
4.21	██████████	119
4.22	██████████	120
4.23	██████████	121
4.24	██████████	122
4.25	██████████	123
4.26	██████████	124
4.27	██████████	125
4.28	██████████	126
4.29	██████████	127
4.30	██████████	128
4.31	██████████	129
4.32	██████████	130
4.33	██████████	131
4.34	██████████	132
4.35	██████████	133
4.36	██████████	136
4.37	██████████	137
4.38	██████████	138
4.39	██████████	139
4.40	██████████	140
4.41	██████████	141
4.42	██████████	142
4.43	██████████	144
4.44	██████████	144
4.45	██████████	145
4.46	██████████	146

4.47	████████████████████	148
4.48	████████████████████	148
4.49	██████████	150
4.50	██████	150
4.51	██████████	151
4.52	████████████████████	153
4.53	██████████	154
4.54	████████████████████	155
4.55	████████████████████	155
4.56	██████	157
4.57	████████████████████	158
4.58	████████████████████	159
4.59	████████████████████	160
4.60	██████████	161
4.61	██████████	162
4.62	██████████	163
4.63	████████████████████	164
5	RESEARCH METHODOLOGY	166
6	REFERENCES	167

List of Tables

Table 1. Thermal Conductivity vs Thermal Resistance	13
Table 2. Thermal conductivities (κ) of common metallic, carbon, and ceramic fillers	13
Table 3. Thermal conductivity of common types of fillers	14
Table 4. Basic physical properties of commercially available TIMs	14
Table 5. Commercial TIMs and their properties	14
Table 6. Advantages and disadvantages of TIMs, by type	16
Table 7. Fabrication methods and thermal performances of advanced thermal interface materials	24
Table 8. Properties of PCMs	26
Table 9. PCM Types and properties	28
Table 10. Advantages and disadvantages of organic PCMs	29
Table 11. Advantages and disadvantages of organic PCM Fatty Acids	30
Table 12. Advantages and disadvantages of salt hydrates	32
Table 13. Advantages and disadvantages of low melting point metals	32

Table 14. Advantages and disadvantages of eutectics.	33
Table 15. Summary of thermal conductivities (κ) of carbon-based TIMs.	42
Table 16. TIMS in EV batteries.	67
Table 17. Global revenues for TIMs 2018-2033, by market.	97

List of Figures

Figure 1. Schematic representation of working principle of a TIM.	10
Figure 2. Thermal Pads die cut to a precise shape, ready for assembly.	20
Figure 3. Thermally conductive liquid epoxy.	22
Figure 4. Strip of 3M thermal conductive adhesive transfer tape 8810 kiss cut on a roll.	22
Figure 5. Thermal resistance of silicone grease with different types of CNTs.	23
Figure 6. Thermal Grease product.	24
Figure 7. PCM mode of operation.	27
Figure 8. Classification of PCMs.	27
Figure 9. Phase-change materials in their original states.	28
Figure 10. Thermal energy storage materials.	35
Figure 11. Phase Change Material transient behaviour.	35
Figure 12. Phase Change Material - die cut pads ready for assembly.	36
Figure 13. SEM image of vertically aligned CNT.	48
Figure 14. Schematic of Thermal Management Materials in smartphone.	63
Figure 15. Coolzorb 5G.	87
Figure 16. Schlegel EMI - Shielding Gaskets.	87
Figure 17. Panasonic G-TIM.	88
Figure 18. Global revenues for TIMs 2018-2033, by market.	97
Figure 19. HI-FLOW Phase Change Materials.	135