INTERFACIAL MICROSTRUCTURE GROWTH MECHANISM OF LEAD-FREE SOLDER USING LASER SOLDERING

MUHAMMAD ASYRAF BIN ABDULLAH

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG
AL-SULTAN ABDULLAH

اونيۏرسيتي مليسيا قهڠ السلطان عبد الله
UNIVERSITI MALAYSIA PAHANG
AL-SULTAN ABDULLAH

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

_____

(Supervisor's Signature)

Full Name : ASSOC. PROF. TS. DR. SITI RABIATULL AISHA BINTI IDRIS

Position : SENIOR LECTURER

Date : 9 JANUARY 2024

اونيۏرسيتي مليسيا قهڠ السلطان عبد الله
UNIVERSITI MALAYSIA PAHANG
AL-SULTAN ABDULLAH

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang Al-Sultan Abdullah or any other institutions.

_____

(Student's Signature)

Full Name : MUHAMMAD ASYRAF BIN ABDULLAH

ID Number : MMF20003

Date : 9 JANUARY 2024

INTERFACIAL MICROSTRUCTURE GROWTH MECHANISM OF LEAD-FREE SOLDER USING LASER SOLDERING

MUHAMMAD ASYRAF BIN ABDULLAH

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Mechanical and Automotive Engineering Technology

UNIVERSITI MALAYSIA PAHANG AL-SULTAN ABDULLAH

JANUARY 2024

ACKNOWLEDGEMENTS

The completion of this project was only made possible with the invaluable guidance and assistance from numerous individuals, and I feel incredibly fortunate to have had their support throughout my thesis. Therefore, I would like to express my heartfelt gratitude to my supervisor, Ts. Dr. Siti Rabiatull Aisha Binti Idris, for granting me the opportunity to undertake this thesis and for providing unwavering support and guidance that enabled me to complete it within the stipulated time frame.

My supervisor never fails to impress with her professional conduct, her passion in the work she does, and her belief in. I am deeply grateful for the unwavering support and guidance that my supervisor has provided me with throughout this project, right from its inception to its culmination. I sincerely appreciate her constant assistance and am thankful for her visionary leadership, her willingness to overlook any errors I may have made, and her unwavering dedication towards charting a course for our future.

I am truly grateful for successfully completing this project within the given timeline set by Ts. Dr. Siti Rabiatull Aisha Binti Idris. It required significant effort on my part, and I could not have done it alone. I would also like to express my appreciation to our colleagues and participants for their support and cooperation during the experimentation phase. Words cannot adequately convey our gratitude for their unwavering dedication, encouragement, and belief in our ability to achieve our goals.

ABSTRAK

Mengikut bukti saintifik, Plumbum (Pb) dikenali sebagai logam yang berpotensi tinggi memberikan kesan buruk ke atas kesihatan manusia. Untuk itu, terdapat pembangunan khusus ke atas elektronik hijau, terutamanya teknologi pembungkusan elektronik termaju yang bertujuan untuk mempromosikan kesihatan masyarakat. Seperti yang kita ketahui, aloi hijau dianggap sebagai pilihan yang selamat untuk persekitaran dan kesihatan manusia. Aloi-aloi ini juga dikenali berdasarkan potensi mereka untuk diguna semula, yang membawa kepada penjimatan kos. Kajian ini bermatlamat untuk menyiasat kesan komposisi aloi pateri hijau yang berbeza terhadap pembentukan dan pertumbuhan sebatian antara logam (IMC) semasa pematerian laser ke atas substrat kuprum metalik. Selain itu, kekuatan sambungan pateri dianalisis melalui ujian mekanikal. Eksperimen dijalankan menggunakan serbuk Sn dan Cu dengan peratusan yang berbeza (Sn-xCu, x = 0.0, 0.3, 0.5, 0.7, 1.0). Dalam kajian ini, proses bermula dengan penyediaan bahan melalui proses metalurgi serbuk. Bahan serbuk ditimbang dan kemudian diadun menggunakan pengisar serbuk pada kelajuan 1300-1500 rpm selama 3 jam. Serbuk campuran kemudian dipadatkan dengan tekanan 5 tan membentuk palet nipis segi empat tepat dengan saiz 3.2x1.5 mm. Kemudian, palet-palet ini dikenakan pematerian laser menggunakan laser gas CO2 dengan kuasa laser 35 watt, masa imbasan 0.04s, jarak fokus 40mm dan kelajuan imbasan 100mm/s. Substrat yang digunakan dalam eksperimen ini adalah electroless nickel immersion gold (ENIG). Proses diikuti oleh penuaan isoterma selama 0, 200, 500,1000 dan 2000 jam pada suhu 150oC. Selepas itu, sampel-sampel ini diuji secara mekanikal menggunakan ujian ricih, mengikut piawaian ASTM D1002. Komposisi, ketebalan dan morfologi IMC yang terbentuk selepas pematerian laser diperiksa menggunakan pelabagai teknik pencirian bahan seperti analisis optik dan imej, analisis pengimbasan mikroskop elektron dan energy-dispersive X-ray. Kajian mendapati komposisi bahan mempengaruhi morfologi IMC, yang mana ia juga mempengaruhi kelakuan pertumbuhannya. Peningkatan kandungan Cu di dalam aloi pateri menyebabkan penurunan ketebalan IMC dengan ketebalan terendah pada 0.3wt% Cu. Walaubagaimanapun, ketebalan ini meningkat perlahan-lahan dengan penuaan isoterma, dan IMC berubah dari bentuk jejarum kepada bentuk rata yang berterusan. Pateri 0.7wt% Cu menunjukkan pekali resapan terendah dan paling berkesan mengurangkan pertumbuhan IMC. Tingkahlaku pembasahan bagi pateri komposit Sn-xCu dipengaruhi oleh kandungan partikel Cu, dengan sudut pembasahan terendah adalah didapati pada 0.7wt% Cu. Penambahan Cu ke dalam aloi pateri telah meningkatkan kekuatan ricih sambungan lap tunggal, dengan kekuatan tertinggi adalah didapati pada 0.7wt% Cu. Walaubagaimanapun, kekuatan ricih sambungan Sn-0.3Cu menurun selepas penuaan isotermal. Kombinasi teknik metalurgi serbuk dan pematerian laser telah meningkatkan keboleharapan sambungan pateri di dalam penghasilan mikroelektronik, sekaligus menyediakan potensi penyelesaian untuk mencapai keboleharapan di dalam proses penghasilan mikroelektronik. Kajian menunjukkan keberhasilan pendekatan ini dalam mencapai komposisi dan mikrostruktur yang sekata bagi prabentuk pateri, sekaligus menghasilkan sambungan pateri yang unggul dengan peningkatan ciri-ciri mekanikal dan haba.

ABSTRACT

According to scientific evidence, plumbum (Pb) is recognized as a metal with the highest potential for adverse impacts on human health. For that, there was a growing emphasis on green electronics, particularly advanced electronic packaging technology, to promote societal health. As we know, green alloys are considered a safer option for the environment and human health. These alloys are also recognized for their potential for reuse, resulting in cost-effectiveness. This study aims to investigate the impact of different compositions of green solder alloys on the development and growth of intermetallic compounds (IMC) during laser soldering of a metallized copper substrate. Besides that, the solder joint strength was analyzed through mechanical testing. The experiment used Sn and Cu powder with different percentages (Sn-*x*Cu, where x = 0.0, 0.3, 0.5, 0.7, 1.0). In this study, the process starts with materials preparation through powder metallurgy process route. Powder material was weighed and then blended using powder milling at the speed range of 1300-1500 rpm for 3 hours. The mixture of powders was compacted using a pressure of 5 tons to produce thin rectangular pallets with dimensions of 3.2 x 1.5 mm. These pallets were then subjected to laser soldering using a CO_2 gas laser, with a laser power of 35 watts, a scanning time of 0.04s, a focal length of 40mm, and a scanning speed of 100mm/s. The substrate employed in the experiment was electroless nickel immersion gold (ENIG). The procedure was further followed by subjecting the samples to isothermal ageing at a temperature of 150^{o}C for durations of 0, 200, 500, 1000, and 2000 hours. After that, these samples were mechanically tested using a shear test, following the ASTM D1002 standard was used to evaluate single-lap-joint adhesively bonded metal specimens (solder alloy). The composition, thickness, and morphology of IMC formed after laser soldering were examined using various material characterization techniques, such as optical and image analysis, scanning electron microscopy, and energy-dispersive X-ray analysis. The study found that the material composition affected the morphology of IMCs, which also influenced their growth behaviour. Increasing the Cu content in the solder alloy decreased the thickness of the IMC, with the lowest thickness observed at 0.3wt% Cu. Nevertheless, the thickness gradually increased with isothermal ageing, and the IMC changed from a needle-shape to a continuous level-off shape. The 0.7wt% Cu solder exhibited the lowest diffusion coefficients and the most effective reduction in IMC growth. The wetting behaviour of Sn-*x*Cu composite solders was significantly affected by Cu particle content, with the lowest wetting angle observed at 0.7wt% Cu. Adding Cu to the solder alloy improved the shear strength of single lap joints, with the highest strength observed at 0.7wt% Cu. However, the shear strength of Sn-0.3Cu joints decreased after isothermal ageing. The combination of powder metallurgy and laser soldering techniques improved the reliability of solder joints in microelectronic production, providing a potential solution for achieving reliability in microelectronic production processes. The study's results demonstrate the effectiveness of this approach in achieving a uniform composition and microstructure of the solder preform, resulting in a superior solder joint with improved mechanical and thermal properties.

TABLE OF CONTENT

DECLARATION

TITLE PAGE

ACKNOWLEDGEMENTS **ii**

ABSTRAK **iii**

ABSTRACT **iv**

TABLE OF CONTENT **v**

LIST OF TABLES **ix**

LIST OF FIGURES **x**

LIST OF SYMBOLS **xiii**

LIST OF ABBREVIATIONS **xiv**

CHAPTER 1 INTRODUCTION **15**

1.1 Project Background 15

1.2 Problems Statement 17

1.3 Objective 18

1.4 Scope 19

1.5 Contribution Project Study 19

1.6 Thesis Layout 20

CHAPTER 2 LITERATURE REVIEW **22**

2.1 Introduction 22

2.2 Electronic Packaging 22

2.2.1 Second Level of Electronic Packaging 24

2.3 Surface Mount Technology (SMT) 25

2.4 Soldering 26

2.5 Solder Material 27

2.6 The Synthesis of a Solder Alloy Through The Implementation of Powder Metallurgy 28

2.7 Lead Contained Solder (Sn-Pb) 30

2.8 Lead Free Solder Series 31

2.8.1 Sn-Cu Solder Series 33

2.8.2 Chemical Interaction Occurring at The Interface Between Sn-Cu Lead-Free Solder Alloy and Copper Substrate 33

2.8.3 Formation of Intermetallic Compounds Following Soldering. 35

2.9 Surface Finish System 36

2.9.1 Characteristics of The Electroless Nickel Immersion Gold (ENIG) 38

2.10 Conventional Soldering 39

2.11 Laser Soldering 39

2.11.1 Laser Parameter Effect of Intermetallic Compound Formation Properties - The Morphology 40

2.11.2 Laser Parameter Effect of Intermetallic Compound Thickness 43

2.12 Mechanical Properties of Lead-Free Solder Alloy 48

2.12.1 Solder Joint Strength 48

2.13 Properties of Vibration-Induced Fracture 51

2.14 Wetting Behaviour of a Copper-Based Solder Alloy 52

2.15 Isothermal Ageing 53

2.16 Summary 55

CHAPTER 3 METHODOLOGY 57

3.1 Introduction 57

3.2 Research Framework 57

3.3 Development of Solder Alloy Using Powder Metallurgy Process 59

3.3.1 Powder Preparation 60

3.3.2 Milling 61

3.3.3 Compaction 62

3.4 Deposition Process of Electroless Nickel Immersion Gold 63

3.5 CO_2 Gas Laser Soldering Process 65

3.6 Isothermal Ageing Process 66

3.7 Characterization Analysis of Intermetallic Compounds 67

3.7.1 Specimens Preparation for Cross Section Analysis 68

3.7.2 Specimens Preparation for Top surface Analysis 68

3.8 Determination of Spread Ratio and Spread Factor 69

3.9 Single-Lap Shear Test Procedure 71

3.10 Summary 71

CHAPTER 4 RESULTS AND DISCUSSION 73

4.1 Introduction 73

4.2 Identification of IMC Type Through Atomic Percentage in EDX Data 73

4.3 Analysis of Wetting Behaviour Through Examination of Spread Ratio, Spread Factor, and Contact Angle 75

4.4 Spreading Area Single Lap Shear Strength 78

4.5 Effect of Ageing for Intermetallic Compound (IMC) Formation 79

4.6 Single Lap Solder Joint Shear Strength Analysis 80

4.7 Fracture Surfaces Single Lap Shear Strength 83

4.8 Cross Section Microstructure of Intermetallic Compound (IMC) Formation 84

4.9 Influence of Intermetallic Compound (IMC) Thickness Following Isothermal Ageing 86

4.10 Top Surface Microstructure of Intermetallic Compound (IMC) Formation 90

4.11 Summary 92

CHAPTER 5 CONCLUSION **93**

5.1 Conclusion 93

5.2 Recommendation for Future Works 94

REFERENCES **95**

APPENDIX A: EDX DATA FOR ATOMIC PERCENTAGE OF TOP SURFACE IMC (0 HOURS, SN-0.3CU WT%) **108**

APPENDIX B: EDX DATA FOR ATOMIC PERCENTAGE OF SPOT CROSS IMC (0 HOURS, SN-0.3CU WT%) **109**

APPENDIX C: LIST OF PUBLICATION **110**

LIST OF TABLES

Table 2.1	Important characteristics of solder alloys are outlined	28
Table 2.2	Binary eutectic solders	32
Table 2.3	The impact of copper percentage on the thickness of the IMC layer in lead-free solder joints during reflow soldering	47
Table 2.4	The impact of varying copper content on the shear strength of lead-free solder alloys	51
Table 2.5	High Temperature storage conditions	54
Table 2.6	Comparative Analysis of Solder Joint Reliability Data from Previous Studies	56
Table 3.1	Chemical composition of the Sn-*x*Cu solder (wt. %)	60
Table 3.2	Chemicals composition for solder etchant	68
Table 4.1	Weighted percentage of predicted IMCs calculation	74
Table 4.2	Computed readings of spread ratio and spread factor associated with varying temperatures	77

LIST OF FIGURES

Figure 2.1	Electronic packaging levels	23
Figure 2.2	Illustration of the wire bonding process, die, and die attachment.	24
Figure 2.3	Surface mount technology concept: an example of a common passive component	26
Figure 2.4	Different method types of material preparation microstructure: a) Casting Sn-0.7Cu, and b) PM Sn-0.7Cu	29
Figure 2.5	A comprehensive strategy to lead-free soldering	32
Figure 2.6	The binary phase diagram of Sn–Cu	35
Figure 2.7	Illustrating of the impacts of liquefied solder on protective and solderable surface coatings.	37
Figure 2.8	Arrangement element layer of ENIG	38
Figure 2.9	The top surface view of the intermetallic compound (IMC) Cu_6Sn_5 located at the joint between Sn/Cu and Sn3.5Ag0.5Cu/Cu connections using specific ranges of laser power and scanning speed. The shape with a yellow border inside the frame is an enlarged view of that part, allowing Ag_3Sn nanoparticles to be clearly seen	41
Figure 2.10	The surface morphology of the intermetallic compound (IMC) Cu_6Sn_5 located at the Sn3.5Ag0.5Cu/Cu transition, using a fiber laser at a specific power and scanning speed.	41
Figure 2.11	SEM images of the interfacial intermetallic compounds (IMCs) from a top-view perspective (a) reflow soldering and (b) laser soldering	42
Figure 2.12	The morphological characteristics of the Cu_6Sn_5 intermetallic compound (IMC) at the interface of Sn and Cu, grown using a specific laser power and scanning speed rate, as observed in cross-sectional analysis	44
Figure 2.13	The change in Cu_6Sn_5 intermetallic compound (IMC) thickness is examined as scan speed is altered for Sn and SAC solders at a constant power of 50 W	45
Figure 2.14	The morphological characteristics of the Cu_6Sn_5 intermetallic compound (IMC) at the interface of Sn and Sn3.5Ag0.5Cu/Cu, grown under specific fibre laser power and scanning speed conditions, as observed through cross-sectional	45
Figure 2.15	The hardness of different solidified solder alloys made of tin and copper with varying copper percentages	49
Figure 2.16	The strength of the solder joints formed by Sn-*x*Cu alloys	50
Figure 2.17	The lifespan under a constant vibration force of 3.5G	52
Figure 2.18	The degree of wettability of the solder on the copper substrate	53

Figure 3.1	Structure of the study flowchart	59
Figure 3.2	Powder metallurgy step	60
Figure 3.3	Milling machine	61
Figure 3.4	Top view grind machine illustration	61
Figure 3.5	Powder compaction process step	62
Figure 3.6	Compress powder rectangular thin pallet	62
Figure 3.7	The procedure for depositing electroless nickel and immersion gold	63
Figure 3.8	Surface finish ENIG layer thickness	65
Figure 3.9	Laser head position during laser soldering process	66
Figure 3.10	Ageing profile	67
Figure 3.11	Schematic diagram from side view, a) before, b) after etching	69
Figure 3.12	The diagram that illustrates the method for computing the contact angle, spread ratio, and spread factor.	70
Figure 3.13	Illustration of shear test	71
Figure 4.1	Weight-percentage IMC calculation	74
Figure 4.2	A visual representation of the area where the wetting angle is measured, as seen in a cross-sectional image	75
Figure 4.3	The trend of average contact angle of Sn-*x*Cu on the coating substrate after soldering at various percentages of Cu	76
Figure 4.4	The changes in spread ratio and spread factor of Sn-*x*Cu on a copper substrate after soldering at various percentages of Cu	77
Figure 4.5	Measuring method for (a) Top view area of the ENIG substrate (b) Shear area	78
Figure 4.6	Top surface spreading area after single lap shear strength	79
Figure 4.7	The top surface IMC microstructure of (a) Sn-0.3Cu 500h, (b) Sn-1.0Cu 500h, (c) Sn-0.3Cu 1000h and (d) Sn-1.0Cu 1000h	80
Figure 4.8	Comparison of shear strength between aged and different copper percentage solder joint	82
Figure 4.9	Optical top view images for the fracture surfaces of the Sn–xCu composite solder joints subjected to (a) Sn-0.3Cu 500H, (b) Sn-1.0Cu 500H, (c) Sn-0.3Cu 1000H and (d) Sn-1.0Cu 1000H	84
Figure 4.10	The EDX cross section IMC microstructure of (a) Sn-0.3Cu 500h, (b) Sn-1.0Cu 500h, (c) Sn-0.3Cu 1000h and (d) Sn-1.0Cu 1000h.	85
Figure 4.11	The view of the solder joint between Sn-*x*Cu and ENIG, as seen in cross section	87
Figure 4.12	The internal structure of the Sn-0.3Cu/ENIG joint at different ageing times: 0 hours, 200 hours, 500 hours, 1000 hours, and 2000 hours.	88

Figure 4.13 The thickness of the intermetallic compound (IMC) as it varies with ageing duration 89
Figure 4.14 The microstructure of the intermetallic compound (IMC) for (a) Sn-0.3Cu and (b) Sn1.0Cu 90
Figure 4.15 The top surface IMC microstructure of (a) Sn-0.3Cu 0h, and (b) Sn-1.0Cu 0h 91

REFERENCES

A, M. S. M. A., Al, A. M. M., Kamarudin, H., H, Z. H. M., & Somidin, F. (2011). Solderability of Sn-0 . 7Cu / Si 3 N 4 lead-free composite solder on. *Physics Procedia*, *22*, 299–304. https://doi.org/10.1016/j.phpro.2011.11.047

Abbas, H., Faizul, M., Sabri, M., Mohd, S., Muhammad, M., Megat, I., Abdulameer, D., & Vknsn, C. (2019). Electrochemical corrosion behavior of Sn-0 . 7Cu solder alloy with the addition of bismuth and iron. *Journal of Alloys and Compounds*, *810*, 151925. https://doi.org/10.1016/j.jallcom.2019.151925

Abdullah, M. A., & Idris, S. R. A. (2023). *Effect of Sn-xCu Solder Alloy onto Intermetallic Formation After Laser Soldering BT - Technological Advancement in Mechanical and Automotive Engineering* (M. Y. Ismail, M. S. Mohd Sani, S. Kumarasamy, M. A. Hamidi, & M. S. Shaari (eds.); pp. 869–880). Springer Nature Singapore.

Abtew, M., & Selvaduray, G. (2000). Lead-free Solders in Microelectronics. *Materials Science and Engineering: R: Reports*, *27*(5), 95–141. https://doi.org/https://doi.org/10.1016/S0927-796X(00)00010-3

Adawiyah, R., Mohamed, B., Tun, U., Onn, H., Hashim, S., Tun, U., Onn, H., Osman, S. A., Tun, U., & Onn, H. (2022). *The Interfacial Reaction Between Sn-Ag-Cu (SAC)/ Cu The Interfacial Reaction Between Sn-Ag-Cu (SAC)/ Cu During Laser Soldering*. *January*.

Agarwal, R., McCluskey, P., Dishongh, D., Javadpour, S., & Mahajan, R. (2001). Electronic Packaging Materials and their Properties. In *IEEE Electrical Insulation Magazine* (Vol. 17, Issue 5). https://doi.org/10.1109/MEI.2001.954592

Akkara, F. J., Zhao, C., Athamenh, R., Su, S., Abueed, M., Hamasha, S., Suhling, J., & Lall, P. (2018). Effect of Solder Sphere Alloys and Surface Finishes on the Reliability of Lead-Free Solder Joints in Accelerated Thermal Cycling. *Proceedings of the 17th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, ITherm 2018*, 1374–1380. https://doi.org/10.1109/ITHERM.2018.8419534

Al-sorory, H., Gumaan, M. S., & Shalaby, R. M. (2023). ZnO nanoparticles and compositional dependence of structural, thermal, mechanical and electrical properties of eutectic SAC355 lead-free solder. *Soldering & Surface Mount Technology*, *35*(3), 125–133. https://doi.org/10.1108/SSMT-06-2022-0045

Ali, U., Khan, H., Aamir, M., Giasin, K., Habib, N., & Owais Awan, M. (2021). Analysis of microstructure and mechanical properties of bismuth-doped SAC305 lead-free solder alloy at high temperature. *Metals*, *11*(7). https://doi.org/10.3390/met11071077

An, T., Fang, C., Qin, F., Li, H., Tang, T., & Chen, P. (2018). Failure study of Sn37Pb PBGA solder joints using temperature cycling, random vibration and combined temperature cycling and random vibration tests. *Microelectronics Reliability*, *91*, 213–226.

Ardebili, H., Zhang, J., & Pecht, M. G. (2018). Encapsulation Technologies for Electronic Applications. In *Materials and Processes for Electronic Applications*. https://doi.org/10.1016/B978-0-12-811978-5.00001-8

Arenas, M. F., & Acoff, V. L. (2004). Contact angle measurements of Sn-Ag and Sn-Cu lead-free solders on copper substrates. *Journal of Electronic Materials*, *33*(12), 1452–1458. https://doi.org/10.1007/s11664-004-0086-x

Association, J. S. S. T. (2004). *Jedec standard*. *November*.

Baoa, N., Xiaowu Hua, Lib, Q., & Lia, S. (2019). *Effect of Cu concentration on the interfacial reactions between Sn-xCu solders and Cu substrate*. 0–9.

Bharath Krupa Teja, M., Sharma, A., Das, S., & Das, K. (2022). A review on nanodispersed lead-free solders in electronics: synthesis, microstructure and intermetallic growth characteristics. *Journal of Materials Science*, *57*(19), 8597–8633. https://doi.org/10.1007/s10853-022-07187-8

Binh, D. N. (2020). Contact Angle of Sn-8Zn-3Bi Lead-free Solder Alloy on Copper Substrate. *Journal of Science and Technology*, *146*, 49–53.

Bogno, A., Eduardo, J., Ramos, C., & Afonso, M. (2014). Microstructural and mechanical properties analysis of extruded Sn – 0 . 7Cu solder alloy ☪. *Integrative Medicine Research*, *4*(1), 84–92. https://doi.org/10.1016/j.jmrt.2014.12.005

Carnarius, M. (2022). *Surface Finishes*. Fast Quality Service Inc.

Chang, C. C., Lin, Y. W., Wang, Y. W., & Kao, C. R. (2010). The effects of solder volume and Cu concentration on the consumption rate of Cu pad during reflow soldering. *Journal of Alloys and Compounds*, *492*(1), 99–104. https://doi.org/https://doi.org/10.1016/j.jallcom.2009.11.088

Chen, L. D., Huang, M. L., & Zhou, S. M. (2010). Effect of electromigration on intermetallic compound formation in line-type Cu/Sn/Cu interconnect. *Journal of Alloys and Compounds*, *504*(2), 535–541. https://doi.org/https://doi.org/10.1016/j.jallcom.2010.05.158

Choi, S., Bieler, T. R., Lucas, J. P., & Subramanian, K. N. (1999). Characterization of the growth of intermetallic interfacial layers of Sn-Ag and Sn-Pb eutectic solders and their composite solders on Cu substrate during isothermal long-term aging. *Journal of Electronic Materials*, *28*(11), 1209–1215. https://doi.org/10.1007/s11664-999-0159-y

Choudhury, M. R., & Debnath, K. (2022). Current and future trends in micro-joining and nano-joining. *Joining Processes for Dissimilar and Advanced Materials*, 209–239.

Chung, C. K., Duh, J.-G., & Kao, C. R. (2010). Direct evidence for a Cu-enriched region at the boundary between Cu6Sn5 and Cu3Sn during Cu/Sn reaction. *Scripta Materialia*, *63*(2), 258–260. https://doi.org/https://doi.org/10.1016/j.scriptamat.2010.04.011

Deeying, J., Asawarungsaengkul, K., & Chutima, P. (2018). Multi-objective optimization on laser solder jet bonding process in head gimbal assembly using the response surface methodology. *Optics & Laser Technology*, *98*, 158–168.

Deng, X., Sidhu, R. S., Johnson, P., & Chawla, N. (2005). Influence of reflow and thermal aging on the shear strength and fracture behavior of Sn-3.5Ag solder/Cu joints. *Metallurgical and Materials Transactions A*, *36*(1), 55–64. https://doi.org/10.1007/s11661-005-0138-8

Deubzer, O. (2019). Chapter 7 - Reduction of hazardous materials in electrical and electronic equipment. In V. Goodship, A. Stevels, & J. B. T.-W. E. and E. E. (WEEE) H. (Second E. Huisman (Eds.), *Woodhead Publishing Series in Electronic and Optical Materials* (pp. 207–230). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-08-102158-3.00007-0

Dong, C., Ma, H., Ma, H., & Wang, Y. (2023). Nucleation and growth of intermetallic compounds on the prefabricated Cu6Sn5 layer. *Materials Chemistry and Physics*, *296*, 127228.

El-rehim, A. F. A., & Zahran, H. Y. (2016). AC. *Journal of Alloys and Compounds*. https://doi.org/10.1016/j.jallcom.2016.11.371

Fabiana Meijon Fadul. (2019). *Soldering*. 1–13.

Flanders, D. R., Jacobs, E. G., & Pinizzotto, R. F. (1997). Activation energies of intermetallic growth of Sn-Ag eutectic solder on copper substrates. *Journal of Electronic Materials*, *26*(7), 883–887. https://doi.org/10.1007/s11664-997-0268-4

Gao, Y -j., Luo, Z., Zhao, J., & Wang, L. (2009). Study on the microstructure and the Shear Strength of Sn-0.7Cu-xZn. *2009 International Conference on Electronic Packaging Technology & High Density Packaging*, 890–893. https://doi.org/10.1109/ICEPT.2009.5270550

Gao, Yanjun, Hui, J., Sun, X., Zhao, F., Zhao, J., Cheng, C., Luo, Z., & Wang, L. (2011). Role of zinc on shear property evolution between Sn-0.7Cu solder and joints. *Procedia Engineering*, *16*(Imc), 807–811. https://doi.org/10.1016/j.proeng.2011.08.1158

Ginga, N. J., & Sitaraman, S. K. (2022). Thermomechanical Reliability Investigation of Carbon Nanotube Off-Chip Interconnects for Electronic Packages. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *12*(8), 1282–1292. https://doi.org/10.1109/TCPMT.2022.3194163

Girisha, L., kumar, R. S., Subbiah, R., Chand, R. R., & Mahesh, M. (2020). *A Text Book on Production Processes*. Shanlax Publications. https://books.google.com.my/books?id=B_5fEAAAQBAJ

Grifa, R. A., & Pozzoli, G. (2019). Electro-medical devices: Environmental regulation on hazardous substances. *Microchemical Journal*, *148*, 568–572. https://doi.org/https://doi.org/10.1016/j.microc.2019.05.047

Halil, K., İsmail, O., Sibel, D., & Ramazan, Ç. (2019). Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy. *Journal of Materials Research and Technology*, *8*(6), 5348–5361.

Hanim, M. A. A., Kamil, N. M., Wei, C. K., Dele-Afolabi, T. T., & Azlina, O. S. (2020). Microstructural and shear strength properties of RHA-reinforced Sn–0.7Cu composite solder joints on bare Cu and ENIAg surface finish. *Journal of Materials Science: Materials in Electronics*, *31*(11), 8316–8328. https://doi.org/10.1007/s10854-020-03367-x

Hasnine, M., Tolla, B., & Karasawa, M. (2017). Effect of Ge addition on wettability, copper dissolution, microstructural and mechanical behavior of SnCu–Ge solder alloy. *Journal of Materials Science: Materials in Electronics*, *28*(21), 16106–16119. https://doi.org/10.1007/s10854-017-7511-4

Hirman, M., & Steiner, F. (2017). Optimization of solder paste quantity considering the properties of solder joints. *Soldering and Surface Mount Technology*, *29*(1), 15–22. https://doi.org/10.1108/SSMT-10-2016-0025

Hlinka, J., Fogarassy, Z., Cziráki, Á., & Weltsch, Z. (2020). Wetting properties, recrystallization phenomena and interfacial reactions between laser treated Cu substrate and SAC305 solder. *Applied Surface Science*, *501*, 144127.

Hu, X., Li, Y., & Min, Z. (n.d.). Interfacial reaction and IMC growth between Bi-containing Sn07Cu solders and Cu substrate during soldering and aging. *Journal of Alloys and Compounds*, 341–347. https://doi.org/DOI:101016/jjallcom201308018

Hu, X., Li, Y., & Min, Z. (2013). Interfacial reaction and growth behavior of IMCs layer between Sn–58Bi solders and a Cu substrate. *Journal of Materials Science: Materials in Electronics*, *24*(6), 2027–2034. https://doi.org/10.1007/s10854-012-1052-7

Hu, X., Qiu, Y., Jiang, X., & Li, Y. (2018). Effect of Cu6Sn5 nanoparticle on thermal behavior, mechanical properties and interfacial reaction of Sn3.0Ag0.5Cu solder alloys. *Journal of Materials Science: Materials in Electronics*, *29*. https://doi.org/10.1007/s10854-018-9684-x

Hu, X., Xu, T., Keer, L. M., Li, Y., & Jiang, X. (2016). Materials Science & Engineering A Microstructure evolution and shear fracture behavior of aged Sn3Ag0 . 5Cu / Cu solder joints. *Materials Science & Engineering A*, *673*, 167–177. https://doi.org/10.1016/j.msea.2016.07.071

Huh, S. H., Kim, K. S., & Suganuma, K. (2002). Effect of Au addition on microstructural and mechanical properties of Sn-Cu eutectic solder. *Materials Transactions*, *43*(2), 239–245. https://doi.org/10.2320/matertrans.43.239

Hung, F.-Y., Lui, T.-S., Chen, L.-H., & He, N.-T. (2008). Resonant characteristics of the microelectronic Sn–Cu solder. *Journal of Alloys and Compounds*, *457*(1), 171–176. https://doi.org/https://doi.org/10.1016/j.jallcom.2007.03.026

Hung, F. Y., Lui, T. S., Chen, L. H., & He, N. T. (2008). Resonant characteristics of the microelectronic Sn-Cu solder. *Journal of Alloys and Compounds*, *457*(1–2), 171–176. https://doi.org/10.1016/j.jallcom.2007.03.026

Islam, M. N., Sharif, A., & Chan, Y. C. (2005). Effect of volume in interfacial reaction between eutectic Sn-3.5% Ag-0.5% Cu solder and Cu metallization in microelectronic packaging. *Journal of Electronic Materials*, *34*(2), 143–149. https://doi.org/10.1007/s11664-005-0225-z

Ismail, N., Jalar, A., Abu Bakar, M., Ismail, R., & Saedi Ibrahim, N. (2020). Effect of flux functional group for solder paste formulation towards soldering quality of SAC305/CNT/Cu. *Soldering & Surface Mount Technology*, *32*(3), 157–164.

Izrul, M., Ramli, I., Arif, M., Mohd, A., Sandu, A. V., Farahnabilah, S., Amli, M., Said, R. M., Saud, N., Mustafa, M., Bakri, A., Vizureanu, P., Rylski, A., Chaiprapa, J., & Nabialek, M. (2021). *Influence of 1 . 5 wt .% Bi on the Microstructure , Hardness , and Shear Strength of Sn-0 . 7Cu Solder Joints after Isothermal Annealing*. 1–13.

Izwan, I., Salleh, M., Sobri, F., Narayanan, P., Sweatman, K., & Nogita, K. (2019). Relationship between free solder thickness to the solderability of Sn–0.7Cu–0.05Ni solder coating during soldering. *Journal of Materials Science: Materials in Electronics*, *30*. https://doi.org/10.1007/s10854-018-00647-5

Jacobson, D. M. (2004a). *Principles of*.

Jacobson, D. M. (2004b). Principles of soldering. In *Choice Reviews Online* (Vol. 42, Issue 03). https://doi.org/10.5860/choice.42-1581

Jaya, N. T., Idris, S. R. A., & Ishak, M. (2019). A Review on Mechanical Properties of SnAgCu/Cu Joint Using Laser Soldering. *The Advances in Joining Technology*, 97–107.

Jiang, B., & Chen, Q. (2020). *Advances in joining technology of carbon fiber-reinforced thermoplastic composite materials and aluminum alloys*. 2631–2649.

Jiang, N., Zhang, L., Liu, Z. Q., Sun, L., Long, W. M., He, P., Xiong, M. Y., & Zhao, M. (2019). Reliability issues of lead-free solder joints in electronic devices. *Science and Technology of Advanced Materials*, *20*(1), 876–901. https://doi.org/10.1080/14686996.2019.1640072

Joo, H., Lee, C., Min, K. D., Hwang, B., & Jung, S. (2020). Mechanical properties and microstructural evolution of solder alloys fabricated using laser-assisted bonding. *Journal of Materials Science: Materials in Electronics*, *Sac 305*, 0–6. https://doi.org/10.1007/s10854-020-04819-0

Judd, M., & Brindley, K. (1999). *Soldering in Electronics Assembly*. 1–22.

Kang, S. K., Lauro, P., Shih, D.-Y., Henderson, D. W., & Puttlitz, K. J. (2005). Microstructure and mechanical properties of lead-free solders and solder joints used in microelectronic applications. *IBM Journal of Research and Development*, *49*(4.5), 607–620. https://doi.org/10.1147/rd.494.0607

Kanlayasiri, K., & Mookam, N. (2022). Influence of Cu content on microstructure, grain orientation and mechanical properties of Sn–xCu lead-free solders. *Transactions of Nonferrous Metals Society of China*, *32*(4), 1226–1241. https://doi.org/https://doi.org/10.1016/S1003-6326(22)65869-2

Kannojia, H. K., & Dixit, P. (2021). A review of intermetallic compound growth and void formation in electrodeposited Cu–Sn Layers for microsystems packaging. *Journal of Materials Science: Materials in Electronics*, *32*, 6742–6777.

Kim, J.-M., Jeong, M.-H., Yoo, S., Lee, C.-W., & Park, Y.-B. (2012). Effects of surface finishes and loading speeds on shear strength of Sn–3.0Ag–0.5Cu solder joints. *Microelectronic Engineering*, *89*, 55–57. https://doi.org/https://doi.org/10.1016/j.mee.2011.03.148

Kottcamp, E. H. (1992). *ASM METALS HANDBOOK VOLUME 3 Alloy Phase Diagrams*.

Kumar, S., Handwerker, C. A., & Dayananda, M. A. (2011). Intrinsic and Interdiffusion in Cu-Sn System. *Journal of Phase Equilibria and Diffusion*, *32*(4), 309–319. https://doi.org/10.1007/s11669-011-9907-9

Kunwar, A., Shang, S., Råback, P., Wang, Y., Givernaud, J., Chen, J., Ma, H., Song, X., & Zhao, N. (2018). Microelectronics Reliability Heat and mass transfer e ff ects of laser soldering on growth behavior of interfacial intermetallic compounds in Sn / Cu and Sn-3 . 5Ag0 . 5 / Cu joints. *Microelectronics Reliability*, *80*(July 2017), 55–67. https://doi.org/10.1016/j.microrel.2017.11.016

Lai, Y., Hu, X., Li, Y., & Jiang, X. (2018). Interfacial microstructure evolution and shear strength of Sn0.7Cu–xNi/Cu solder joints. *Journal of Materials Science: Materials in Electronics*, *29*(13), 11314–11324. https://doi.org/10.1007/s10854-018-9219-5

Lee, D. H., Jeong, M. S., & Yoon, J. W. (2022). Comparative study of interfacial reaction and bonding property of laser- and reflow-soldered Sn–Ag–Cu/Cu joints. *Journal of Materials Science: Materials in Electronics*, *33*(10), 7983–7994. https://doi.org/10.1007/s10854-022-07948-w

Lee, H.-T., & Chen, M.-H. (2002). Influence of intermetallic compounds on the adhesive strength of solder joints. *Materials Science and Engineering A*, *333*(1–2), 24–34. https://doi.org/10.1016/S0921-5093(01)01820-2

Li, L. F., Cheng, Y. K., Xu, G. L., Wang, E. Z., Zhang, Z. H., & Wang, H. (2014). Effects of indium addition on properties and wettability of Sn–0.7Cu–0.2Ni lead-free solders. *Materials & Design*, *64*, 15–20. https://doi.org/https://doi.org/10.1016/j.matdes.2014.07.035

Li, Y., Chen, C., Yi, R., & Ouyang, Y. (2020). Special brazing and soldering. *Journal of Manufacturing Processes*, *60*, 608–635.

Liu, Y., Ren, B., Xue, Y., Zhou, M., Cao, R., & Chen, P. (2021). Microelectronics Reliability Microstructure and mechanical behavior of SnBi-xAg and SnBi-xAg @ P-Cu solder joints during isothermal aging. *Microelectronics Reliability*, *127*(September), 114388. https://doi.org/10.1016/j.microrel.2021.114388

Lv, Y., Yang, W., Mao, J., Li, Y., Zhang, X., & Zhan, Y. (2020). Effect of graphene nano-sheets additions on the density, hardness, conductivity, and corrosion behavior of Sn–0.7 Cu solder alloy. *Journal of Materials Science: Materials in Electronics*, *31*, 202–211.

Ma, H., Ma, H., Kunwar, A., Shang, S., Wang, Y., Chen, J., Huang, M., & Zhao, N. (2018a). Effect of initial Cu concentration on the IMC size and grain aspect ratio in Sn–xCu solders during multiple reflows. *Journal of Materials Science: Materials in Electronics*, *29*, 602–613.

Ma, H., Ma, H., Kunwar, A., Shang, S., Wang, Y., Chen, J., Huang, M., & Zhao, N. (2018b). Effect of initial Cu concentration on the IMC size and grain aspect ratio in Sn–xCu solders during multiple reflows. *Journal of Materials Science: Materials in Electronics*, *29*(1), 602–613. https://doi.org/10.1007/s10854-017-7952-9

Mahdi, E. M. (2011). Failure analysis of a second level electronic package. *2011 IEEE Regional Symposium on Micro and Nanoelectronics, RSM 2011 - Programme and Abstracts*, 232–235. https://doi.org/10.1109/RSM.2011.6088331

Mattox, D. M. (2010). *Chapter 3 - The "Good" Vacuum (Low Pressure) Processing Environment* (D. M. B. T.-H. of P. V. D. (PVD) P. (Second E. Mattox (ed.); pp. 73–145). William Andrew Publishing. https://doi.org/https://doi.org/10.1016/B978-0-8155-2037-5.00003-4

Meng, F., Morin, S. A., Forticaux, A., & Jin, S. (2013). Screw Dislocation Driven Growth of Nanomaterials. *Accounts of Chemical Research*, *46*(7), 1616–1626. https://doi.org/10.1021/ar400003q

Nabihah, A., & Nurulakmal, M. S. (2019). Effect of In Addition on Microstructure, Wettability and Strength of SnCu Solder. *Materials Today: Proceedings*, *17*, 803–809. https://doi.org/https://doi.org/10.1016/j.matpr.2019.06.366

Nabila, J., Idris, S., & Ishak, M. (2019). Effect of fibre-lasers parameters on interfacial reaction and wetting angle of two different types of SAC305 solder fabrication on Cu pad. *IOP Conference Series: Materials Science and Engineering*, *469*, 12117. https://doi.org/10.1088/1757-899X/469/1/012117

Nabila, T. J., Idris, S., & Ishak, M. (2019). *Effect of fibre-lasers parameters on interfacial reaction and wetting angle of two different types of SAC305 solder fabrication on Cu pad*. https://doi.org/10.1088/1757-899X/469/1/012117

Nishikawa, H., & Iwata, N. (2015a). Formation and growth of intermetallic compound layers at the interface during laser soldering using Sn–Ag Cu solder on a Cu Pad. *Journal of Materials Processing Technology*, *215*, 6–11. https://doi.org/https://doi.org/10.1016/j.jmatprotec.2014.08.007

Nishikawa, H., & Iwata, N. (2015b). Journal of Materials Processing Technology Formation and growth of intermetallic compound layers at the interface during laser soldering using Sn – Ag Cu solder on a Cu Pad. *Journal of Materials Processing Tech.*, *215*, 6–11. https://doi.org/10.1016/j.jmatprotec.2014.08.007

Pal, M. K., & Gácsi, Z. (2020). *ANTAL KERPELY DOCTORAL SCHOOL OF MATERIALS SCIENCE & TECHNOLOGY Development of ceramic particle reinforced SAC305 lead-free solder composite material*. *November*, 1–100. https://www.kerpely.uni-miskolc.hu/files/13101/Manoj Pal disszertáció.pdf

Pal, M. K., Gergely, G., Koncz-Horváth, D., & Gácsi, Z. (2021). Investigation of microstructure and wetting behavior of Sn–3.0Ag–0.5Cu (SAC305) lead-free solder with additions of 1.0 wt % SiC on copper substrate. *Intermetallics*, *128*(August 2020). https://doi.org/10.1016/j.intermet.2020.106991

Pan, J., Silk, J., Powers, M., & Hyland, P. (2011). Effect of gold content on the reliability of SnAgCu solder joints. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *1*(10), 1662–1669. https://doi.org/10.1109/TCPMT.2011.2160398

Pandian, G. P. (2017). *EFFECT OF LONG-TERM AGING ON LEAD-FREE SOLDER AND SURFACE FINISH*.

Park, S., Chul, J., Park, J., & Kim, Y. (2016). Microelectronics Reliability Drop-shock reliability improvement of embedded chip resistor packages through via structure modi fi cation. *MR*, *63*, 194–200. https://doi.org/10.1016/j.microrel.2016.05.003

Patel, S., Pandey, D. K., Patil, S. A., Patel, H. M., Bindal, A., Sharma, R. S., & Bhattacharya, A. N. (2020). Solder Immersion Process of Ceramic Column Grid Array Package Assembly for Space Applications. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *10*(4), 717–722. https://doi.org/10.1109/TCPMT.2019.2961424

Poole, I. (2016). *Surface Mount Technology & SMT Devices*. Electronics-Notes.

Prabhu, K. N., & Fernandes, P. (2007). Determination of wetting behavior, spread activation energy, and quench severity of bioquenchants. *Metallurgical and Materials Transactions B: Process Metallurgy and Materials Processing Science*, *38*(4), 631–640. https://doi.org/10.1007/s11663-007-9060-3

Qiu, H., Hu, X., Li, S., Wan, Y., & Li, Q. (2020a). Shear strength and fracture surface analysis of lead-free solder joints with high fraction of IMCs. *Vacuum*, *180*(January), 109611. https://doi.org/10.1016/j.vacuum.2020.109611

Qiu, H., Hu, X., Li, S., Wan, Y., & Li, Q. (2020b). Shear strength and fracture surface analysis of lead-free solder joints with high fraction of IMCs. *Vacuum*, *180*(January), 109611. https://doi.org/10.1016/j.vacuum.2020.109611

Ramli, M. I. I., Mohd Salleh, M. A. A., Yasuda, H., Chaiprapa, J., & Nogita, K. (2020). The effect of Bi on the microstructure, electrical, wettability and mechanical properties of Sn-0.7Cu-0.05Ni alloys for high strength soldering. *Materials & Design*, *186*, 108281. https://doi.org/https://doi.org/10.1016/j.matdes.2019.108281

Ramli, M. I., Salleh, M. A., Sandu, A. V, Amli, S. F., Said, R. M., Saud, N., Abdullah, M. M., Vizureanu, P., Rylski, A., Chaiprapa, J., & Nabialek, M. (2021). Influence of 1.5 wt.% Bi on the Microstructure, Hardness, and Shear Strength of Sn-0.7Cu Solder Joints after Isothermal Annealing. In *Materials* (Vol. 14, Issue 18). https://doi.org/10.3390/ma14185134

Razizy, F. M., Zhang, N. Z., Hashim, M. S., Azlina, O. S., & Azmir, O. S. (2022). *The Effect of Isothermal Ageing Treatment on Different PCB Surface Finishes: Simulation and Experimental BT - Recent Progress in Lead-Free Solder Technology: Materials Development, Processing and Performances* (M. A. A. M. Salleh, M. S. Abdul Aziz, A. Jalar, & M. I. Izwan Ramli (eds.); pp. 171–194). Springer International Publishing. https://doi.org/10.1007/978-3-030-93441-5_8

Ryu, B.-H., Choi, Y., Park, H.-S., Byun, J.-H., Kong, K., Lee, J.-O., & Chang, H. (2005). Synthesis of highly concentrated silver nanosol and its application to inkjet printing. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *270–271*, 345–351. https://doi.org/https://doi.org/10.1016/j.colsurfa.2005.09.005

Salleh, M. A. A. M., Al Bakri, A. M. M., Somidin, F., Sandu, A. V., Saud, N., Kamaruddin, H., McDonald, S. D., & Nogita, K. (2013). A comparative study of solder properties of Sn-0.7Cu lead-free solder fabricated via the powder metallurgy and casting methods. *Revista de Chimie*, *64*(7), 725–728.

Sánchez, F., Bolarín, A. M., Tello, A., Hernández, L. E., & Bas, J. A. (2006). Diffusion at Cu/Sn interface during sintering process. *Materials Science and Technology*, *22*(5), 590–596. https://doi.org/10.1179/174328406X83950

Satyanarayan, & Prabhu, K. N. (2011). Reactive wetting, evolution of interfacial and bulk IMCs and their effect on mechanical properties of eutectic Sn–Cu solder alloy. *Advances in Colloid and Interface Science*, *166*(1), 87–118. https://doi.org/https://doi.org/10.1016/j.cis.2011.05.005

Saunders, N., & Miodownik, A. P. (1990). The Cu-Sn (Copper-Tin) system. *Bulletin of Alloy Phase Diagrams*, *11*(3), 278–287. https://doi.org/10.1007/BF03029299

Shangguan, D. (2005). *Lead-Free Solder*.

Sharif, A. (2019). *Harsh environment electronics: interconnect materials and performance assessment*. John Wiley & Sons.

Shen, J., & Chan, Y. C. (2009). Microelectronics Reliability Research advances in nano-composite solders. *Microelectronics Reliability*, *49*(3), 223–234. https://doi.org/10.1016/j.microrel.2008.10.004

Shi, R.-Z., Chen, M.-Q., Huang, H.-J., Zhou, M.-B., & Zhang, X.-P. (2021). Solder Preforms Composed of High Cu-content Sn-xCu Alloys for Power Electronic Packaging and Characterization of the Processing Performance and Joint's Properties. *2021 22nd International Conference on Electronic Packaging Technology (ICEPT)*, 1–5. https://doi.org/10.1109/ICEPT52650.2021.9568097

Shim, J.-H., Oh, C.-S., Lee, B.-J., & Lee, D. N. (1996). Thermodynamic Assessment of the Cu-Sn System. *International Journal of Materials Research*, *87*(3), 205–212. https://doi.org/doi:10.1515/ijmr-1996-870310

Soares, T., Cruz, C., Silva, B., Brito, C., Garcia, A., Spinelli, J. E., & Cheung, N. (2020). Interplay of wettability, interfacial reaction and interfacial thermal conductance in Sn-0.7 Cu solder alloy/substrate couples. *Journal of Electronic Materials*, *49*(1), 173–187.

Song, Q., Li, A., Qi, D., Qin, W., Li, Y., & Zhan, Y. (2022). *Intermetallics Interface reaction and mechanical properties of Sn58Bi-XCr / Cu30Zn (Cu7Sn) solder joints under isothermal aging conditions*. *150*(August).

Su, S, Hamasha, S., & Hamasha, K. (2019). Effect of Surface Finish on the Shear Properties of SnAgCu-Based Solder Alloys. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *9*(8), 1473–1485. https://doi.org/10.1109/TCPMT.2019.2928267

Su, Sinan, Jian, M., & Hamasha, S. (2019). Effects of Surface Finish on the Shear Fatigue of SAC-Based Solder Alloys. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *PP*, 1. https://doi.org/10.1109/TCPMT.2019.2942806

Sun, L., Chen, M., & Zhang, L. (2019). Microstructure evolution and grain orientation of IMC in Cu-Sn TLP bonding solder joints. *Journal of Alloys and Compounds*, *786*, 677–687.

Surfacemountprocess. (2015). *Surface Mount Technology*. GoDaddy.Com, LLC.

Tian, R., Hang, C., Tian, Y., & Zhao, L. (2018). Growth behavior of intermetallic compounds and early formation of cracks in Sn-3Ag-0.5 Cu solder joints under extreme temperature thermal shock. *Materials Science and Engineering: A*, *709*, 125–133.

Vianco, P. T. (1999). An overview of surface finishes and their role in printed circuit board solderability and solder joint performance. *Circuit World*, *25*(1), 6–24. https://doi.org/10.1108/03056129910244518

Vogel, N. (2011). Investigations on Microstructure and Mechanical Properties of the Cu/Pb-free Solder Joint Interfaces. In *Springer Theses* (Vol. 53, Issue 9). http://link.springer.com/10.1007/978-3-642-35133-4

Vuorinen, V., Laurila, T., Mattila, T., Heikinheimo, E., & Kivilahti, J. K. (2007). Solid-State Reactions between Cu(Ni) Alloys and Sn. *Journal of Electronic Materials*, *36*(10), 1355–1362. https://doi.org/10.1007/s11664-007-0251-0

Wang, L., Fu, X., He, J., Shi, X., Chen, T., Chen, P., Wang, B., & Peng, H. (2020). Application challenges in fiber and textile electronics. *Advanced Materials*, *32*(5), 1901971.

Wassink, R. J. K. (1984). *Soldering in Electronics*. Electrochemical Publications. https://books.google.com.my/books?id=P1aaAAAAIAAJ

Wentlent, L. A., & Genanu, M. (2018). Effects of Laser Selective Reflow on Solder Joint Microstructure and Reliability. *2018 IEEE 68th Electronic Components and Technology Conference (ECTC)*, 425–433. https://doi.org/10.1109/ECTC.2018.00070

Wentlent, L. A., Genanu, M., & Alghoul, T. (2018). Effects of laser selective reflow on solder joint microstructure and reliability. *2018 IEEE 68th Electronic Components and Technology Conference (ECTC)*, 425–433.

Wright, A. (2015). Printed Circuit Board Surface Finishes - Advantages and Disadvantages. *Epec Engineered Tecnologies*, 1–15.

Wu, C. M. L., Yu, D. Q., Law, C. M. T., & Wang, L. (2002). Microstructure and mechanical properties of new lead-free Sn-Cu-RE solder alloys. *Journal of Electronic Materials*, *31*(9), 928–932. https://doi.org/10.1007/s11664-002-0185-5

Yang, C., Song, F., & Lee, S. W. R. (2011). Effect of interfacial strength between Cu6Sn5and Cu3Sn intermetallics on the brittle fracture failure of lead-free solder joints with OSP pad finish. *Proceedings - Electronic Components and Technology Conference*, 971–978. https://doi.org/10.1109/ECTC.2011.5898627

Yang, M., Li, M., Wang, L., Fu, Y., Kim, J., & Weng, L. (2011). Cu6Sn5 Morphology Transition and Its Effect on Mechanical Properties of Eutectic Sn-Ag Solder Joints. *Journal of Electronic Materials*, *40*(2), 176–188. https://doi.org/10.1007/s11664-010-1430-y

Yang, W., Lv, Y., Zhang, X., Wei, X., Li, Y., & Zhan, Y. (2020a). Influence of graphene nanosheets addition on the microstructure, wettability, and mechanical properties of Sn-0.7 Cu solder alloy. *Journal of Materials Science: Materials in Electronics*, *31*, 14035–14046.

Yang, W., Lv, Y., Zhang, X., Wei, X., Li, Y., & Zhan, Y. (2020b). Influence of graphene nanosheets addition on the microstructure , wettability , and mechanical properties of Sn - 0 . 7Cu solder alloy. *Journal of Materials Science: Materials in Electronics*, *1*. https://doi.org/10.1007/s10854-020-03920-8

Yoon, J.-W., & Jung, S.-B. (2008). Effect of immersion Ag surface finish on interfacial reaction and mechanical reliability of Sn–3.5Ag–0.7Cu solder joint. *Journal of Alloys and Compounds*, *458*(1), 200–207. https://doi.org/https://doi.org/10.1016/j.jallcom.2007.04.014

Yoon, J. W., Kim, S. W., Koo, J. A. M., Kim, D. G., & Jung, S. B. (2004). Reliability investigation and interfacial reaction of ball-grid-array packages using the lead-free Sn-Cu solder. *Journal of Electronic Materials*, *33*(10), 1190–1199. https://doi.org/10.1007/s11664-004-0122-x

Yu, C., Lu, H., & Li, S. (2008). Effect of Zn addition on the formation and growth of intermetallic compound at Sn-3.5 wt% Ag/Cu interface. *Journal of Alloys and Compounds*, *460*(1–2), 594–598. https://doi.org/10.1016/j.jallcom.2007.06.031

Yu, C., Yang, Y., Li, P., Chen, J., & Lu, H. (2012). Suppression of Cu3Sn and Kirkendall voids at Cu/Sn-3.5Ag solder joints by adding a small amount of Ge. *Journal of Materials Science: Materials in Electronics*, *23*. https://doi.org/10.1007/s10854-011-0412-z

Zaimi, N. S. M., Salleh, M. A. A. M., Sandu, A. V., Abdullah, M. M. A. B., Saud, N., Rahim, S. Z. A., Vizureanu, P., Said, R. M., & Ramli, M. I. I. (2021). Performance of Sn-3.0Ag-0.5Cu composite solder with kaolin geopolymer ceramic reinforcement on microstructure and mechanical properties under isothermal ageing. *Materials*, *14*(4), 1–19. https://doi.org/10.3390/ma14040776

Zeng, K., & Tu, K. N. (2002). Six cases of reliability study of Pb-free solder joints in electronic packaging technology. *Materials Science and Engineering: R: Reports*, *38*(2), 55–105. https://doi.org/https://doi.org/10.1016/S0927-796X(02)00007-4

Zhao, H., Nalagatla, D. R., & Sekulic, D. P. (2009). Wetting Kinetics of Eutectic Lead and Lead-Free Solders: Spreading over the Cu Surface. *Journal of Electronic Materials*, *38*(2), 284–291. https://doi.org/10.1007/s11664-008-0590-5

Zhao, M., Zhang, L., Liu, Z.-Q., Xiong, M.-Y., & Sun, L. (2019). Structure and properties of Sn-Cu lead-free solders in electronics packaging. *Science and Technology of Advanced Materials*, *20*(1), 421–444. https://doi.org/10.1080/14686996.2019.1591168

Zhao, M., Zhang, L., Sun, L., Xiong, M. Y., Jiang, N., & Xu, K. K. (2020). Effects of nanoparticles on properties and interface reaction of Sn solder for microelectronic packaging. *International Journal of Modern Physics B*, *34*(8), 1–3. https://doi.org/10.1142/S0217979220500642

Zhao, N., & Pan, X. (2018). *Effects of copper content in Sn-based solder on the intermetallic phase formation and growth during soldering Effects of copper content in Sn-based solder on the intermetallic phase formation and growth during soldering*. https://doi.org/10.1088/1757-899X/361/1/012008

Zhimin, L., Shen, F., Yang, Z., Xu, D., Wei, S., Peng, Z., Wang, L. wei, & Wang, D. (2021). Effects of Isothermal Aging on Interfacial Microstructure and Shear Properties of Sn-4.5Sb-3.5Bi-0.1Ag Soldering with ENIG and ENEPIG Substrates. *Metals*, *11*, 2027. https://doi.org/10.3390/met11122027