NUMERICAL ANALYSIS OF ULTRA-FINE PACKAGE ASSEMBLY WITH SAC305-TIO_2 NANO-REINFORCED LEAD FREE SOLDER AT DIFFERENT PEAK TEMPERATURE

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledge by giving explicit references. Bibliography/references are appended.

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ABSTRAK

Tesis ini bertujuan untuk menentukan kesan suhu puncak di kawasan pembasahan sendi solder ultra-halus yang bertetulang yang diperkuat dengan nanopartikel TiO2 dalam perhimpunan elektronik dan untuk menyiasat ketegangan terma pada lapisan senyawa intermetallik (IMC). Kajian ini memberi tumpuan kepada pengagihan nanopartikel, ketinggian fillet dan ketegangan haba lapisan IMC. Pelbagai peratusan berat nanopartikel TiO2 dengan solder bertetulang SAC305 percuma dan suhu puncak yang berbeza digunakan. Siasatan untuk mendapatkan semua pengagihan zarah, ketinggian fillet, strain termal adalah dengan menggunakan Ansys Workbench 18.2. Keputusan yang diperolehi disahkan oleh hasil percubaan dengan menggunakan sistem mikroskop elektron transmisi resolusi tinggi dilengkapi dengan spektrometer sinar-X dispersif tenaga (EDS), dan mikroskop elektron pengimbasan emisi bidang ditambah pula dengan mesin difraksi EDS dan sinar-X. Penemuan kajian ini adalah suhu yang lebih tinggi di kawasan pembasahan yang berkisar antara 240 ° C dan 255 ° C memberikan pengagihan zarah yang lebih baik, dan ketinggian fillet dari solder dengan menggunakan suhu dalam julat memenuhi keperluan piawaian IPC. Semakin tinggi suhu puncak memberikan ketegangan terma yang lebih tinggi pada lapisan IMC.

ABSTRACT

This thesis aims to determine the effect of peak temperature on the wetting region of ultra-fine lead-free solder joints reinforced with TiO2 nanoparticles in an electronic assembly and to investigate thermal strain on the intermetallic compound (IMC) layer. This study focuses on the nanoparticles distributions, fillet height and thermal strain of the IMC layer. Various weight percentages of the nanoparticles TiO2 with the SAC305 lead free reinforced solder and different peak temperature will be used. The main aim of this project is to obtain all the particles distributions, fillet height, thermal strain through the use of Ansys Workbench 18.2. The results obtained are validated by the experimental result obtained using high-resolution transmission electron microscope system equipped with an energy dispersive X-ray spectrometer (EDS), and a field emission scanning electron microscope coupled with an EDS and X-ray diffraction machine. The findings on this study shows that for higher temperature of the wetting region that ranges between 240°C and 255°C gives better particles distributions. Additionally, fillet height of the solder within this temperature range meet the requirement of the IPC standards that state that the measurement of the fillet formation for the joining of the device to the PCB pad should adhere to solder thickness of +25% of the termination height which is 0.0889mm. The best fillet height obtained is 0.1408988mm from using 250°C. The maximum thermal strain that exerted on the IMC layer recorded is from the sample of 255°C.

CHAPTER 1 : INTRODUCTION

1.1 Overview

Nowadays, microelectronic assemblies in use today utilize Pb-Sn solders for interconnection. With the advent of chip scale packaging technologies, the usage of solder connections has increased [1]. The electronic components manufacturers have strived to meet the consumer's demand that include highly reliable and low cost components. The use of smaller passive components in products is expected to reduce the size of the devices manufacture though it would test the mettle of the designers maintain of even enhance the reliability of the device. Recently, the addition of new materials into the conventional solder pastes provides a viable solution however thorough study is still required to optimize the material characteristics and properties of the nano-particle filled solder paste [2].

Reliability of the electronic components and soldering process depends on the solder melting temperature. The soldering process temperature is usually higher than the melting temperature depending on the application. For instance, the highest temperature for the reflow oven of SAC305 solder paste could be be 25 °C higher than its melting temperature (217 °C). High processing temperature could damage the electronic components either by damaging the material by exceeding its decomposition temperature or melting the internal solder connections especially to the solder joint.

Mainly, flux chemistry and the reflow profile are two factors causing the voids during the soldering process. Voids are cavities that form in the solder joint. Voids can be seen through the image of X-ray in SAC305 solder used to attached a BGA (Ball Grid Array) to PCB as shown in Figure 1.1. During the soldering process, voids can be generated by the outgassing that gets entrapped in a solder joint. Outgassing produced when the solvent evaporates and rheological additives occur in the solder paste during heating processes. Outgassing may also be generated by metallization of the substrate, component, or solder powder surface during the fluxing reaction in the reflow process[3]. Except for the voids caused by outgassing flux in the reflow process, voids in the solders to connect the Si die to the substrate can also be formed by thermo- or electromigrations [4]. By developing a better lead-free solder, solder voids can be reduce and enhance the reliability of the solder[5].

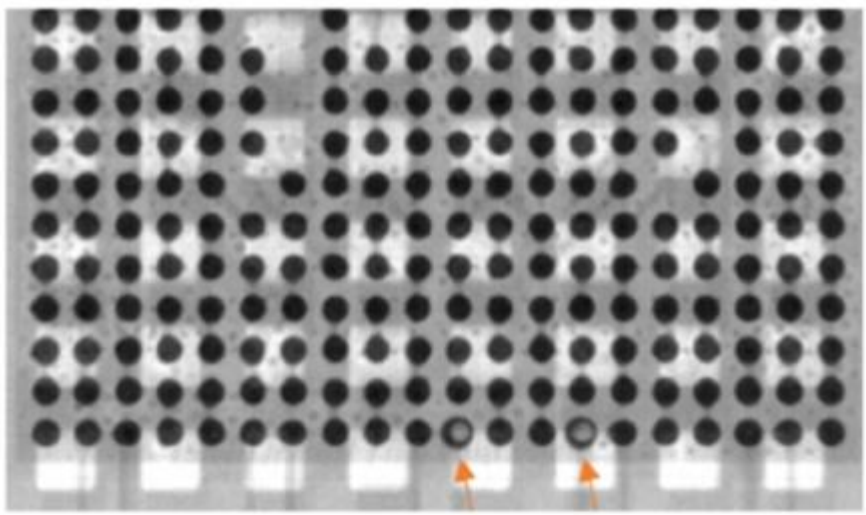


Figure 1.1: SAC305 solder voids

Based on previous researchers, the implementation of the titanium oxide (TiO2) nanoparticles shown that it can enable better performance of the solder [6]. There are a few parameters that affect the solder when the nano particles is added to the solder; ultimate tensile strength, yield strength, micro-hardness test and shear strength [6]–[10].

1.2 Problem Statement

Soldering of micro-electronic passive devices has become an important aspect in the semiconductor field. Detail study typically on the use of nano-reinforced particles into the solder paste as a mean to increase the properties of the solder is required to improve solder reliability. Addition of this nano-particles needs to be thoroughly study in terms of its optimum thermal profile for improved strength through good spread of nano-particles in the solder.

1.3 Objectives

1. To determine the effect of peak temperature in the soaking and wetting regions of the solder thermal profile.
2. To compare the results obtained from the simulation with experimental data.

1.4 Scope of Work

For my project the scope of works include:

1. Study the methods of discrete particle method (DPM) to obtain the distribution of particles.
2. Study the effect of peak temperature for the wetting region on the fillet height and thermal stresses on the IMC layer.

CHAPTER 2 : LITERATURE REVIEW

2.1 Strength of solder

Based on previous researchers, the addition of nano-reinforced particles into the SAC305-TiO2 nano-reinforced lead free has greatly contributed to the strength of the solder, ultimate tensile strength, yield strength, micro-hardness test and shear strength [7]. By adding new materials into the solder, we need to concern about thermo-mechanical stresses (CTE-coefficient of expansion) of solder, substrate and component that affect the quality [2].

On the research of the different weighted percentage of nano-reinforced lead free solder, the ultimate tensile strength, yield stress, micro hardness and shear stress increases with the increment of the weight percentage of the nano particles of TiO. Besides that, the time formation of wetted solder also increases as the weight percentage increases. It was investigate by using the discrete phase method (DPM) to track the movement of particles. The result obtained from the simulation then being compared with the experimental data of HRTEM (High Resolution Transmission Electron Microscope System) [2].

Temperature had a significant influence on failure mode of solder joint. Strength of SAC305 bulk solder is higher than that of hard and brittle IMC at room temperature. Therefore, crack of solder joint readily occurred in IMC. However, crack path transferred from IMC to bulk solder under temperature-vibration loading with increase of temperature. Temperature affected mechanical property of solder joint resulting in a decrease of strength of bulk solder compared to strength of IMC. Consequently, crack gradually shifted from IMC to bulk solder during temperature-vibration test [11] .

2.2 Ramp and Dwell Time

Solder melting temperature affects the soldering process and the performance as well as reliability of the electronic components. Depending on the application, the soldering process temperature is usually higher than the melting temperature. For example, the peak reflow oven temperature of SAC305 solder paste could be 25 °C higher than its melting temperature (217 °C). High processing temperatures can damage the electronic components either by melting the internal solder connections. [12]

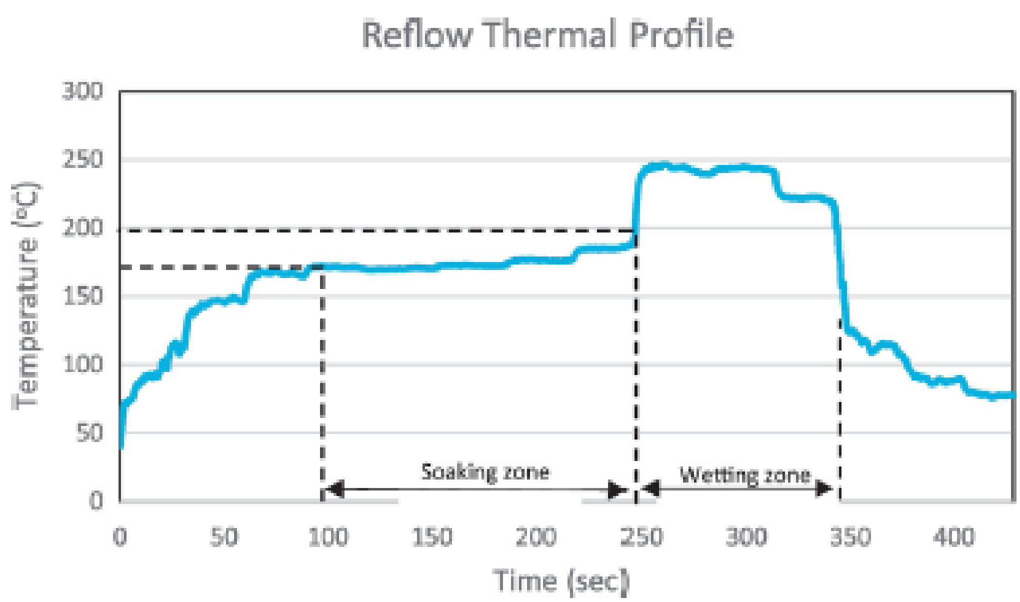


Figure 2.1: Reflow thermal profile of nano-reinforced lead free solder[2]

Solder wettability is the ability of molten solder to cover the metal surfaces in the solder joint. Wettability is determined by the compatibility between the solder, the component finish, and the PCB pad surface finish. The solder must have good wetting behavior on lead free finishes and during reflow and wave soldering. Fluxes contain chemicals designed to improve the wettability of solder paste and wave soldering to the component leads and PCB pads. Proper flux selection and optimization of the reflow profile or of the wave solder machine parameters are necessary to form reliable solder joints to connect components to PCB pads/holes [12].

The structure of the wetting temperature and temperature profile give effect to the structure of the solder. It is obvious that the style of temperature profile has a great effect on the reliability of solder fatigue life. The longer dwell time and the steeper ramp, the shorter the fatigue life of solder joints. Based on the experiment conducted by F. Wang and X. Gao on the effects of different temperature profile on solder joints in PBGA Packages [13], it was shown in Figure 2.2 that as the ramp time decreases while the cycling time is kept constant, the accumulated inelastic energy density increases. This experiment was also proved by [14].

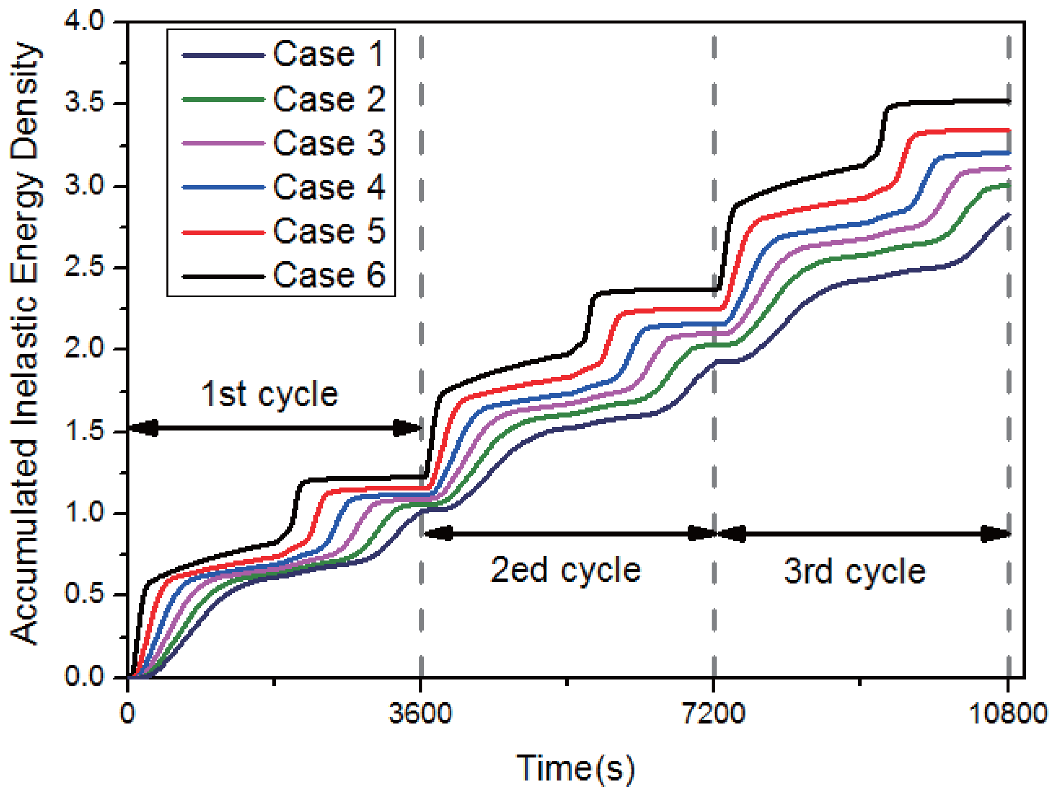


Figure 2.2: Accumulated strain energy density of each case

Table 2.1: Cases of Experiment

Case	Dwell Time (min)	Ramp time (min)	Ratio of Dwell Time/ Ramp Time
1	0	30	0
2	5	25	0.2
3	10	20	0.5
4	15	15	1
5	20	10	2
6	25	5	5

2.3 Formation of Intermetallic Compound (IMC) layer

A process in which two substrates or more joining together into a joint clearance is called soldering. During the process of soldering, there is a reaction between the solder and the substrate (liquid and solid). Because of this, the reaction created intermetallic Compound (IMC) at the joint interface. There are four phases on how the IMC layer starts to form which are preheating, ramping, soaking and cooling.

First is preheating region where during soldering process, when the soldering temperature is slightly above the liquid temperature of the solder in which an interfacial reaction between the substrate and the solder take place[15]. The temperature at that time does incapable to turn the solder into fully liquid state thus, Sn atoms from the solder and Cu substrate at the contact region is lower. Because of that, the concentration of the Cu atoms is higher than Sn atoms which in turn causes a thin layer and fine IMC layer to be formed in the interface [16].

Secondly, it enters ramping process. This is the region that the temperature reaches 250°C and the solder will be fully in molten state and it will spread to the Cu substrate. The liquid–solid state diffusion between the elements of the molten solder and the solid substrate will take place at this time [14]. The concentration of the Sn atoms is higher that it moves to the contact region and formed a coarse η-Cu_6Sn_5 (hexagonal) IMC layer on top of the fine ε-Cu_3Sn IMC layer during the preheating phase. These processes can be summarized in Figure 2.3.

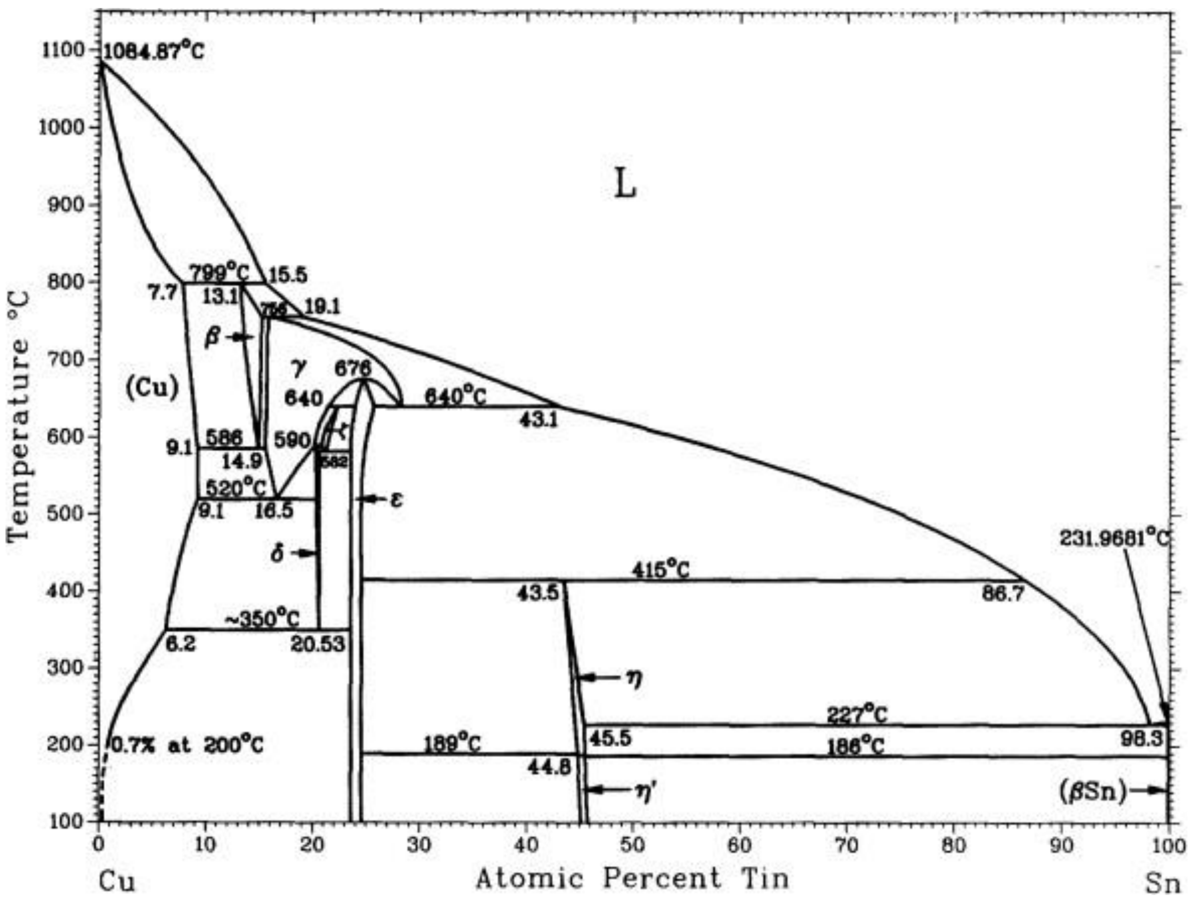


Figure 2.3: Binary Cu-Sn phase diagram

The composition of solder being used affects the morphology of η-Cu_6Sn_5 IMC grains. The shape of the grain can either be hemispherical or scallop when a near-eutectic or eutectic solder is used. For the case of solder composition that is far away from the eutectic region, the grain is faceted. The shape of the IMC layer may not be uniform because there might be uneven distribution of the Cu atoms in the joint [15].

Thirdly, soaking region. It is a region when it reaches the peak temperature, the solder will be held or maintained for a short amount of time to let the substrate to wet and spread thoroughly as shown in Figure 2.4. The temperature that is held for a short amount of time is called dwell time. The IMC layer will continue growing in this phase [16].

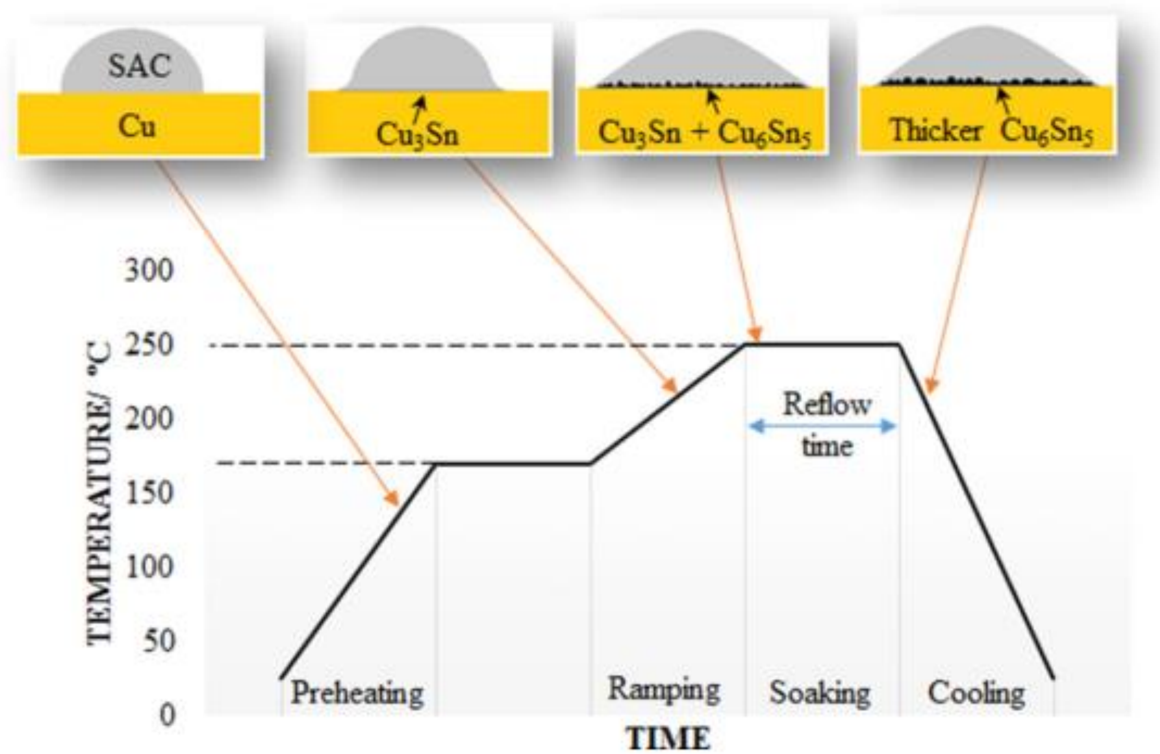


Figure 2.4: General soldering profile

Last phase is cooling phase. When the solder joint is being subjected to subsequent cooling, as the temperature decrease, the solubility of the Cu atoms from the solid substrate also decreases. When the temperature drops below liquidus temperature of the solder, the Cu that is being precipitated will stay on top of the IMC interface due to the low energy state. This will exhibits the IMC layer to be thicker and maintain the scallop shape [16].

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 Numerical Simulation

For the numerical simulation of the 3D model of the capacitor, to mimic the environment of reflow oven, finite volume method (FVM) is being used and solve by using multiphase and two eulerian phases involved. For the wetting process of the nano-reinforced lead free solder, volume of fluid (VOF) is being used while the movement of particles inside the solder is solved by using dispersed phase method (DPM).

The model is developed based on the reflow oven thermal profile of nano-reinforced lead free solder (SAC305) at different temperatures of the wetting zone since this is the most crucial zone for the formation of IMC layer. To compute the solution, Figure 3.1, 3.2, and 3.3 shows the properties of SAC305 lead-free solder paste nano-reinforced, titanium oxide (TiO2) and intermetallic layer (IMC) respectively.

Properties	SAC305
Density, p	7380 kg/m^3
Specific heat capacity, Cp	230 J kg ^{o} K
Thermal Conductivity	58 Wm/K
Viscosity	0.002 kg/ms
Standard state enthalpy	0.04 J/mol

Figure 3.1: Properties of SAC305 lead-free solder paste

Properties	TiO_2
Density, p	4250 kg/m^3
Specific heat capacity, Cp	686 J kg ^{o} K
Thermal Conductivity	8.95 Wm/K
Diameter, d	≈20nm

Figure 3.2: Properties of nano-reinforced (TiO2)

Table 1. Room temperature properties of intermetallics determined in this testing program.

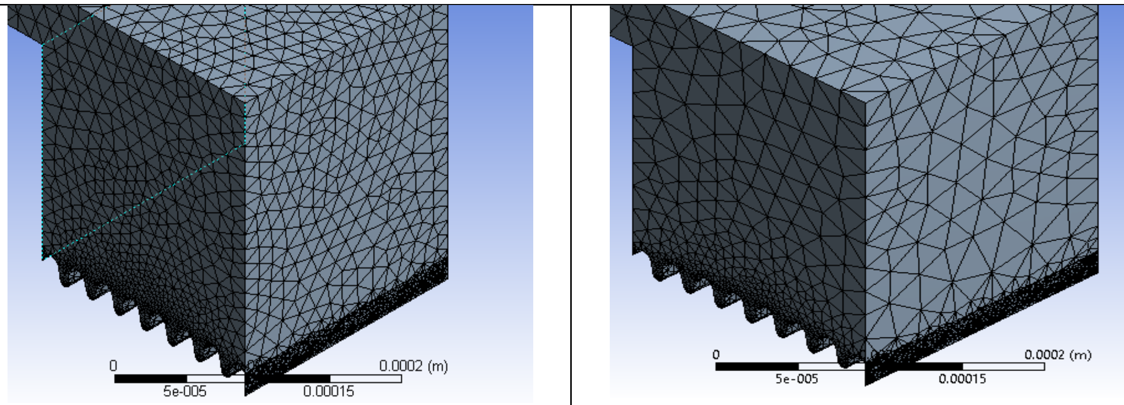
	Cu_6Sn_5	Cu_3Sn	Ni_3Sn_4
Vickers Hardness Kg/mm^2	378 +/- 55	343 +/- 47	365 +/- 7
Toughness MPa$\sqrt{m}$	1.4 +/- 0.3	1.7 +/- 0.3	1.2 +/- 0.1
Youngs Modulus GPa	85.56 +/- 1.65	108.3 +/- 4.4	133.3 +/- 5.6
Poisson's Ratio	0.309 +/- 0.012	0.299 +/- 0.018	0.330 +/- 0.015
Thermal Expansion PPM/C	16.3 +/- 0.3	19.0 +/- 0.3	13.7 +/- 0.3
Thermal Diffusivity cm^2/sec	0.145 +/- 0.015	0.240 +/- 0.024	0.083 +/- 0.008
Heat Capacity J/gram/deg	0.286 +/- 0.012	0.326 +/- 0.012	0.272 +/- 0.012
Resistivity micro ohm-cm	17.5 +/- 0.1	8.93 +/- 0.10	28.5 +/- 0.1
Density gm/cc	8.28 +/- 0.02	8.90 +/- 0.02	8.65 +/- 0.02
Thermal Conductivity $\frac{watt}{cm\text{-}deg}$	0.341 +/- 0.051	0.704 +/- 0.098	0.196 +/- 0.019

Figure 3.3: Cu_6Sn_5 material properties

These nano particles are patched inside the molten solder during two-ways interaction of simulation between continuous phase (molten solder) and discrete phase (nano-particles).

3.1.1 Grid Independent Test

Mesh independent analysis is conducted on the 3D model developed using FVM Ansys Workbench in order to identify the most optimum mesh grid resolution for an accurate computational simulation result. The meshed grid at different resolutions of medium and fine were used in the independent grid analysis as shown in Figure 3.4.



Fine mesh | Medium mesh

Figure 3.4: Mesh model of fine and medium mesh

According to the data obtained in the mesh analysis, the optimum mesh that is compatible with the simulation model is fine resolution with the discretization error within 5% standard limits. As seen from Table 3.1, the suitable mesh grid used in this simulation study is fine mesh model with 15281 number of nodes and 69129 number of elements since it optimizes both computation time and accuracy of the obtained solution.

Table 3.1: Grid Independent

Mesh model	Grid Resolution	Number of nodes	Number of elements	Max thermal strain (Pa)
1	Coarse	5671	22868	0.0031687
2	Medium	8642	36934	0.0035214
3	Fine	15281	69129	0.0045999
4	Fine	16025	69856	0.0046154
5	Fine	16142	70761	0.0046111

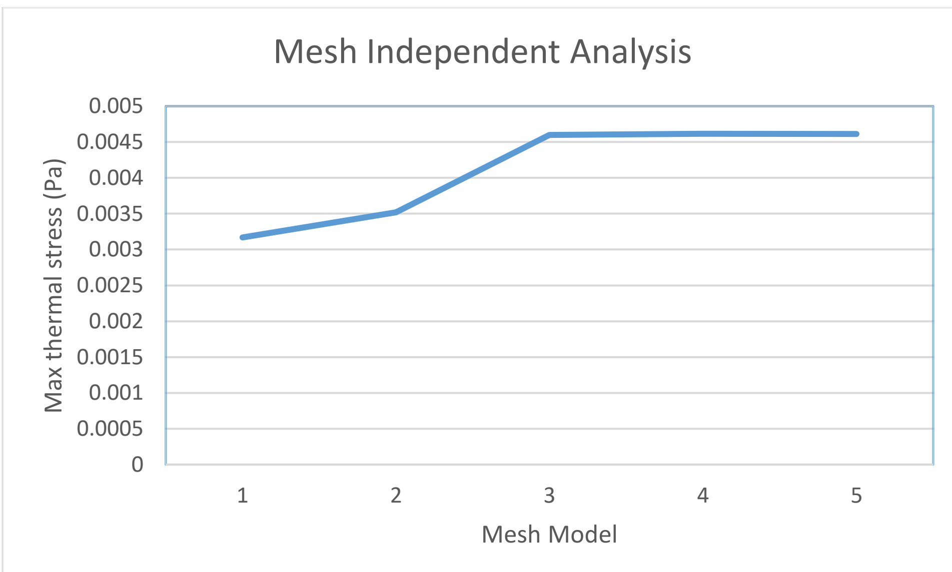


Figure 3.5 : Mesh Independent Analysis

3.1.2 Mesh Generation

Mesh model generated for the simulated soldering process of 01005 capacitor is based on the real size environment of the reflow oven. The environment size is based on the heater area at the wetting zone as can be found in the reflow thermal profile of nano-reinforced lead free solder. Figure 3.6 shows a real size FR4-printed circuit board (PCB) with a thickness of 2.0 mm manufacture using Organic solder able preservative surface finish and an ultra-fine 01005 capacitors that are mounted on the PCB.

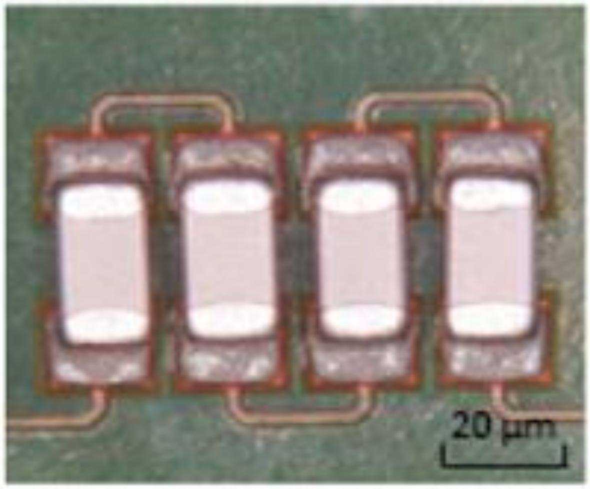


Figure 3.6: 01005 capacitor

The complexity of the study is mainly on the ultra-fine package analysis typically at the wetting area of the ultra-joint sized. The density of the mesh cells of 01005 capacitor used are also fine tune based on the size of the ultra-fine joint. As the ultra-fine package and ultra-fine joint of the solder occurs at nano-scale level, the formation of the wetted solder is important in order to optimize the reliability of the device and in line with IPC-A-610 that governs the acceptability of electronic assembly requirements. The nanoparticles distribution that will contribute to this occurrence needs to be analyzed in detail for optimization purpose.

3.2 Mathematical Model and Governing Equations

For continuous phase.

For a 3D-simulation of 01005 capacitor with nano-reinforced solder, a two-way interactions between Eulerian continuous phase flow and the discrete particle phase flow will be utilized. For the continuous flow of the molten wetting solder, Navier Stokes equations that consist of continuity, momentum and energy will be used as follow:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$$

Equation 1: Continuity equation

$$\rho C_p \left(\frac{\partial T}{\partial t} + \vec{u} \nabla \mathrm{T} \right) = \nabla (\mathrm{k} \nabla \mathrm{T}) + \Phi$$

Equation 2: Energy equation

$$\frac{\partial}{\partial t} (\rho \vec{u}) + \nabla \cdot (\rho \vec{u} \vec{u}) = -\nabla P + \nabla \cdot \tau + \rho \vec{g}$$

Equation 3: Momentum equation

in which, ρ is the density of the fluid, u is the velocity of the velocity, τ is the shear stress and g = −9.81 m/s is the gravity. For the multiphase model of the continuous phase, two Eulerian phases will be solved involving air as the primary and SAC305 as the secondary phase. The interaction between these two phases are associated with the surface tension coefficient. The molten solder have an interfacial tension with the base metal and the fluid domain. In this study, the SAC lead-free solder, Sn-3.0Ag-0.5Cu (SAC305) with surface tension coefficients, σ value of 0.54 n/m.

Where, Young's equation: $\gamma_{SG} = \gamma_{LS} + \gamma_{LG} \cos \theta$

γLG – surface tension of the liquid−gas boundary

γSG – surface tension of the solid−gas boundary

γLS– surface tension of the liquid−solid boundary

θ – contact angle

For the simulation, the volume of fluid (VOF) method was adopted to track the free surface flow of both molten solder and air interaction. The range of volume fraction used to distinguish the different phases range from 0 to 1. The VOF equation is defined as:

$$\frac{\partial \rho}{\partial t} f + \vec{u} \cdot \nabla f = 0$$

Equation 4: VOF Equation

in which f is the fluid volume fraction. The molten solder region is denoted as 1 when it is initially patch in the simulation.

<u>For discrete particle phase</u>

To track the movement of the nano-reinforced TiO_2 particles injected into the molten solder, discrete phase method (DPM) is being used. Since the particles is being distributed throughout the molten solder, the two ways interaction between the continuous and discrete phase need to be simulated. In the continuous phase Eulerian model is being solved while for the discrete phase, the equation denoted are solver on a Langrangian frame. The discrete phase particle, the particle force balance is associated with the particle inertia and other forces is given by:

$$\frac{\partial u_p}{\partial t} = F_D(u - u_p) + g_x \frac{(\rho_p - \rho)}{\rho_p} + F_x$$

Equation 5: Particle force balance equation

where $F_D(u-u_p)$ is the drag force that equates to each of the particle,

$$F_D = \frac{18\mu}{\rho_p d_p^2}\left(\frac{C_D Re}{24}\right)$$

Equation 6: Drag force

with:

u=fluid phase velocity, u_p=particle velocity, μ=molecular viscosity of the fluid, ρ=fluid density and ρ_p=particle density, d_p=particle diameter and F_x is the additional forces that interact with the particles due to mass, acceleration and pressure gradient in the fluid based on the consideration that $\rho > \rho_p$.

$$F_x = \frac{\rho}{\rho_p} u_p \left(\frac{\partial u}{\partial x}\right)$$

Equation 7: Thermopheric force

The nano-size particle will be suspended at certain temperature gradient and is expected to experience thermophoresis force that is associated with the particle given as:

$$F_x = -D_T \frac{1}{m_p T}\left(\frac{\partial T}{\partial x}\right)$$

Equation 8: Thermophoresis force

in which D_T is the thermophoric coefficient.

The particles that are suspended in the fluid (molten solder) is subjected to an additional force, called Brownian force. To calculate the Brownian force, the Brownian equation is being used.

$$F_B = \xi \sqrt{\frac{\pi S_o}{\Delta t}}$$

Equation 9: Brownian Equation

Here, ξ is the zero-mean, unit-variance-independent Gaussian random numbers and S_o is modelled as:

$$S_o = \frac{216\ v\ k_B\ T}{\pi^2 d_p^5 \left(\frac{\rho_p}{\rho}\right)^2 C_c}$$

Equation 10: Gaussian random number

where v is kinematic viscosity, k_B =1.38e−16 erg/K is the Boltzmann constant, T is the temperature and C_c is the Cunningham factor. As the Cunningham factor takes into consideration the drag law that is associated with particle, this can be computed as:

$$C_c = 1 + \frac{2\lambda}{d_p}\left(1.257 + 0.4e^{-\left(\frac{1.1 d_p}{2\lambda}\right)}\right)$$

$$F_D = \frac{18\mu}{\rho_p d_p^2 C_c}$$

Equation 11 and 12

where λ is the particle's mean free path,

$$\lambda = \frac{1}{\sqrt{2}\pi n d^2 \rho}$$

Equation 13

with n denoting the particle number density.

Because of low particles Reynolds number, force that commonly being used for the nano-sized particles is Saffman's lift force. This force is acting in the upward direction.

$$F_L = \frac{2K\ v^{\frac{1}{2}} \rho d_{ij}}{\rho_p d_p (d_{ik} d_{ki})^{\frac{1}{4}}} (u - u_p)$$

Equation 14: Saffman's Lift Force

v = kinematic viscosity

K = 2:594; constant

d_{ij} ; d_{ik}, d_{ki} =deformation tensor

In this study, the Reynold number is considered to be very small given as ≈10e−11, and the velocity magnitude of the fluid and particles, $u \approx u_p$. This can be expressed as the particles Stoke's number given as:

$$Stoke's\ Number = \frac{\rho_p d_p u}{18\mu}$$

Equation 15: Stoke's number equation

with value of ≈10e−9. As this value is very small frequently less than 1, the particle movement and distribution can be associated with the continuous phase of the fluid. The particle movement will then be used to follow the formation of the molten solder in the continuous phase due to the fluid domain having high viscosity and very low velocity.

3.3 Boundary Condition

For different peak temperature of wetting and soaking region of the nano-reinforced lead free solder being injected, a study will be conducted to analyse the particle distribution inside the molten solder after the reflow process is completed. Initially, 5 mil of molten solder is being patched into the mesh grid of the model. The boundary condition for both capacitor and PCB is assigned as no slip boundary and reflect [20]. Because of the motion of the molten solder (continuous phase), constant change in the momentum of the nano-particles will be reflected at the boundary. For the upper part of the reflow oven, it is where the heat is generated with the temperature boundary condition being set up there.

The boundary condition for both walls of the component and PCB are assigned as reflect and no-slip boundary conditions. Due to the continuous motion of the nanoparticles, constant change in the momentum of the nanoparticles will occur causing some nanoparticles to be reflected at the boundary while some nanoparticles will be retained at the vicinity of the wall [21]. In this study, due to the nano-scale size of the nanoparticles and the velocity exerted by the nanoparticles are much smaller in magnitude, the nanoparticles motion are mostly influenced by the motion of the molten solder. The retained momentum of the nanoparticles can be neglected as we do not assume all particles will be reflected on the walls and only nanoparticles at the vicinity of the walls will be reflected. In a study conducted by F.C. Ng et al., it was shown that accretion of the particles occur at the solder ball as a results of continuous collision between the particles and solder balls [15] . The study has found that there will be collision of the particles with the boundary within a narrow range thereby requiring the use of the reflect boundary condition. The nanoparticles are subsequently dispersed randomly and left suspended in the molten fluid. The nanoparticles as being dispersed in molten fluid will be tracked more accurately without under simplifying the collision with the boundary.

For the boundary conditions, the wall will be set to no-slip boundary condition. For the wetting stage, the contact angle and wall adhesion will be set as required in the surface tension value of 0.54 n/m [22]. The reflect boundary is used for both walls that have contact with the molten solder. For the nano-reinforced lead free solder that is small in size and the volume of the particles injected that is less than 1%, the interaction between the particles can be neglected. The overall boundary conditions can be summarized as:

$$Molten\ solder, fluid\ VOF = 1, On\ wall, u = v = w = 0; T = T_{wall}; \frac{\partial p}{\partial n} = 0 \frac{\partial p}{\partial n} = 0$$

$$On\ flow\ front: P = P_{atn} - \frac{\sigma}{R} = P_{atn} - \frac{2\sigma cos\theta}{h}$$

$$DPM\ velocity, u_p = 0$$

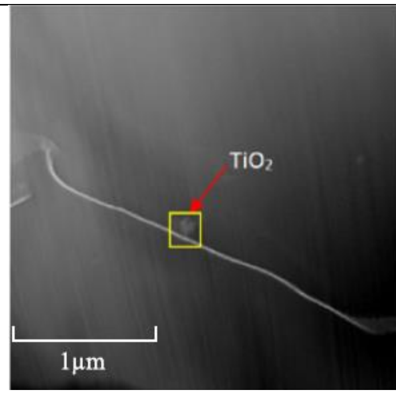
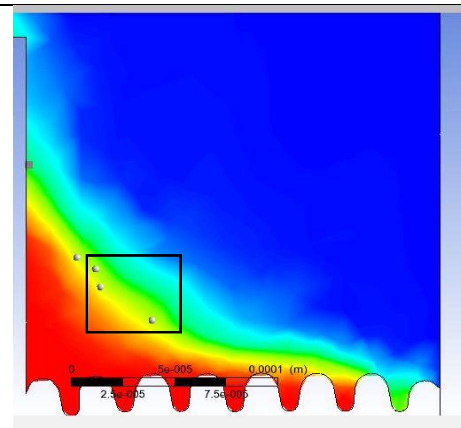
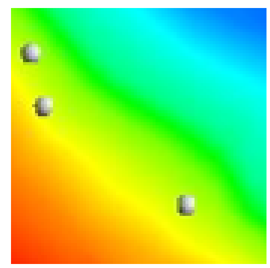
CHAPTER 4 : RESULTS AND DISCUSSIONS

4.1 Validation of Results

The results of the simulation were compared with the experimental results. The experiment has been conducted on the ultrafine package assembly 01005 capacitor with SAC305+0.15% addition of TiO_2 reinforced lead free solder at different weight percentages of 0.01%, 0.05% and 0.15%. The soldering process was performed by using a standard thermal reflow profile in the reflow oven of (Vitronics Soltec XPM2). The solder paste has been pasted on the PCB board and ultrafine package 01005 capacitor mounted to the solder paste.

Using Finely Focused Ion Beam, a cross-sectioned cut of the solder joint was inspected by using High Resolution Transmission Electron Microscope (HRTEM) equipped system with Energy Dispersive X-ray Spectroscopy (EDS). Nanoparticles distributions of the obtained experimental results were compared with simulation results.

Figure 4.1 shows that both results has mutual agreement on the nanoparticles distributions. It was shown that, the nanoparticles were evenly distributed throughout the solder joint for both experimental and simulations. As the weight percentage of the nanoparticles TiO_2 increases, the particles tend to move to higher region due to the buoyancy effect. This because the density of the solder are denser than TiO_2 nanoparticles. It means that to prevent accumulation of the nanoparticles in the wetted solder, the increase in the weight percentage of the nanoparticles should be taken into considerations.

	Experimental Result (HRTEM micrograph/EDS pattern)	Simulation
SAC-305+0.01% TiO_2		 
SAC-305+0.05% TiO_2