OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

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UNIVERSITI SAINS MALAYSIA

2021

OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

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August 2021

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honours degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

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

Signed…… zaimhanif …… (Muhammad Zaim Hanif Bin Nazarudin)

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This thesis results from my own investigations, except where otherwise stated.

Other sources are acknowledged by giving explicit references.

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ACKNOWLEDGEMENT

Alhamdulillah, all praises be to Allah, the Most Beneficent and the Most Merciful. He granted me strength, patience, and wisdom to carry out this final year project in challenging situation of COVID-19 pandemic that became public health emergency crisis in worldwide. Foremost, I would like to express my sincerest gratitude to my supervisor Associate Professor Dr. Mohamad Aizat Bin Abas for constant encouragement, valuable suggestion, and guidance during my completion of final year project. Due to pandemic, we have never meet in direct, but he patiently provides me continuous support and encouragement with his knowledge and experience throughout online meeting. He also allowed me to contact him through WhatsApp for asking question about the project. I really appreciated the effort shown by my supervisor that has given me a clear vision and solution to handle this project with care. Thus, it is possible for me to achieve the target as best as I could do in this project. In addition, I would like to express my appreciation to Mr. Saiful Majdy as USM postgraduate student for assisting me through the completion of this project. There is a lot of knowledge and information gained by sharing of his expertise in modelling the simulation in ANSYS Fluent. With the help from Mr. Saiful, I have saved my time to learn and solve the problem occurs during running the simulation. Moreover, I would like to express my utmost gratitude to the School of Mechanical Engineering and course coordinator Dr. Muhammad Fauzinizam Bin Razali, for planning and making a good guideline to final year student that has to consider the situation of COVID-19 pandemic. Finally, I would like to express my deepest appreciation to my beloved family and friends as supportive and encouragement towards me to complete this research study.

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LIST OF SYMBOLS

D_{hole}	Diameter of the hole
D_{lead}	Diameter of the lead
a	Lead radius
h	Height of PCB
r	Circular pad radius–Lead radius
V_{hole}	Volume of the hole
V_{lead}	Volume of the lead
$V_{total\ solder}$	Total volume of solder
V_{fillet}	Volume of fillet
$V_{hole\ rest}$	$V_{hole} - V_{lead}$
t	Time
∅	The contact angle
σ_{sg}	Surface free energy of a solid body
σ_{lg}	Surface tension of the liquid
σ_{sl}	Solid and liquid interfacial tension

LIST OF ABBREVIATIONS

3D	Three Dimensional
PTH	Pin-Through-Hole
PCB	Printed Circuit Board
FEM	Finite Element Method
FSI	Fluid-Structure Interaction
FVM	Finite Volume Method
VOF	Volume of Fluid
CFD	Computational Fluid Dynamic
CAD	Computer-Aid Design
IPC-A-610	Acceptability of Electronic Assemblies
SAC305	95.5Sn-4.0Ag-0.5Cu
SIMPLE	Semi-Implicit Method

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MENGOPTIMUMKAN PARAMETER PEMATERIAN LASER PADA PERANTI PASIF

ABSTRAK

Pematerian laser adalah proses tanpa sentuhan yang penting dalam teknologi pematerian untuk komponen mini kerana ia dapat memancarkan pemanasan terkawal dari sinar laser ke lokasi tertentu sendi pateri dan proses ini juga dapat mencegah kerosakan komponen lain pada alat elektronik. Parameter proses pematerian laser juga penting untuk diketahui iaitu kekuatan laser, masa proses dan bentuk pancaran laser untuk menghasilkan hasil pematerian yang konsisten. Walaubagaimanapun, dalam kajian penyelidikan ini akan menumpukan pada model VOF dalam perisian ANSYS Fluent kerana parameter proses pematerian laser telah diberikan oleh Western Digital. Matlamat utama kajian ini adalah untuk mengoptimumkan parameter yang mempengaruhi keberkesanan dalam proses pematerian laser pada peranti pasif. Parameter yang isipadu solder dan suhu dapat mempengaruhi pembentukan bentuk fillet, halaju, dan tekanan solder. Simulasi berangka telah dilakukan untuk mengenal pasti isi pateri SAC305 yang sesuai dan suhu proses yang boleh mempengaruhi kebolehpercayaan sendi pateri seperti kekosongan. Oleh itu, parameter dalam proses pematerian perlu dikendalikan untuk menghasilkan kualiti pateri yang baik, jangka hayat yang panjang, dan lebih dipercayai. Hasil yang diperoleh dari simulasi dapat mevisualisasikan aliran solder SAC305 pada akhir proses reflow dalam kontur pecahan isipadu dan suhu. Hasil visualisasi dapat menunjukkan lintasan terperinci dari solder ketika menjalani reflow termal. Selain itu, hubungan baik dapat dilihat antara hasil simulasi yang diperoleh dan pengesahan dari standard IPC. Kajian model VOF menunjukkan pendekatan simulasi yang dapat digunakan untuk mensimulasikan proses pematerian laser yang dapat menghasilkan hasil yang baik dari sambungan solder.

OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

ABSTRACT

Laser soldering is a non-contact process that important in soldering technology for miniature components because it can emit a controlled heating from laser beam to a specific location of solder joint and this process also can prevent damaging other components on electronic devices. The process parameter of laser soldering also important to be known which is laser power, process time and shape of laser beam to produce a consistent soldering result. However, in this research study will focus on VOF model in ANSYS Fluent software because the process parameter of laser soldering has been given by Western Digital. The main goal of this study is to optimise the parameters that affect the effectiveness in laser soldering process on passive devices. The parameter which is solder volume and temperature can affect the formation of fillet shape, velocity, and pressure of solder. Numerical simulation has been conducted to identify the suitable solder volume of SAC305 and the process temperature that can affect in solder joint reliability such as void. Thus, the parameters in the soldering process needed to be controlled to produce a good quality, long lifespan, and more reliable solder joint. The results obtained from the simulation can be visualise the flow of SAC305 solder at the end of reflow process in contour of volume fraction and temperature. The visualisation results can show the details trajectory of solder as it undergoes the thermal reflow. Besides, good relation can be seen between the simulation results obtain and validation from IPC standard. The study of VOF model showed the usable of simulation approach to simulate the process of laser soldering that can produce a good results of solder joint.

CHAPTER 1

INTRODUCTION

1.1 Overview of the overall structure of the project

In a recent year, electronic devices have become smaller in advanced technology transformation. This is because the competition between industry to produce high reliability electronic devices in small size. The demands from electronic market consumer become the faster growing markets around the world. According to Alam [1], the consumer demands highly reliable and low-cost components. Thus, it has pushed every engineer capability in these modern days. The electronic industry will focus more on the miniaturisation devices. For instances, the miniaturisation components of smart phones, computer, laptop, and others electronic devices. The need of miniaturisation is to make the devices smaller, low weight and powerful to be used in all around aspect of electronic devices. In addition, the smaller the components of devices, the more difficult on producing the devices. The production process such as to assemble the components of devices will be the challenge for industry. Thus, the collaboration between industry and researching institution is important to solve the challenging issue.

The industry that has been collaborate in this project was Western Digital Sdn. Bhd. The company has provided the sample that will be studied in this project. In the world of data storage and analysis, the technology is growing at a fast rate and providing a challenge for Western Digital to contribute to the transformation of industry and provide value to their customers. Western Digital also needs access to the resources and information that may improve existing product and develop new technologies. In this project, the electronic devices connector process and assembly using laser soldering technology are being studied. In the past, most studies focused on mechanical contact of soldering.

Nowadays, electronic devices have become much smaller in the industry because of the process of miniaturisation of electronic devices, as mentioned above. This technology is a non-contact process that uses a precisely focused laser beam to control the heating of the solder as shown in Figure 1.1. The process is to transfer the energy to a location of soldering where the absorbed energy will heat the solder until it reaches the melting temperature.

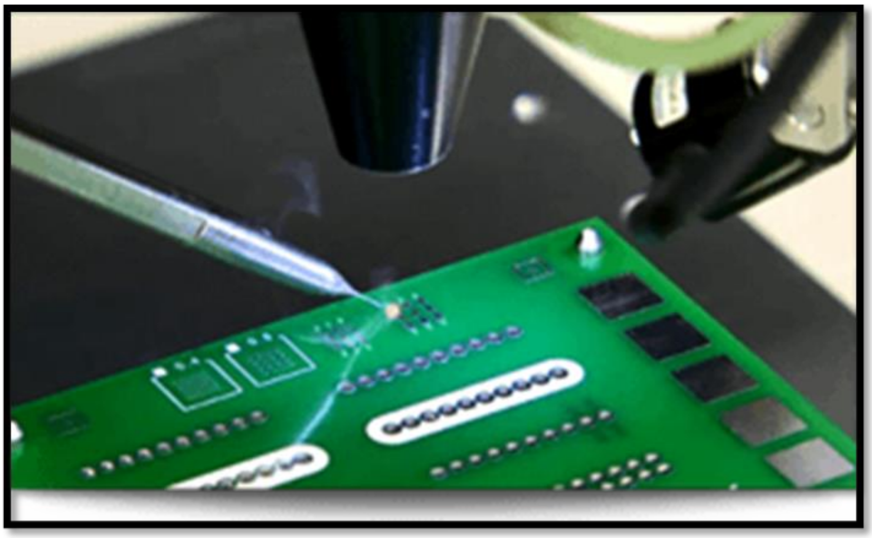

Figure 1.1 Laser soldering technique

The advantages of laser soldering are fast and non-destructive to an electrical joint. This will cause the creation of a reflow process that the molten solder reflows in a molten state and creating a permanent solder joint. The conventional method of soldering that used hot iron soldering as shown in Figure 1.2 is not reliable and time-consuming in production.

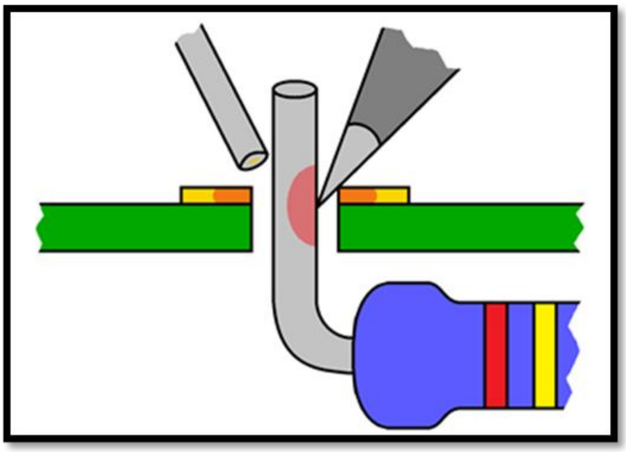

Figure 1.2 Hot Iron soldering Technique

During laser soldering processes, it could affect the effectiveness of electronic devices. To ensure the quality of the solder based on the IPC standard for soldered electrical and electronic assembly, there are many process parameters, physical design and assembly conditions needed to be considered [2]. The first parameter is filling height that will affect the strength of the solder joint. This will cause quality issues and product void because of incomplete filling of solder in pin-through holes (PTH). Next, is the volume of solder that will cause the bridging issue because of the excess solder. This will affect the malfunction of the circuit. Moreover, reliability issues due to volume and temperature of solder in pin-through holes (PTH) are one of the challenging issues needed to be considered in this research. The reliability issue of electronic devices can be determined by many methods. The most common suitable method is using prediction by simulations methods.

There are many methods to solve any engineering problem such as Analytical method, Numerical method, and Experimental method. For this study, a numerical method is suitable to predict the reliability of solder joints through Ansys Fluent software. This software has the capabilities to model the flow of solder with different volume and temperature. The need of this software is to predict the solder joint defects, including cracks, void formation, and unfilled PCB holes that is less than 50% volume of solder is the challenging issue due to the small size of PTH [2]. Using simulation methods, we can predict the shape of solder with different volume of solder. Thus, we can select the suitable volume for soldering. Moreover, the effect of volume and temperature of solder can be observed in the results.

The study involves numerical simulation on Ansys Software. Numerical simulation is one of the 3 methods to solve engineering problems. This method can solve real life complicated problems such as in electronic devices. This is because the electronic devices have an issue that is difficult to detect failure such as in PCB because of microscopic size components. This will cause short circuit or components burning up that occur because of undetected problems such as bridging issues. This issue is a microscopic phenomenon that is difficult to detect during inspection. Thus, this study will explain the use of numerical simulation based on the parameters that could affect the effectiveness of laser soldering process.

There are many parameters that could affect the effectiveness of laser soldering process such as inconsistency of filling height, volume of solder, reliability issue, type of solder, orientation of solder joint in pin-through holes (PTH) and thermal expansion coefficient. Using Ansys Software, this research will create a model for laser soldering process and be able to run the simulation for real case problems based on the process parameter, physical design, and assembly conditions of the solder joint [2].

These parameters must be investigated, which can be done by numerical simulation. Numerical methods such as FEM are used to discretize integral versions of equations. All numerical approaches have the same basic idea which is to measure the entire domain surface or volume at a few locations and then interpolate the findings. Before getting the solution, the unknown will be expected to vary over a domain. For example, when a machine is built with linear quadrilateral elements, the assumption is that displacement would vary linearly over the domain, whereas for 8 nodded quadrilateral elements, the hypothesis is that displacement will vary parabolically. This could or could not be the case. This may or may not be the case in real life, and hence all numerical procedures are predicated on a hypothesis. There are many methods for verifying numerical as well as practical or field result correlation correctness and error minimisation.

In previous research, finite element analysis (FEA) that are involved in prediction the failure of solder joints by simulation methods [3]–[5]. However, this research mainly focuses on reliability of solder joints in other soldering processes. In addition, there is no research being done on the optimisation of laser soldering parameters on passive devices. This could be ideally considered to increase the quality of solder joints in the laser soldering process. Furthermore, numerical simulation results cannot be taken as a result because it must be verified by experimental or calculation method. This is because we need to compare for verify the validity of this study to know the range of the results. The numerical analysis results are important for greater understanding of researchers in the electronic industry.

The aim of this project is to study laser soldering parameters on passive devices that need to be optimised. In this study, we will look on the numerical analysis of different volume and temperature of solder during laser soldering to validate numerical findings with the experiment sample from Western Digital. This research will focus on the volume and temperature of solder on PTH. Last, numerical simulation from the information provided by Western Digital is used for validation of simulated result. This research should increase the understanding of process parameter and geometry of solder during laser soldering.

1.2 Problem Statement

Laser soldering is important technology in electronic industry. Even this technology has been used in the industry for quite some time to replace conventional soldering technique that uses hot iron soldering. This process is a non-contact process that uses a technique of focusing laser beams to control the heating of the solder. Laser soldering technique parameter must be considered controlling the issue happened such as defect to the components of the devices. The challenging issue is to find the suitable volume of solder needed to fill up the pin-through-hole (PTH) and the effect of temperature for this research. The solder volume distribute must be controlled exactly to prevent insufficient or too much volume that can lead to void of the components such as interconnection failure or bridging issue that can cause short circuit on the devices.

Figure 1.3 shows the sample of final electronic assembly component images from Western Digital. This is an important type of components for chip manufacturing. The standard related to technical mounting procedure for capacitor leg contact with PCB board are given in this section to determine the void in the component after soldering process. This will be the main defects to the components when mounting the capacitor leg contact with PCB. The consideration of solder volume is the most important in reliability issue and quality of the product.

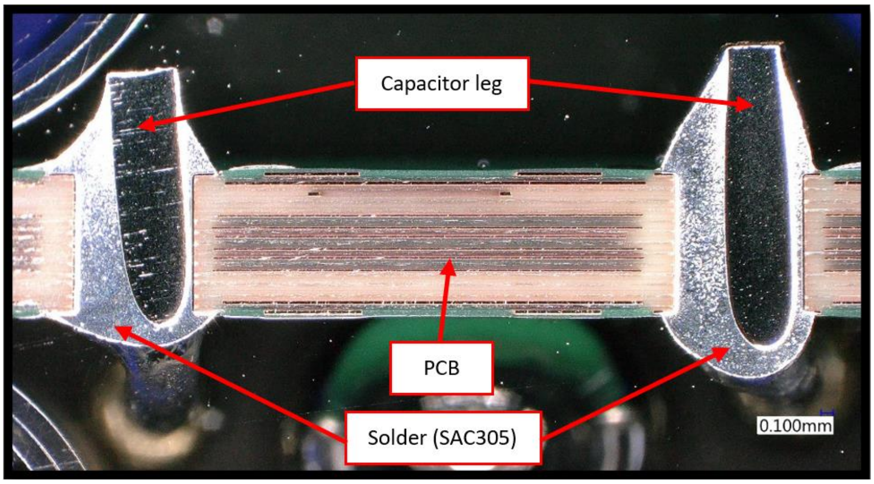

Figure 1.3 Final assembly of electronic joint

Figure 1.4 shows the sample of images of components joint using laser soldering without void. The components joint shows a good concave fillet shape appeared in solder.

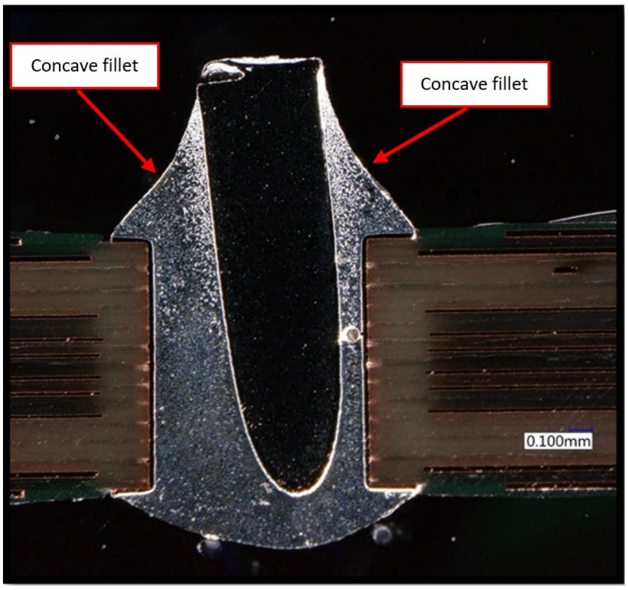

Figure 1.4 Sample of component joint without void with desirable fillet shape

From the sample, some of the solder joint has the chance of failure. Figure 1.5 (a) – (d) shows the sample of images of components joint with micro-void and undesirable fillet shape. The micro-voids are produced by the small hole that is in solder.

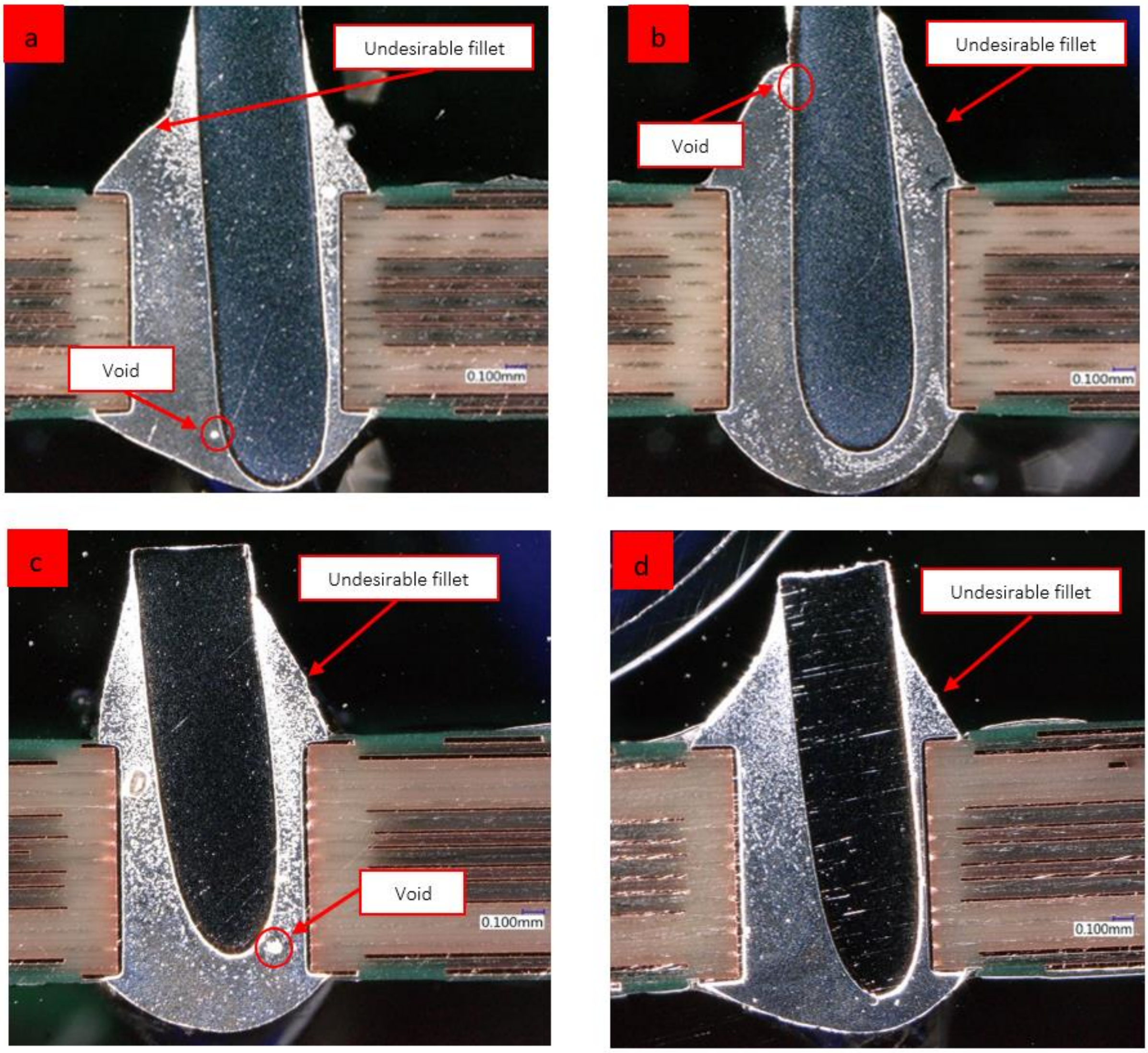

Figure 1.5 Sample component joint with micro-void and undesirable fillet

Furthermore, the change in temperature will produce the change in stress and strain in solder joints. Thus, it may lead to micro-void that can cause crack on the solder joints. This also will cause the lifetime and reliability of devices to become shorter.

To ensure the quality of the solder based on the IPC standard for soldered electrical and electronic assembly, there are many process parameters, physical design and assembly conditions needed to be considered [2]. Important parameters that will influence this failure are volume of solder and temperature. For example, the effect of fillet shape and stand-off height depends on the volume of solder. Moreover, thermal expansion of the SAC305 solder will be affected to the change in temperature. Besides, the capacitor and PCB are made of materials with various coefficients of thermal expansion. Thus, the laser soldering will be the suitable for this case because the laser will be more precise to solder the contact area that needed to be solder without damaging other components.

The main factor that will become failure of the solder joint is the process parameter such as volume and temperature of solder. The factor that leads to the failure of solder joint are micro-void, undesirable fillet, incomplete filling, bridging and reflow process needs to be studied. This factor will affect the reliability and lifetime of solder joint on through-hole components, that may be completely examined using simulation approaches.

1.3 Project Objectives

This research

1. To investigate and optimise laser soldering parameter which is volume and temperature of solder that affect the effectiveness laser soldering process on passive devices with the aid of the contour of volume fraction SAC305, temperature profile, velocity, and pressure of SAC305.
2. To visualise and identify the shape of fillet, volume fraction of SAC305 and reflow process of solder on pin-through-hole (PTH).
3. To analyse the quality, lifespan and reliability of solder joint based on IPC standard characteristics after soldering process.

1.4 Outline of the Project

In this research study will focus on the parameter case studies of different volume of solder SAC305 and temperature. The investigation was conducted on simulation of Fluid-Structure Interaction (FSI) and Volume of Fluid (VOF) multiphase modelling application for soldering the passive devices in Ansys Fluent software. The project numerical simulation will investigate the parameter that affect the effectiveness of laser soldering process on passive devices which is to make a solder joint between capacitor leg and PCB in pin-through-hole.

This simulation of SAC305 fluid interaction and flow will be studied with the different volume of solder with the assumption of constant density and viscosity to investigate the formation of fillet shape, void, and wetting time during laser soldering process. Moreover, for the effect of different temperature will be studied with the several dynamic viscosities that vary with the change of temperature.

The boundary condition of the 3D model is important to be apply properly based on the benchmark of reference for laser soldering because it will affect the result from the sample and information given by Western Digital. The main priority of boundary condition is to ensure the simulation is correctly conducted to analyse the quality of solder joint based on IPC standard characteristics after reflow soldering process. This research is developed to operate suitable numerical simulation for better understanding to optimise laser soldering parameter than can be used in electronic industry.

1.5 Thesis Outline

The content of this thesis is divided into five chapters:

- Chapter 1 summarizes laser soldering parameters and explanation of numerical simulation.
- Chapter 2 discusses the literature as well as important insights into the elements that influence laser soldering performance and parameters such as Pin-through-hole technology, issue of solder failure, volume solder and temperature optimization design for sac305, numerical simulation, and the IPC-A-610 standard are all topics covered in this section. This literature review also discussed the previous research and study about the numerical simulation in the soldering process.
- Chapter 3 explains the methods applied to simulate the laser soldering process in this work, including capacitor and PCB modelling, meshing, and simulation setup.
- Chapter 4 explores the results and discuss the effect of different solder volume and temperature setup on the laser soldering simulation.
- Chapter 5 highlights the thesis's findings and makes recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The advanced technology of soldering demand in electronic industry has pushed the researchers and engineers to work on the improvements in solder quality and reliability with the change of solder production process. The assembly of the smaller components of passive devices such as capacitor is the challenge in this industry. When the components are smaller, it will be difficult to detect the defect of the component due to miniaturisation of devices. In this chapter will go through some of the past work that has been done in relation to the current laser soldering technique. Many researchers have recently expressed interest in soldering but least in the study related to laser soldering. However, they have conducted several laboratory tests and simulations that can be useful to be references in these soldering fields. Their results and recommendations are discussed from their article published throughout this chapter.

2.2 Laser soldering characteristics

The demand for innovative, highly controlled laser soldering technologies has grown in response to trends toward smaller size of electronic devices and the usage of thinner, complicated, costly, temperature-sensitive, and multi-function components in the electronic equipment industry. Thermally sensitive components and complicated three-dimensional circuit geometry are common in current high-density electronic subassemblies that cannot be soldered using traditional wave or reflow soldering techniques [6].

Laser soldering is the important technology in electronic assembly. In this study, the main point of laser soldering is to connect the capacitor and printed circuit board on pin-through-hole (PTH) using SAC305 as solder. Nowadays, laser soldering is commonly used in industry because of the precise and faster process compared to other type of soldering. This process is contactless and can avoid mechanical contact that can give some quality issue to the product. Some research of laser soldering in electronics industry shows it will affect the effectiveness of soldering in any components on the devices. The ways in which laser energy interacts with the different materials used and how heat is transferred within joints to heat the solder joint [3].

Laser soldering process is a technology that can control the laser beam to transfer the energy to the accurate location where the solder is melts to produce mechanically and electrically solid connections of the solder joint. The benefits of controlling the shape and location of the heated area can make the solder joint more reliable with no contact to other components on the electronic devices. There are several types of laser beam shape shown in Figure 2.1. However, laser soldering process is of more benefit to interconnections using solders with a wide range of melting temperatures when compared with convectional infrared reflow process [7].

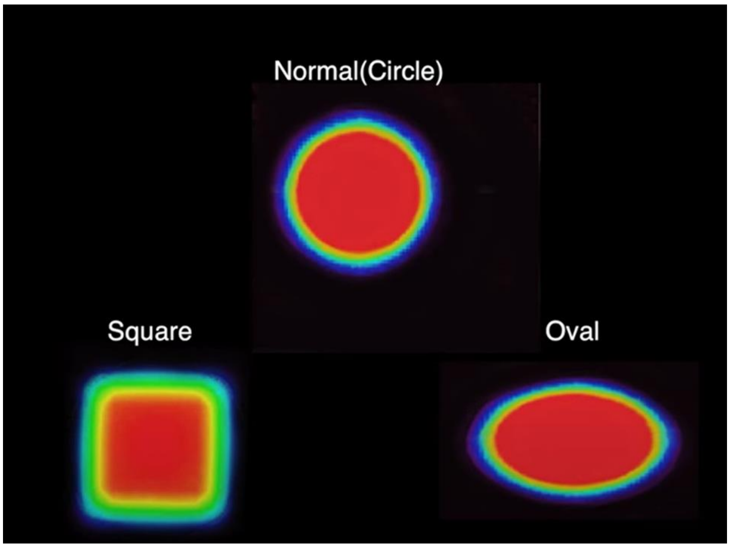

Figure 2.1 Type of laser beam shape

The optimised parameter sets with high desirability levels for laser reflow energy in terms of laser current and pulse width [8]. For laser soldering there are parameters needed to be considered such as the laser beam wavelength, structure, and materials of the joint. Thus, we need to select a suitable type of laser based on characteristics such as the energy emitted and effect on the interaction of heat with solder materials.

The processes involved in forming laser soldered joints vary according to the application, but typically they include the following steps [3]. First, the solder must be placed near the laser at the parts that need to be joint. Next, the focus laser energy will be pointed to the joint with appropriate of energy and duration. Last, the step is repeated for subsequent joints.

2.3 Nano-reinforced free lead (Pb)

The usage of solder has commonly been applied in manufacturing the printed-circuit-board (PCB) to provide the soldered joints connection between components to the pads on board or pin-through hole. The melting solder will provide a solid and strong bond between components due to the reflow process of soldering. To improve the solder joint reliability, quality and to prevent the defects in the final assembly process, there are many factors needed to be study such as the solder particle's properties. The properties of solder particle include the composition and mechanical properties that have been designed to the solder. The design of solder particle properties acts as an important parameter that needs to be known because there are many types of solder with different properties.

Researchers now recognise that using SAC 305 in electronic assemblies causes fragility, void formation, wetting issues, process temperature problems, and fatigue issues, all of which are common failure mechanisms for solder connection dependability. Failure of a solder junction might cause the failure of an electronic product. As a result, experts are continuing their study to improve the efficiency of SAC solder during the reflow soldering process [9], [10]. The recommended solder by Western Digital for this research in laser soldering is using SAC305 lead-free alloy that contains 96.5 % tin, 3% silver, and 0.5% copper. SAC305 lead-free alloy is non highly toxic in properties[11]–[13]. SAC305 solder is an option commonly used as standard soldering materials because it offers acceptable melting temperature, availability, low cost, superior wetting, and fluidity as compared to other Sn-based.

2.4 Parameter of soldering

There are many research papers that investigate the method and parameter to improve the quality, reliability, and lifespan of solder joint during reflow process. The effects of solder volume, temperature, and materials properties on pin-through-hole (PTH) is determined by using Numerical Simulation during laser soldering process. The filling levels and fillet profiles should be designed to achieve an optimum joint strength and with a certain degree of reliability [2]. This study has investigated the effect of filling levels and fillet shape on solder joints strength. During the process, stress and strain forces were observed from the capillary forces that cause the molten solder to flow into the PCB hole. This study concludes that 0.2 fillet profile has lowest displacement and stress on PTH compared to 0.1 fillet profile because spreading process for 0.2 fillet profile has less capillary force exert on PTH [14]. As a result, the fillet profiles and filling level must be design correctly to get a suitable solder joint strength and reliability,

Moreover, the effects of solder joint shape and height on thermal fatigue lifetime are studied to extend the lifespan of solder joints in power electronics devices [4]. The temperature cycling can cause a high standoff solder joint to deform and releasing the thermal tension that has built up in the solder joint. Besides, a tall solder joint changes the stress and strain distribution in the solder joint and protects the solder joint's weak contacts with the chip and substrate. The result in this study shows high standoff-shape solder joints can give beneficial to a higher lifetime. The solder joint geometry and height are the main factor that affect the formation of crack initiation and propagation time.

However, insufficient of solder height may cause interconnection failure between capacitor and printed circuit board [5]. The wettability and thickness of the printed solder are two parameters that may influence the formation of solder height. The solder height must meet the Industrial Standard Requirements for Soldered Electrical and Electronic Assemblies acceptance criterion with different weight percentage of nanoparticles in solder. This study has investigated the reflow process to produce a good quality solder joints without formation of voids by modifying the equipment and selection of addition nanoparticles that can improve the wettability of pure SAC305.

Optimising the standoff height and the fillet for solder volume and the amount of solder dispensed needs to be controlled to prevent from bridging [15]. If the solder volume is low, it needs additional width of solder to cover the area of the joint that will affect to reduce standoff height and fillet. As a result, the best design and assembly process parameters need to be designed such as sufficient solder volume to improve solder joint reliability.

Nguty and Ekere [16] investigate that the behaviour of molten solder viscosity varies at different range of temperature. Besides, based on the experiments results from Nur Hidayah Mansur [17], when the temperature of SAC305 increases, the viscosity of molten solder will decrease. Abdul Aziz [18] concluded that 523 K gives better solder performance compared to the temperature ranging from 456 K to 643 K on wave soldering. The temperature is needed to be controlled for a better wetting performance because a higher temperature can shorten the wetting time, pattern and area [18]. The important parameter states by the researchers are the temperature, viscosity, and wettability of solder.

Based on the properties of liquid, the viscosity is inversely proportional to temperature. Hence, the increase of temperature, will decrease the viscosity. When the viscosity is decreased, better wettability of SAC305 solder will occur to be spread well over the bonding of the solder joint. The wetting time will be shorter due to increasing the velocity of molten solder.

In a static solder fillet on PTH, there are no pressure gradients exist horizontally and the pressure occurs in the vertical direction that varies proportionally to the distance from the fillet profile. As a result, a constantly changing pressure differential exists across the profile because the fillet profile reduces in height as the molten solder moves further away from the capacitor leg.

This will cause the defect such as void to the solder joint because the solidified solder must withstand the residual stress produces by the thermal expansion between the particles of solder. High stress and void will cause the deduction of package reliability in the subsequent manufacturing process [19]. The results obtained by Rusdi shows that the pressure is dominant to filling time, fluid flow and velocity profile [20]. For this research, to maintain the stress to be low, the velocity of molten solder needs to be increased by controlling the temperature of solder.

2.5 IPC standard and Pin-through-hole technology

In this research, laser soldering will fill the pin-through-hole (PTH) with different temperature of molten solder to make a connection of solder joint. Through Hole technology is a technique for manufacture electronics circuits that is the pin-through-hole (PTH) components such as capacitor is place into through holes of printed circuit board (PCB). Using laser soldering equipment, the ends of components are attached to the PCB on the other side with molten solder to form a joint.

There are many factors that affect the formation of solder joint happened in electronic industry. Thus, IPC standard plays the important role to standardise the assembly and production requirements of electronic equipment and assemblies. It was founded in 1957 as the Institute of Printed Circuits industry association. IPC Standards and Publications improve the products for its specialise needs. The reference for validation of these simulation results is refer to the IPC-A-610 standard.

2.6 Numerical Simulation

The research on electronic assembly and reliability of solder joint is a commonly performed by using numerical approach such as Fluid-Structure Interface (FSI), Finite Element Method (FEM) and Finite Volume Method (FVM). This numerical approach is used to reduce the amount of cost for experiment setup and materials in manufacturing process. The capability of numerical simulation is to make a prototype of any real case problem using a computer software that related to the case of investigation. The validation numerical simulation has been proved by many researchers.

The fluid-structure interaction (FSI) is a multi - physics interaction of fluid dynamics and structural mechanics principles. When a fluid flow collides with a structure, stresses and strains apply to the solid body that can causing deformations. Depending on the pressure and velocity of the flow as well as the material characteristics of the actual structure, these deformations might be extremely substantial or very minor that can be affected to the materials.

Using finite element analysis for fatigue lifetime of a lead-free solder joint under thermal cycling and found that reliability of the solder joint depends on void configuration [21]. The simulation results provide a better understanding of capillary flow using finite volume-based simulation and are useful in predicting trends for engineers in industry [22]. Validation of the simulation results with the experimental data shows that the computational fluid dynamics (CFD) simulation trends match the experimental ones with an average percentage [23]. Moreover, the simulation results were proved by the experiment results using the CFD modelling. The effects of PTH pin shape can be investigated during molten solder filling in wave soldering [24].

According to Moukalled [25], the Finite Volume Method (FVM) is a numerical method that converts partial differential equations that represent the conversation of laws over differential volume into discrete algebraic equations over finite volumes elements similarly as finite element method. The discretization of the geometric domain which in FVM is discretized into non-overlapping elements or volume, is the initial stage in the solution process. By integrating the partial differential equations over each discrete element, the solutions are computed into algebraic equations. The values of the dependent variable for each of the elements are then determined by solving the system of algebraic equations.

The flux entering a particular volume is equal to that leaving the neighbouring volume, the finite volume approach is conservative because some components in the conservation equation are converted into face fluxes and analysed at the finite volume faces. The FVM is the favoured approach in CFD because of its inherent conservation property. The FVM also has the advantage of being able to be formed in physical space on unstructured polygonal meshes. Last, because the unknown variables are analysed at the centroids of the volume elements, not at their boundary faces, the FVM makes it simple to apply a variety of boundary conditions in a non-invasive manner.

These aspects make the Finite Volume Method ideal for numerical modelling of a wide range of fluid flow, heat, and mass transfer applications. Moreover, the advancements in the method have been strongly linked to improvements in CFD. Computational Fluid Dynamics is one of most recent Computer Aided Engineering techniques commonly used, and it simulates a wide range of flow phenomena, from turbulent or laminar that is in single phase incompressible flows to compressible all-speed flows and also multiphase flows. The FVM's initial potential was restricted to simple the physics and geometry over structured grids, but it is now capable to cope with a wide range of complicated physics and applications.

2.7 Summary of research scope

In the research study by the author, there is no research has been done on the CFD method for laser soldering process of passive devices such as capacitor on the PTH. Moreover, there is no parametric research on SAC305 solder to fill the PTH during laser soldering. However, there are several research that related to this project to be taken as references. As a result, a technique for simulating the laser soldering process is very useful. Unfortunately, the soldering simulation is time consuming because of long transient time that need to be considered. Thus, the numerical simulation model will concentrate on the volume and temperature of solder during reflow process in laser soldering. The Volume of Fluid (VOF) method is employed and ANSYS FLUENT is used for numerical simulation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter describes the method and procedures used to investigate the effect of volume and temperature of solder behaviour during laser soldering process on pin-through-hole (PTH). The ANSYS Fluent software is used to run the multiphase modelling include the mixture of phase such as gas, liquid and solid. Each phase in a multiphase flow may be characterised as a class of defined material with a certain inertia reaction that reacts with the flow and the potential field in which it is involved. There are many multiphase models available in ANSYS Fluent. The model that can be used in this research study is volume of fluid model (VOF). This VOF model is utilised to model a molten solder flow in laser soldering. The function of this model is to develop for two or more immiscible fluid where the reaction between the fluid is considered. The momentum equation in VOF model is shared by the fluids and the volume fraction of each fluid in each cell that is located across all domains. This model also can apply to a solid-liquid interface for filling the PTH and for the wetting process of SAC305 solder.

The ANSYS Fluent software may analyse the solidification and melting issues at a constant melting temperature with different volume or at different melting temperature with constant volume. These advance features enable the ANSYS Fluent to simulate a wide range of solidification and melting issues, including melting and solidification of solder by performing transient flow simulation during laser soldering process.

The understanding of materials properties of SAC305 solder before starting the numerical simulation is important to be known. Table 3.1 shows the properties of SAC305 lead free solder.

Table 3.1 Properties of SAC305 solder

Properties SAC305	
Density	7500 kg/m^3
Specific Heat Capacity,	230 J kg K
Thermal conductivity	58 Wm/K
Viscosity	0.0022 kg/ms
Standard State Enthalpy	0.004 J/mol

However, if a constant viscosity was applied in the simulation with varies temperature, there is no effect on the velocity and pressure because the velocity is depend on the viscosity. If the viscosity is constant, the velocity will be constant. Thus, the dynamic viscosity is applied in the simulation based on Figure 3.1 shows the Viscosity of SAC alloys.

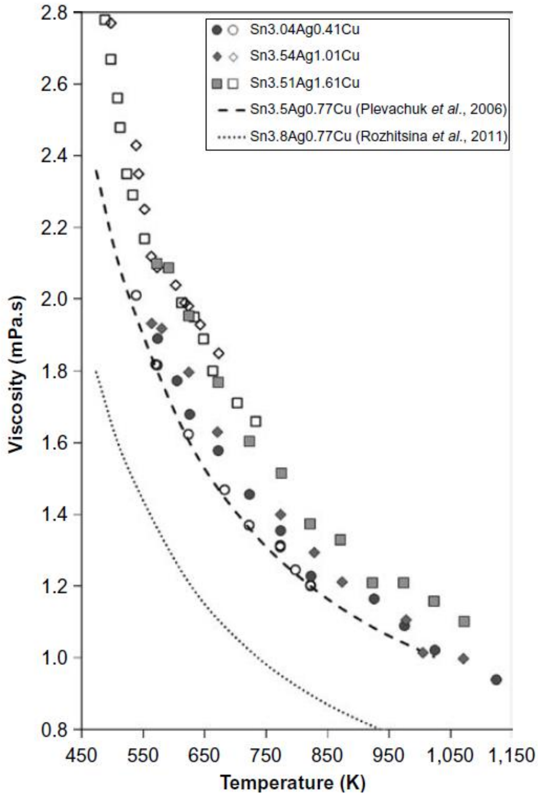

Figure 3.1 Dynamic Viscosity varies with temperature [26].

Table 3.2 Assumption of dynamic viscosity SAC alloys [26]

Temperature, K	Viscosity, mPa.s
500	0.0022
600	0.0017
642.35	0.00158
700	0.0014
800	0.0012
900	0.0011

The transient conductive heat transfer for circle geometry of laser beam is numerically investigated using VOF model in Ansys Fluent. The numerical method developed the propagation of conduction with the temperature applied in laser soldering process. The temperature is set in boundary condition to simulate the conductive heat transfer for laser soldering process. The name of boundary which is beam source is set as the bodies that produce heat in simulation.

3.2 Numerical Simulation Procedures

The model's outline is created in advance. To solder the capacitor leg, the laser soldering procedure is performed in PTH of the PCB's circular pad. The model's scale must be decided ahead of time. The simulation is carried out on a millimeter scale near the capacitor on the PCB. Figure 3.7 shows the modelling for the ANSYS Fluent of FVM numerical simulation methodology. 3-D modelling and meshing analysis are the first steps. Following that, the FVM interaction model is conducted, as well as the mathematical modelling validation. Data extraction and optimisation will be produced after finishing the setup for the analysis.

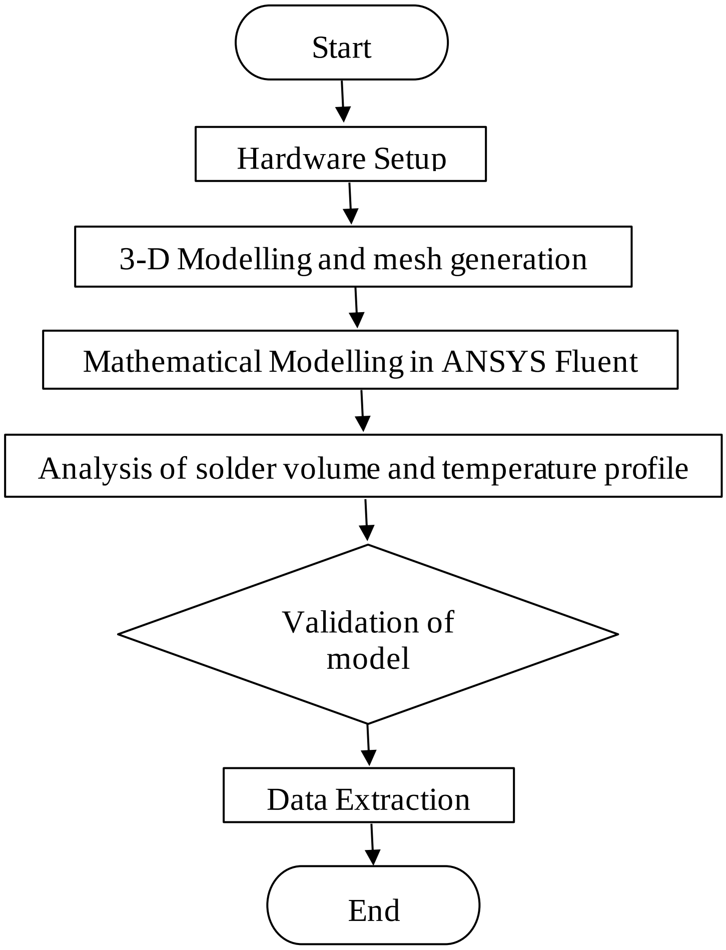

Figure 3.2 Flowchart of ANSYS Fluent simulation setup

3.2.1 Geometrical Design Modelling

The geometrical design model has been created using SOLIDWORKS. The model comprises 5 components which are PCB, capacitor, circular pad, laser beam and air domain as shown in Figure 3.2. The first trial of the model has been created with full dimensional shown in Figure 3.3. However, simplification had been done to reduce the computational time and limitation of the Ansys Fluent which is the simulation only covers a small part at a specific location where the reflow process is occurs during the soldering process that will be highlighted for this research.

From the full capacitor model, it has been closed-up to only one side of lead and PCB. The closed-up model shown in Figure 3.4. Then, the file is imported in Parasolid (.x_t) file to Design Modeller ANSYS Workbench.

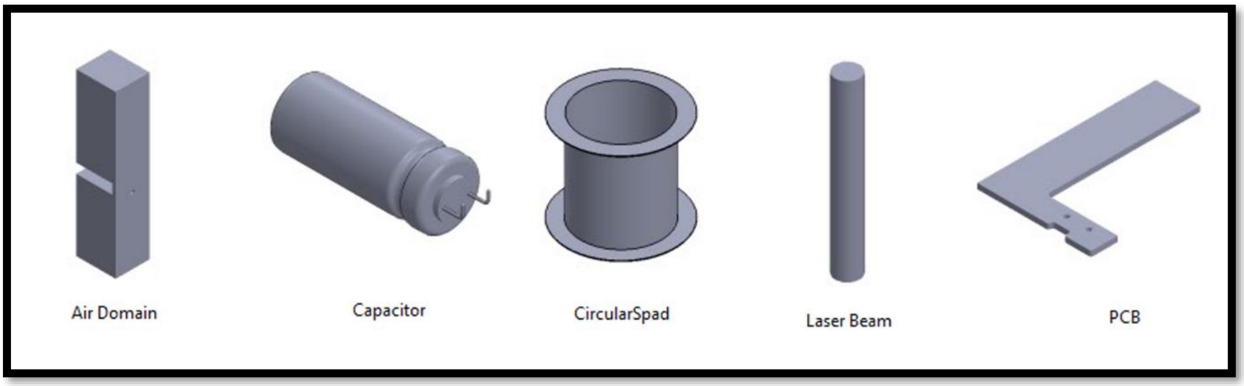

Figure 3.3 List of components parts.

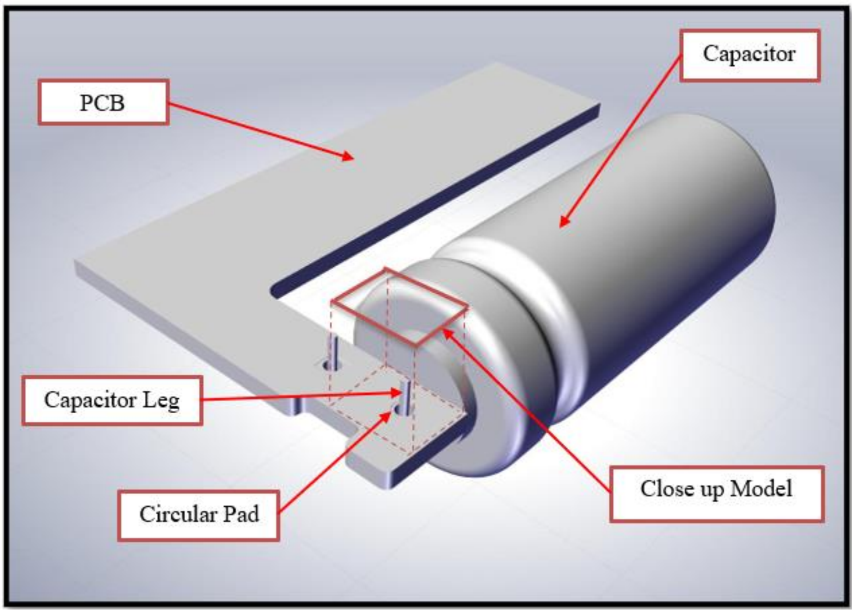

Figure 3.4 Full model of simulation

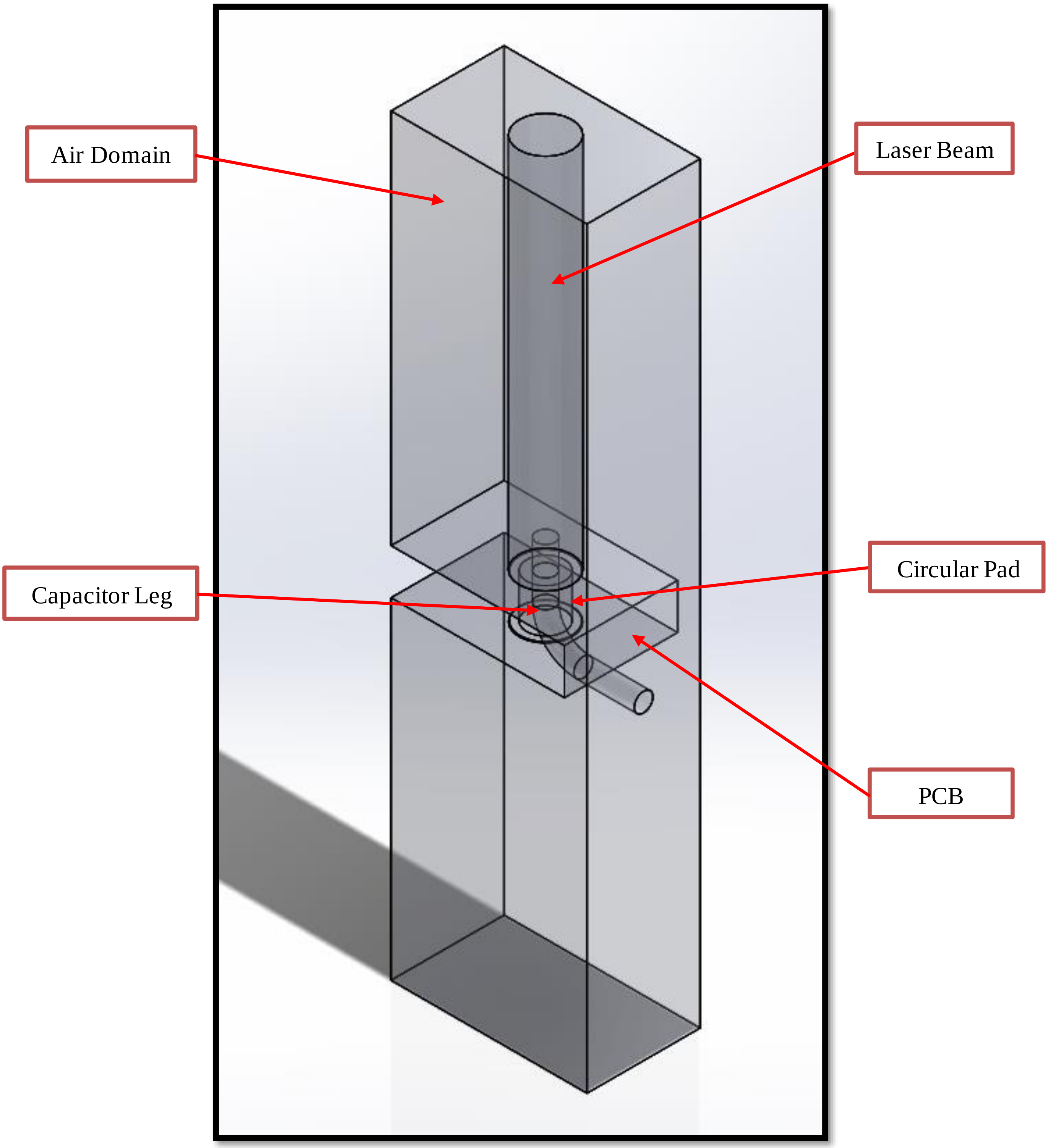

Figure 3.5 Close up simulated model

3.2.2 Meshing

The mesh model generated for the simulated laser soldering process of close-up components is based on the actual size of passive device and laser beam. The size of air domain and laser beam bodies that occupied the component are based on the heated area at the wetting zone in reflow process of SAC305 solder. Besides, the name of the boundaries which is outlet, beam source, lead, PCB wall and circular pad has been assigned as wall that shown in Figure 3.5. The internal of the soldering body is the location of both SAC305 solder and air is placed. Moreover, the top lead of the soldering body is assigned as the fluid interface. The soldering body also has an internal zone where the molten solder filled the PTH that was located inside the circular pad to form a fluid connection of solder joint between the bodies in simulation.

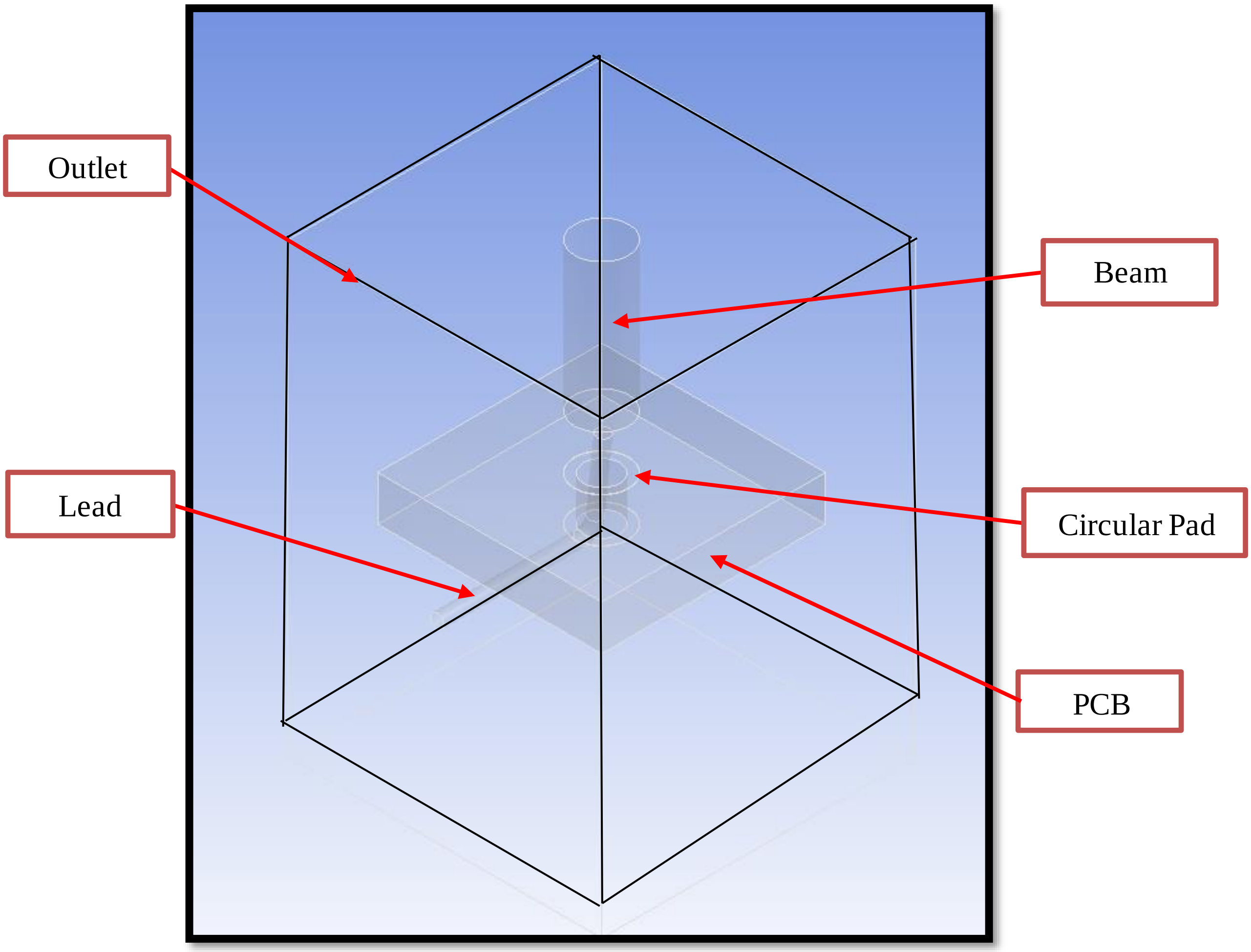

Figure 3.6 Wall assign on Soldering body