OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

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OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

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DECLARATION

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LIST OF ABBREVIATIONS

USM	Universiti Sains Malaysia
PTH	Pin Through Hole
IPC	Institute for Printed Circuits
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	96.5Sn-3.0Ag-0.5Cu
SAC405	95.5Sn-4.0Ag-0.5Cu
SIMPLE	Semi-Implicit Method
WD	Western Digital

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OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

ABSTRAK

Pematrian laser ialah proses bukan sentuhan yang penting dalam teknologi pematerian untuk komponen kecil kerana ia boleh mengeluarkan pemanasan terkawal dari pancaran laser ke lokasi tertentu sambungan pateri dan proses ini juga boleh mengelakkan kerosakan komponen lain pada peranti elektronik. Parameter proses pematerian laser juga penting untuk diketahui iaitu kuasa laser, masa proses dan bentuk pancaran laser untuk menghasilkan hasil pematerian yang konsisten. Walau bagaimanapun, dalam kajian penyelidikan ini akan memfokuskan kepada model VOF dalam perisian ANSYS Fluent dan Steady State Heating dalam ANSYS Mechanical 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 iaitu jarak pancaran laser dan jenis pateri boleh mempengaruhi pembentukan bentuk fillet, halaju, dan tekanan pateri. Juga, kesan sinaran haba dari pancaran laser dikaji. Simulasi berangka telah dijalankan untuk mengenal pasti jarak pancaran laser yang sesuai dan pemilihan jenis pateri yang boleh menjejaskan kebolehpercayaan sambungan pateri seperti pembentukan lompang. Oleh itu, parameter dalam proses pematerian perlu dikawal untuk menghasilkan kualiti yang baik, jangka hayat yang panjang, dan sambungan pateri yang lebih dipercayai. Keputusan yang diperoleh daripada simulasi boleh menggambarkan aliran pateri pada akhir proses pengaliran semula dalam kontur pecahan isipadu dan suhu. Hasil visualisasi boleh menunjukkan trajektori butiran pateri semasa ia mengalami pengaliran semula haba. Selain itu, hubungan yang baik dapat dilihat antara hasil simulasi yang diperoleh dan pengesahan daripada piawaian IPC. Kajian model VOF menunjukkan pendekatan simulasi yang boleh digunakan untuk mensimulasikan proses pematerian laser yang boleh menghasilkan hasil sambungan pateri yang baik.

OPTIMIZATION OF LASER SOLDERING PARAMETERS ON PASSIVE DEVICES

ABSTRACT

Laser soldering is a non-contact process that is 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 and Steady State Heating in ANSYS Mechanical because the process parameter of laser soldering has been given by Western Digital. The main goal of this study is to optimize the parameters that affect the effectiveness in laser soldering process on passive devices. The parameter which is laser beam distance and solder type can affect the formation of fillet shape, velocity, and pressure of solder. Also, the effects of heat radiation from the laser beam are studied. Numerical simulation has been conducted to identify the suitable laser beam distance and the selection of solder type that can affect in solder joint reliability such as void formation. 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 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 project’s structure

Electronic gadgets have shrunk in size over the past few years as modern technology has progressed. This is due to the industrial competitiveness to manufacture high-reliability electronic equipment in small sizes. The electronic market consumer needs are becoming one of the world's fastest developing markets. the consumer needs highly dependable and low-cost components. As a result, this has challenged every engineer's potential in the current world. The electronic industry will place a greater emphasis on miniaturised components. Miniaturization components in smart phones, computers, laptops, and other electronic devices, for example. Miniaturisation is required to make gadgets compact, lighter, and more powerful so that they may be utilised in all aspects of electronic equipment. Furthermore, the smaller the parts of electronics, the more difficult it is to manufacture them. Industry will face challenges in the production process, such as assembling hardware components. As a result, coordination between industry and research institutions is critical to address this difficult problem.[1]

This project is completed in close collaboration with Western Digital Sdn. Bhd. They provide us with all the required data and samples on their experimentation with laser soldering. Innovation in the world of data storage and analysis is rapidly evolving, posing a challenge for Western Digital to contribute to industry change and give value to its customers. Western Digital also need access to the resources and data that could be used to improve current products and develop new ones. The electronic device connection technique and assembly utilising laser soldering technology are investigated in this research. Most previous research focused on physical soldering connection.

Because of the process of miniaturisation of electronic devices, as was discussed before, electronic gadgets have gotten considerably smaller in the industry. As presented in Figure, this method is a non-contact procedure that employs a carefully focused laser beam to regulate the solder heating. The energy is transferred to a soldering point, where the absorbed energy heats the solder until it reaches melting temperature.

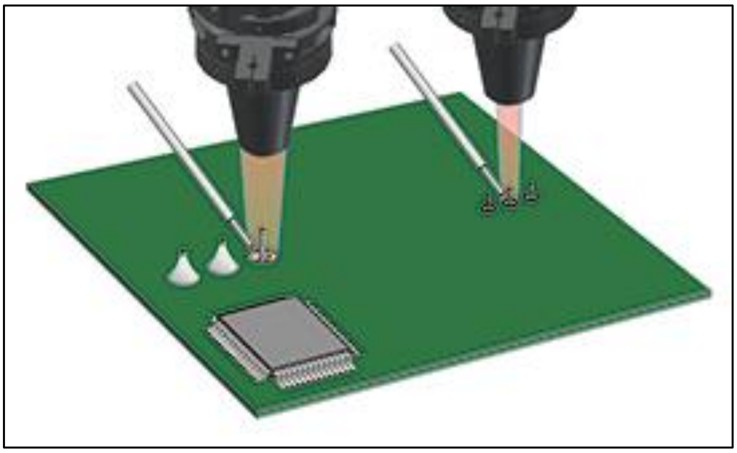

Figure 1.1 Laser Soldering method [2]

Laser soldering has the advantage of being efficient and non-destructive to an electrical connection. This will result in the formation of a reflow process in which the molten solder reflows in a molten state, resulting in the formation of a permanent solder junction. The traditional soldering process, which uses a hot iron, as shown in Figure 1.2, is unreliable and time-consuming in production.

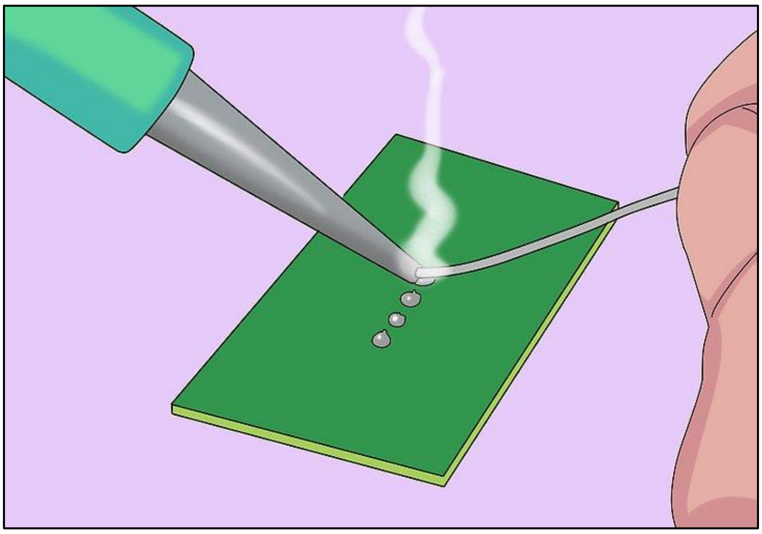

Figure 1.2 Traditional soldering method [3]

To ensure the quality of the solder produced by using laser soldering method, a standard was set by the Institute for Interconnecting and Packaging Electronic Circuits (IPC). Many process characteristics, physical design, and assembly requirements must be regarded for soldered electrical and electronic assembly [4]. Stated in the IPC standard, the first parameter is the filling height, which has an influence on the solder joint's strength. Because of the partial filling of solder in pin-through holes (PTH), this will result in defects and product voids. The volume of solder, on the other hand, is what will cause the bridging issue due to the extra solder. This will have an impact on the circuit's failure. Moreover, reliability issues due to heigh of laser beam and lead angle in pin-through holes (PTH) are one of the main parameters that is needed to be researched in this project. Many ways may be used to determine the reliability of electrical components. Prediction via simulations techniques are the most commonly suitable method.

Any engineering problem may be solved using several different methods, like analytical, numerical, and experimental methods. Using Ansys Fluent software, a numerical method is appropriate for predicting the quality of solder junctions in this study. This software can simulate the flow of solder with different laser beam heights and lead angles. The aim for this software is to anticipate solder connection flaws such as cracking, void development, and unfilled PCB holes with less than 50% solder volume, which is a difficult issue owing to PTH's small dimensions [4].

Many factors can influence the effectiveness of the laser soldering process, including filling height, solder volume, reliability issues, solder type, solder connection orientation in pin-through holes (PTH), and thermal expansion coefficient. This study will use Ansys Software to construct a model for the laser soldering process and conduct simulations for real-world challenges depending on process parameters, physical design, and solder joint assembly circumstances [4].

These parameters must be analysed, which may be accomplished by numerical simulation. To discretize integral versions of equations, numerical techniques such as FEM are utilised. The underlying principle behind all numerical techniques is to measure the whole domain surface or volume at a few points and then interpolate the results. The unknown will be anticipated to alter over a domain before reaching the solution. When a machine is created with linear quadrilateral components, the assumption is that displacement will change linearly throughout the domain, but displacement will vary parabolically with 8 nodded quadrilateral members. It's possible that this is the case, but it's also possible that it may not be. This may or may not be the case in practise, hence all numerical processes are based on assumption.

There are a variety of ways for ensuring numerical, practical, or field result correlation accuracy and error minimization.

In prior study, finite element analysis (FEA) was used to predict solder joint failure using simulation methods [5]–[7]. This study, on the other hand, is focused mainly with the stability of solder joints in different soldering methods. Furthermore, no study on the optimization of laser soldering settings on passive devices is being conducted. This might be a good way to improve the solder joint quality in the laser soldering process. Furthermore, numerical simulation results must be confirmed by an experimental or calculation approach before being accepted as a result. This is because we need to compare in order to evaluate the study's validity and determine the range of outcomes. The numerical analysis results are crucial for researchers in the electronic industry to have a better understanding.

This project's objective is to investigate laser soldering parameters on passive devices that need to be optimized. We will analyse the numerical analysis of different laser beam distances and lead angles during laser soldering in this study. Finally, the outcome is determined using numerical simulation based on the data given by Western Digital. The goal of this study is to have a better knowledge of the process parameters and solder structure while employing laser soldering.

1.2 Problem Statement

In the electronic industry, laser soldering is a crucial technique. Even yet, this technology has been employed in the industry for a long time to replace the traditional hot iron soldering approach. This is a non-contact procedure that controls the solder heating using a technique of directing laser beams. The laser soldering technique parameter must be addressed when regulating an issue such as a fault in the device's components. For this study, the difficult issue is determining the appropriate laser beam distance and the right lead angle that will output the best results.

Western Digital's final electronic assembly component photos are shown in Figure 1.3. This is a crucial component in the chip manufacturing process. This section contains the standard for technical installation instructions for capacitor leg contact with the PCB board in order to detect the void in the component following the soldering operation. When attaching the capacitor leg contact with the PCB, this will be the primary problem. In terms of product dependability and quality, laser beam distance and lead angle are the most crucial factors to consider.

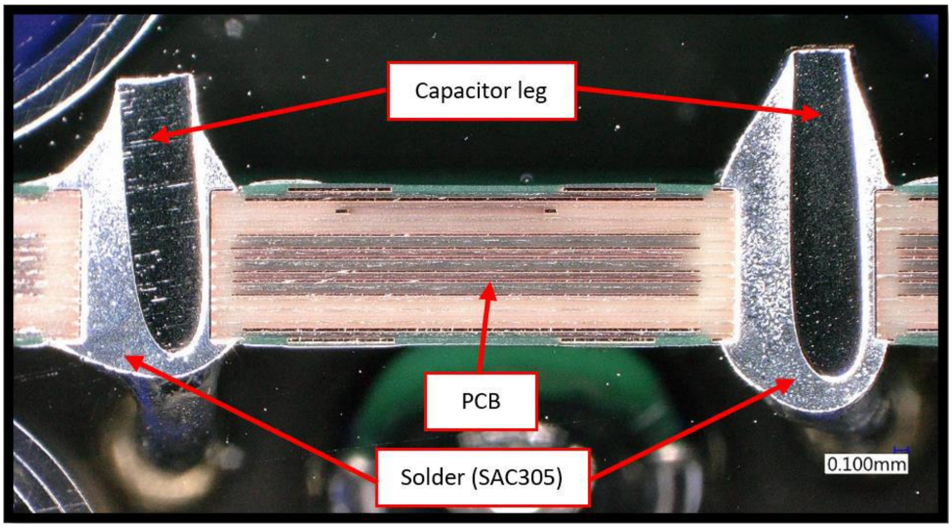

Figure 1.3 Assembly of electronic joint

Figure 1.4 displays an example of photos of components soldered together without voids using laser soldering. The solder joint on the components reveals a decent concave fillet shape.

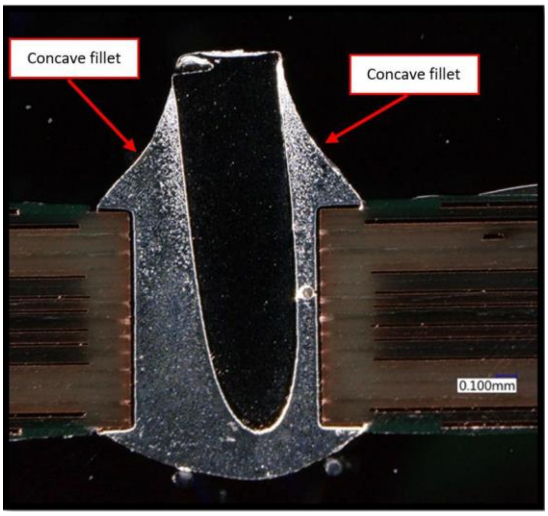

Figure 1.4 Component joint without void with desirable fillet shape sample

Some of the solder joints in the sample have a possibility of failure. Figure 1.5 (a)–(d) displays a sample of pictures of laser-soldered components with micro-voids and unattractive fillet shapes. The micro-voids are caused by a tiny hole in the solder.

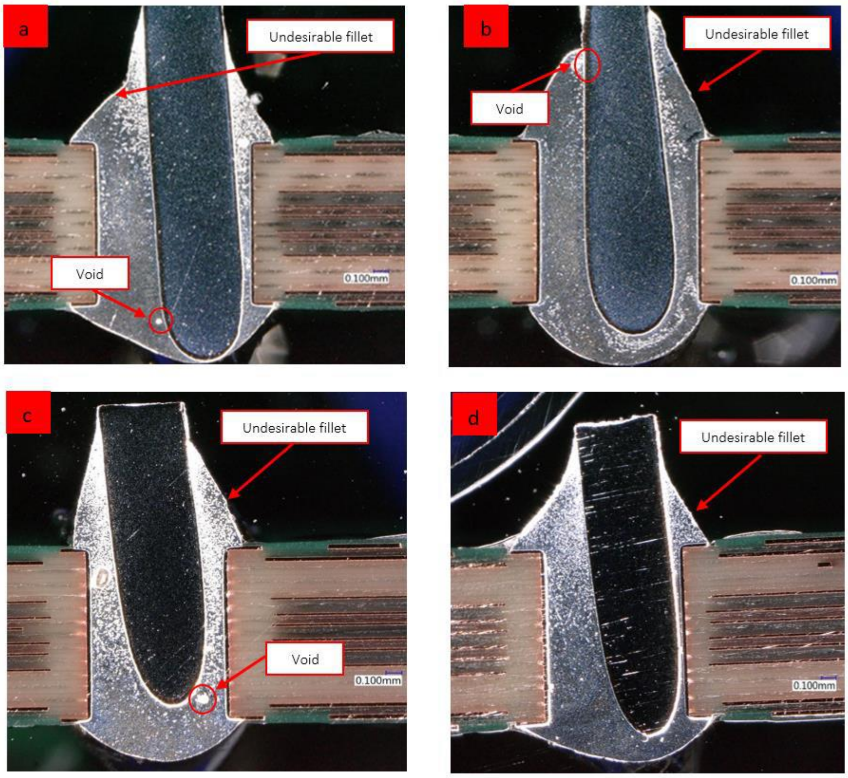

Figure 1.5 Component joints with micro-void and undesirable fillet sample

Many process parameters, physical design, and assembly circumstances must be examined to assure the quality of the solder based on the IPC standard for soldered electrical and electronic assembly [4].

Laser beam height and solder type are two important factors that will impact this failure. Furthermore, the capacitor and PCB are comprised of materials with varying thermal expansion coefficients. As a result, laser soldering will be ideal in this situation since the laser will be more precise in soldering the contact region that has to be soldered without causing damage to other components. It is necessary to investigate the factors that cause solder joint micro-voids, undesired fillets, partial filling, bridging, and the reflow process. This factor will have an impact on the solder joint's dependability and longevity on through-hole components, which may be thoroughly investigated using simulation techniques.

1.3 Objectives

This research aims to,

1. To optimise laser soldering parameter that affect the effectiveness soldering process on passive devices.
2. To investigate the changing effect of different Laser beam distance and solder type during reflow soldering on the contour of volume fraction of solder, static temperature, velocity, and pressure of solder during soldering process.
3. To visualise and identify the shape of fillet, volume fraction of solder and reflow process of solder on pin-through-hole (PTH).
4. To analyse the quality, lifespan and reliability of solder joint based on IPC standard characteristics after soldering process.
5. To study the effects of heat radiation in laser soldering.

1.4 Outline of this Project

The focus of this research will be on parameter case studies in different laser beam distances and solder types. The study used Ansys Fluent software to simulate Fluid-Structure Interaction (FSI) and Volume of Fluid (VOF) multiphase modelling techniques for soldering passive devices. The numerical simulation for this project will look at the factors that determine the effectiveness of the laser soldering process on passive devices, specifically the solder junction between the capacitor leg and the PCB in pin-through-hole.

The formation of fillet shape, void, and wetting time during the laser soldering process will be investigated using this simulation of the solder fluid interaction and flow with different laser beam distances under the premise that the solder has constant density and viscosity. Furthermore, the influence of different lead angles on the solder shape and filling will be investigated using numerous different angles of the capacitor leg.

Because it will impact the outcome from the sample and information provided by Western Digital, the boundary condition of the 3D model must be applied appropriately based on the benchmark of reference for laser soldering. The main goal of the boundary condition is to guarantee that the simulation is appropriately carried out in order to assess the quality of the solder joint after the reflow soldering process using IPC standard parameters. This study seeks to utilize an appropriate numerical simulation to gain a better understanding of how to optimise laser soldering parameters for implementation in the electronic industry.

1.5 Thesis Outline

The following chapters make up the contents of this thesis:

- The first chapter provides an overview of laser soldering parameters as well as an explanation of numerical simulation.
- Pin-through-hole technology, solder failure, volume solder and temperature optimization design, laser beam types, numerical simulation, and the IPC-A-610 standard are all discussed in Chapter 2. The earlier research and study on numerical simulation in the soldering process were also mentioned in this literature review.
- The methods used to replicate the laser soldering process in this study, including capacitor and PCB modelling, meshing, and simulation setup, are discussed in Chapter 3.
- The effects of different laser beam distance, solder type used and heat radiation effects on the laser soldering simulation are discussed in Chapter 4.
- Chapter 5 summarizes the conclusions of the thesis and gives recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In general, it has been demonstrated that laser soldering, and in particular semiconductor laser-based methods, have huge potential in niche markets of electronics manufacturing, where they allow for the cost-effective replacement of traditional techniques as well as the development of entirely new assembly methods. It has also been demonstrated that knowledge of the absorption and heat transfer properties of the materials used is critical to the success of applications. In many circumstances, the unique features of semiconductor lasers provide them an edge over other laser power sources [5]. The current advancements in laser soldering technology have seen a massive jump from electronics company, to adopt this method into their more traditional based soldering method. However, the current method has its limitations as the laser soldering method requires very specific parameter requirements that is needed to be optimized for every type of PCB, components and connection types [8].

2.2 Laser Soldering Parameters

One of the types of research that has been done is in the optimization on laser soldering parameters onto lead free solder joint. This research mainly focuses on solder shape dependence on heat absorption and the effects of different parameters on the wettability joint [9]. What had been shown is that the rate of connecting between the solder and the substrate is affected by the contact area and volume of the solder. The better the solder to joint, the greater the contact area. As shown in this study, lead-free solder wire with a spherical form joins better than lead-free solder wire with a straight-lined shape[9]. Also, the wettability joint of solder improves as the power output increases. However, to get a decent wettability joint, a balance of controlling the power output and irradiation duration parameters must be considered[9]. The ability of molten solder to form connections between solder and substrate is measured by wettability of solder joints, which is crucial in the fabrication of electrical components[10]. The contact angle range that is permissible should be less than 45º, and the narrower the contact angle, the better the wettability joint[11]. The wetting regions of solder on pads grew greater when the output laser power was increased, as demonstrated above. As the output laser power rose, the area of solder to melt grew greater, as did the contact areas between the solder and the substrate's surface, causing the solder's spherical form to gradually fade and become more flattened, resulting in larger wetting areas[12]. Meanwhile, if the solder irradiation duration is insufficient, the solder molten solidifies rapidly, leaving insufficient time for solder to spread more on the substrate surface, lowering the wetting angle. As a result, a balance between power output and heating duration is essential to obtain an acceptable wetness.

The laser soldering method is a technique that uses a laser beam to precisely direct energy to the specific region where the solder melts, resulting in physically and electrically solid solder joints. Controlling the size and position of the heated region has the potential to improve the solder joint's reliability while avoiding contact with other electrical components. Figure 2.1 illustrates numerous different laser beam shapes. When comparing to convectional infrared reflow, the laser soldering procedure is more favourable to interconnections using solders with a wide range of melting temperatures [13].

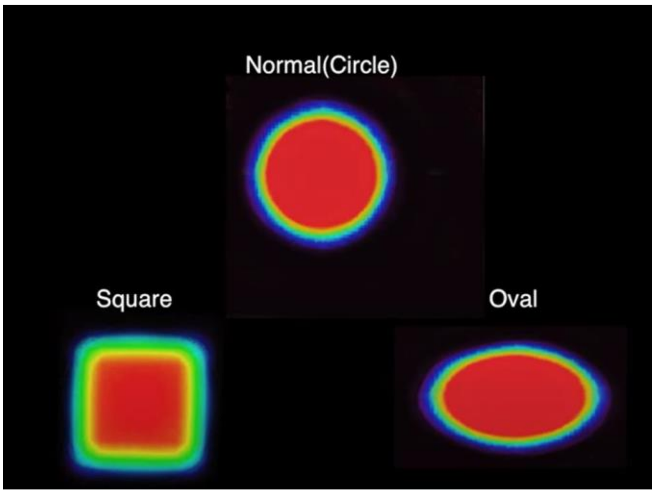

Figure 2.1 Different Laser Beam shapes

Next, the impact of temperature or flow-ability during high temperature to the formation of void and ability to fill in the through hole gap has also been research. They presented the results of a research of the industry's laser soldering technique for lead-free solder (SAC305) in terms of flow visibility, void generation, and solder volume. The lead angle plays an important role in flow visualisation, with a 90-degree angle providing the ideal medium for solder to flow between the solder pad and the lead component. This improves wettability by distributing the adhesive force between the surface and the fluid evenly. In comparison to the experimental observation, the solder distribution is better, with more than 90% of the solder volume fraction dispersed over the area between the solder pad and the lead wall[7]. Higher volume fraction values have a lesser tendency to generate voids as compared to volume fraction distribution. The contact between solder and the copper surface on the solder pad fluctuates due to differences in lead angle and temperature. Due to asymmetric force distribution and greater temperature, larger lead angles tend to generate more voids than lower lead angles, giving more energy for the solder to flow. According to numerical modelling, the most effective temperature range for solder flow is between 600K and 700K, which is often used in the industry. According to simulation findings, the 600K temperature configuration provides the optimum solder dispersion and the lowest operational cost to heat the solder[7]. the best combination of lead angle at 90º and temperature profile at 600K can improve solder volume distribution[7].

To avoid bridging, the standoff height and the fillet must be optimised for solder volume and the amount of solder dispensed [14]. If the solder volume is low, more solder width is required to cover the connection region, resulting in a reduction in standoff height and fillet. As a result, the optimal design and assembly process characteristics, such as enough solder volume to increase solder connection reliability, must be specified.

The impact of different solder volumes have also been researched, where The effect of various SAC305 solder volumes on the filling level, fillet shape, void creation, velocity, and pressure of a through-hole capacitor connected on a PCB using a single diode laser soldering spot was done [15]. If the solder volume is low, more solder width is required to cover the connection region, resulting in a reduction in standoff height and fillet height. To produce a desirable fillet shape and prevent voids that cause flaws in the solder joint, the volume of solder must be adjusted. In the research, the preferred volume of solder is 1.5404 mm3 at 642.35 kelvin, with a filling duration of 1.7 seconds. The filling time will be affected by the volume increase. The more the amount of solder used, the larger the volume of solder used in the PTH. As the filling time rises, the PTH comes into closer contact with the molten solder, increasing the stress on the structure. A significant concentration of stress on the PTH might result in undesired flaws and weaken the structure's durability. As a result, PTH stresses have a substantial influence on the reliability of the finished product [15].

2.3 Types of lasers used in Laser Soldering

The lasers used in the laser soldering process are split into 3 main types based on its suitability for laser soldering. The first one is the carbon dioxide laser which is a gas type laser and has a wavelength of 10.6μm based on the region of the far infrared [16]. It is strongly absorbed by flux after being extensively reflected from metal surfaces, and the heated flux then transfer the heat towards the solder and metals in the joint. A combination of carbon dioxide, nitrogen, and helium serves as the active medium in a carbon dioxide laser. The light production techniques are more effective when nitrogen molecules are used to excite the CO_2 molecules, which is the lasing gas. Helium performs a dual function in helping the population inversion continue by causing co_2 molecules to fall from the lower laser level to the ground level and boosting heat transfer from excited nitrogen molecules to the co_2 molecules. Pumping the gas via the heat exchanger cools the carbon dioxide laser, which has an efficiency of up to 20% [16]. The downsides of having to use this laser is that the cost to operate this method is very inefficient. It has a very poor electrical energy input to laser light output ratio. Next is that a continuous supply od CO_2 is required to keep the process running, thus it requires frequent maintenance. Finally, CO_2 lasers are generally larger in size and can be hard to be applied to smaller joints and CO_2 also cannot be transferred via an optical fiber.

Another type of laser being used in the laser soldering industry is the Nd: YAG laser. This laser is solid state. Neodymium-doped Yttrium aluminium garnet is used as the lasing material. Neodymium is an impurity that substitutes for yttrium atoms of a similar size. It emits light with a wavelength of 1.06μm, which is near infrared. Neodymium delivers the highest degree of power of any doping element, making it a great lasing material [17]. The maximum amount of energy that may be stored in a typical rod is roughly half a joule due to the tiny size of Nd:YAG rods and the optical characteristics of neodymium atoms. For soldering, beam intensities between 10 and 20 watts are typically utilised. Because solder effectively absorbs thermal radiation at 1 μm, the Nd:YAG laser has a high heating efficiency [18]. However, the downside of using this laser is that regular maintenance for the light bulbs is needed and the energy intensity is uneven because the overall energy being transferred by the laser is decreased.

The most common type of laser being used and which Western Digital is currently using are diode lasers. The mechanism of this laser is similar to a diode that consist of a PN junction that works in forward bias mode. They are sometimes referred to as semiconductor diodes with wavelengths between 790 and 980 nm. By injecting electrons, a population inversion is created in the active zone. A distinctive threshold current density is reached during laser operation by recombining electrons and holes in the active zone. By adjusting the Al-doping of the $Al_xGa_{1-x}As$ semiconductor and so affecting the bandgap width, it is possible to modify the laser's wavelength within specified bounds [19]. Electrons are fed into this diode, where they mix with holes. In a process known as resonance, some of their surplus energy is released as photons that interact with more electrons to produce even more photons. This repetitive process of converting incoming electrons into photons is comparable to the stimulated emission that takes place in a traditional gas-based laser. The advantages of having to use this laser compared to others are that first It has a higher absorbance in metals and a lower absorbance in the typical organic materials used to make PCBs and other substrates because of its shorter wavelength. Next is that it provides manufacturers with a versatile and effective solution to address heating issues. It also provides a balanced energy distribution regardless of the laser size. Finally, the overall operating cost is low as the laser is maintenance free and for a high-power diode laser system, the highest conversion efficiency of changing the input electrical efficiency of around 59 % results in a total electrical efficiency of approximately 40 % [19].

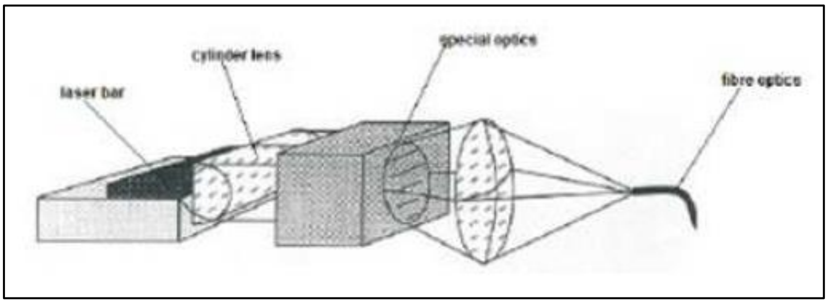

Figure 2.2 The diode laser soldering optics

2.4 Solder types

In terms of Solder types, generally there are a total of 7 different types of solder types, ranging from Type 1 to 7 with its difference being its individual ball particle sizes where higher number types have smaller sizes but higher surface areas. Type 3, Type 4, and Type 5 solder types are the most common solder types used in electronics. The kind is determined by the solder particle size. Type 5 is the recommended type for pitched components[20]. The size of the solder powder has a significant impact on solder performance[21]. Regardless of solder powder size, the wetting or spread of the no clean solder was uniform. The water-soluble solder wetting or spread dropped as the solder powder size fell, but it was still greater than the no clean solder pastes overall. For most electronic assemblies, the solder balling performance of the no clean and water-soluble type 3 and 4, and 5 solder pastes was satisfactory. The IPC solder balling test revealed that the no clean and water-soluble type 6 solder had high solder balling performance. The no-clean and water-soluble type 3, 4, and 5 solder had excellent grazing performance. For both type 6 solder, the graping was undesirable. Excessive solder balling and graping can occur when type 6 solder powder is used in a solder [21]. The low voiding behaviour was consistent across all the no clean solder. As the solder powder size reduced, the voiding in the water-soluble solder pastes increased. The particle size of solder powder and a variety of other parameters influence voiding. With a change in solder powder size, voiding behaviour may alter, and the process may need to be adjusted to reduce voiding[21]. Users should be aware of these performance changes when using solder pastes with lower solder powder particles so that the SMT process may be tweaked properly.

Some types of solder such as SnAgCu lead-free solder shows that with increased laser output power or laser output duration, the temperature distribution, peak temperature, liquid lifespan, and cooling rate all rise [6]. In detail, increasing the laser output power or time appropriately contributes to the formation of a fine and uniform microstructure and an increase in microhardness, whereas increasing the laser output power or time excessively causes microstructure coarsening and non-homogenization, as well as the formation of void defects and a decrease in microhardness [6]. While the thermal stress and deformation rise when the laser processing settings are increased, this is mostly concentrated on the copper pads and may have a detrimental influence on the as-soldered sample's dependability [6]. Overall, the simulated and actual results are in good agreement, demonstrating that the finite element model can accurately predict temperature and stress distributions, which may help with optimization of the laser soldering parameters for the electronic components and PCB.

2.5 IPC Standard and Pin-through-hole (PTH) technology

In this study, laser soldering will be used to fill pin-through-holes (PTH) with various laser beam height to melt the solder to form a solder joint connection. Through Hole Technology is a method of producing electronic circuits in which pin-through-hole components such as capacitors are inserted into the printed circuit board's pin through holes (PTH). The ends of components are soldered to the PCB on the other side using molten solder using laser soldering equipment.

In the electronic industry, there are several elements that influence the development of solder joints. As a result, the IPC standard is critical in standardising the assembly and manufacturing requirements of electronic equipment and assemblies. The Institute of Printed Circuits industry association was created in 1957. IPC Standards and Publications help to improve products for specific applications. The IPC-A-610 standard should be used as a reference for validating these simulation outcomes.

2.6 Numerical Simulation

Numerical methods such as Fluid-Structure Interface (FSI), Finite Element Method (FEM), and Finite Volume Method (FVM) are extensively used in studies on electronic assembly and solder joint durability. This numerical method is implemented in the manufacturing process to lower the cost of experiment setup and materials. Numerical simulation is the process of generating a prototype of any real-world situation using computer software that is connected to the subject under inquiry. Many scholars have demonstrated the validity of numerical simulation validation. The fluid-structure interaction (FSI) is a multi-physics interaction involving fluid dynamics and structural mechanics. When a fluid flow collides with a structure, the solid body is subjected to stresses and strains, which can result in deformations. Depending on the flow's pressure and velocity, as well as the material qualities of the real structure, these deformations might be incredibly large or very little, affecting the materials.

Finite element analysis was used to determine the fatigue lifespan of a lead-free solder junction under thermal cycling, and it was discovered that the solder joint's reliability is based on the void arrangement [22]. The simulation results are important in determining trends for engineers in industry and give a better knowledge of capillary flow via finite volume-based modelling [23]. Validation of the simulation findings against experimental data reveals that the computational fluid dynamics (CFD) simulation trends match the experimental trends by an average of 80% [24]. Furthermore, the experiment findings with CFD modelling matched with the simulation results. During molten solder filling in wave soldering, the impacts of PTH pin shape can be studied [25].

The Finite Volume Method (FVM) is a numerical method that, like the finite element method, translates partial differential equations that reflect the interaction of laws over differential volume into discrete algebraic equations over finite volume elements [26]. The initial stage in the solution process is the discretization of the geometric domain, which in FVM is discretized into non-overlapping components or volume. The solutions are computed into algebraic equations by integrating the partial differential equations over each discrete element. Solving the system of algebraic equations yields the values of the dependent variable for each of the components.

Because some components of the conservation equation are translated to face fluxes and examined at the finite volume faces, the finite volume method is conservative. Because of its natural conservation feature, the FVM is the preferred technique in CFD. On unstructured polygonal meshes, the FVM also has the benefit of being able to be generated in physical space. Finally, because the unknown variables are examined at the volume elements' centroids rather than their outer faces, the FVM makes it straightforward to apply a variety of non-invasive boundary conditions.

The Finite Volume Methodology is suitable for numerical modelling of a wide range of fluid flow, heat, and mass transfer applications because of all these features. Furthermore, improvements in the method have been closely tied to advances in CFD. Computational Fluid Dynamics (CFD) is a relatively new computer-aided engineering approach that models a wide range of flow phenomena, ranging from turbulent or laminar single-phase incompressible flows to compressible all-speed flows and multiphase flows. The FVM's early capabilities were limited to simple physics and geometry over structured grids, but it can currently handle a broad range of complex physics and applications.

2.7 Research scope

There is no research on the CFD approach for laser soldering process of passive devices such as capacitors on the PTH in the author's research study. However, there are several studies that may be used as references for this project. As a result, a method for modelling the laser soldering process comes in handy. Unfortunately, because to the lengthy transient period that must be considered, the soldering simulation takes a long time. As a result, the numerical simulation model will focus on the **laser beam height, different solder types** and **heat radiation effects** during the laser soldering reflow process. The Volume of Fluid (VOF) method is employed and ANSYS Fluent and ANSYS Mechanical is used for numerical simulation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter highlights the approach and steps taken to investigate how the distance of the laser beam during the laser soldering process affects pin-through-hole (PTH). The multiphase modelling, which mixes phases including gas, liquid, and solid, is conducted using the ANSYS Fluent software. A multiphase flow's phases may be considered of as multiple types of specified materials, each of which has a specific inertia response that interacts with the flow and potential field around it. In ANSYS Fluent, there are several multiphase models available. The volume of fluid (VOF) model may be applied in this research inquiry. This VOF model is used to simulate a laser soldering molten solder flow. This model's objective is to design for two or more immiscible fluids while considering how the fluids respond to one another. The fluids and the volume fraction of each fluid in each cell that is distributed across all domains share the momentum equation in the VOF model. This approach is also applicable to the filling of PTH and the wetting of solder at solid-liquid interfaces.

Before beginning the numerical simulation, it is crucial to be aware of the solder's material characteristics that is used in this research. The characteristics of solders are shown in Table 3.1. Most of the properties shown below is in regards with the temperature of the current soldering setup which is 642.35K.

Table 3.1 SAC305 solder properties [27]

Properties	*SAC305 (Sn96.5Ag3.0Cu0.5)*	
Density, ρ	7500	kg/m^3
Specific Heat Capacity, C_p	230	J kg K
Thermal Conductivity	58	Wm/K
Viscosity	0.0022	Kg/ms
Standard State Enthalpy	0.004	J/mol

Table 3.2 SAC405 solder properties [28]

Properties	*SAC405 (Sn95.5Ag4.0Cu0.5)*	
Density, ρ	7390	kg/m^3
Specific Heat Capacity, C_p	90	J kg K
Thermal Conductivity	58	Wm/K
Viscosity	0.0022	Kg/ms
Standard State Enthalpy	0.004	J/mol

Table 3.3 Sn63Pb37solder properties

Properties	*Sn63Pb37*	
Density, ρ	8400	kg/m^3
Specific Heat Capacity, C_p	82	J kg K
Thermal Conductivity	50.9	Wm/K
Viscosity	0.0013	Kg/ms
Standard State Enthalpy	0.004	J/mol

Table 3.4 Sn96.5Ag3.5 solder properties

Properties	*Sn96.5Ag3.5*	
Density, ρ	7370	kg/m^3
Specific Heat Capacity, C_p	210	J kg K
Thermal Conductivity	55	Wm/K
Viscosity	0.01	Kg/ms
Standard State Enthalpy	0.002	J/mol

However, because the velocity is dependent on the viscosity, there is no influence on the velocity and pressure if a constant viscosity was used in the simulation with constant temperature. The velocity will be constant if the viscosity is constant. As a result, the simulation is based on Figure 8, which depicts the viscosity of SAC alloys. From this figure, we can see that at 642.35K, the SAC305 have a viscosity of 0.00158 mPa.s.

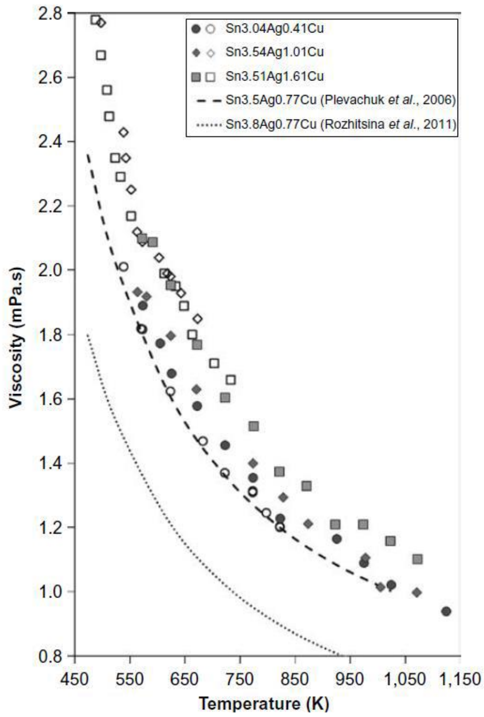

Figure 3 Dynamic Viscosity Varies With Temperature

Table 5 Assumption of Dynamic Viscosity for SAC Alloys

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

Using the VOF model in Ansys Fluent, the transient conductive heat transfer for the laser beam's circular shape is numerically explored. In the process of laser soldering, the numerical approach established the propagation of conduction with temperature. To model conductive heat transfer for the laser soldering process, the temperature is determined in boundary conditions. In the simulation, the bodies that create heat are set as the name of the boundary that is the beam source which will appear in various distances from the PCB.

3.2 Procedure of numerical simulation (Fluent)

The summarized procedure for the whole simulation setup is illustrated in Figure 3.2 below. The circular PCB pad which consists of the PTH is used for the laser soldering process to connect the capacitor leg. It is necessary to choose the model's scale in advance. The modelling for the ANSYS Fluent of FVM numerical simulation approach is shown in Figure 3.7. The first steps are 3-D modelling and meshing analysis. The FVM interaction model and the mathematical modelling validation are then carried out. After the setup for the analysis is complete, data extraction and optimizations will be made.

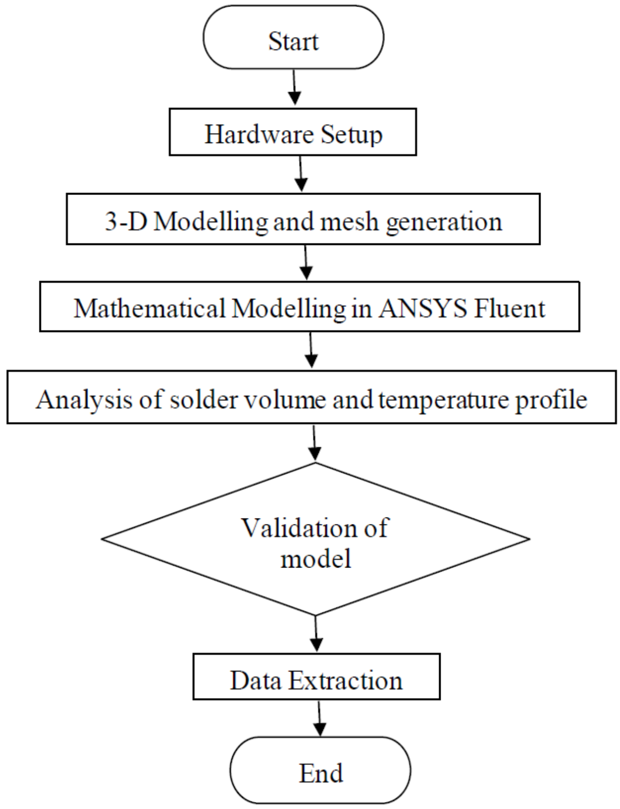

Figure 3.4 ANSYS Fluent simulation setup flowchart

3.2.1 Modelling of geometrical design

SOLIDWORKS has been used to construct the geometric design model. The model is made up of 5 parts: a PCB, a capacitor, a circular pad, a laser beam, and an air domain as in the Figure 3.4 below. The Ansys Fluent simulation only covers a small segment at a specific point where the reflow process is occurring during the soldering process that will be highlighted for this research. This limitation and computational time reduction was achieved by this simplification. Only one side of the lead and PCB have been closed from the complete capacitor variant. the model that is closed is shown in Figure 3.5. The file is then loaded into Design Modeler ANSYS Workbench as a Parasolid (.x t) file.

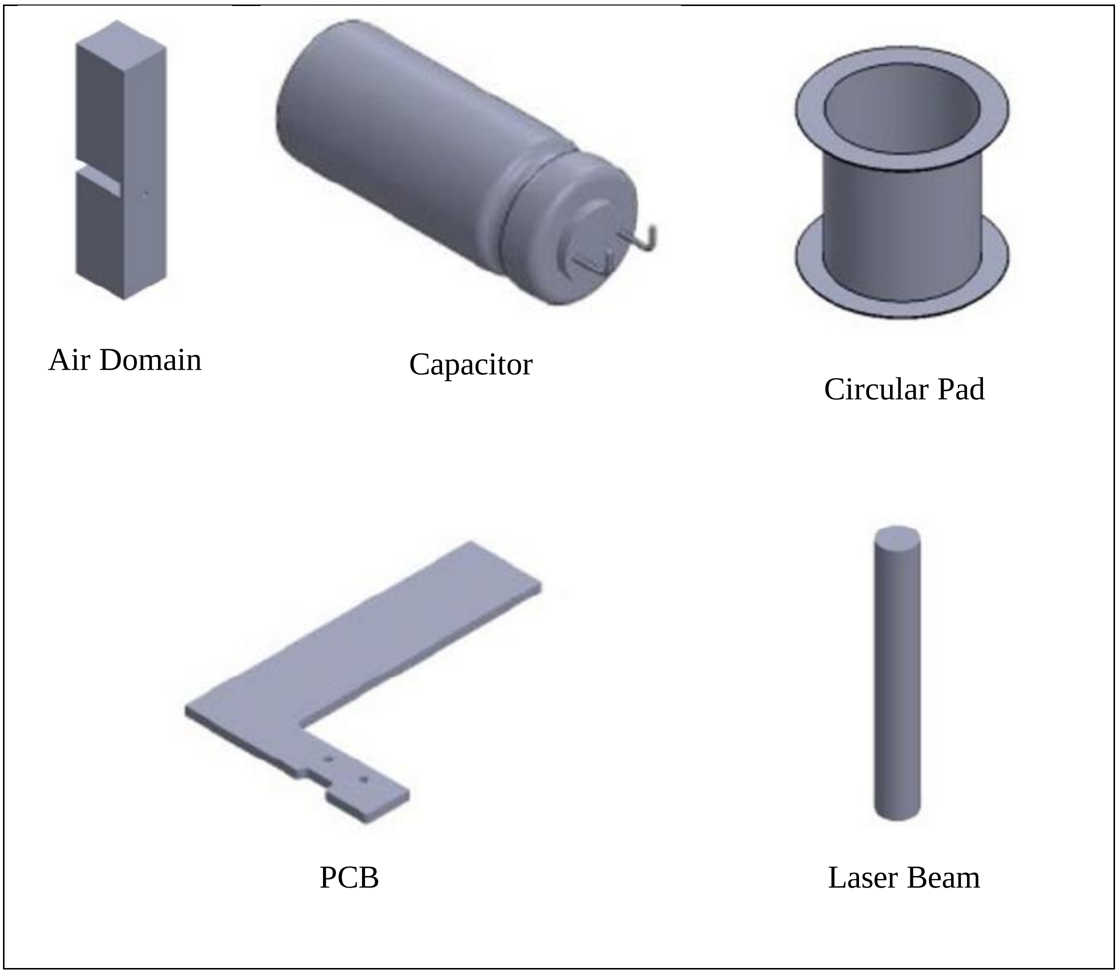

Figure 3.5 Geometrical design of 5 components

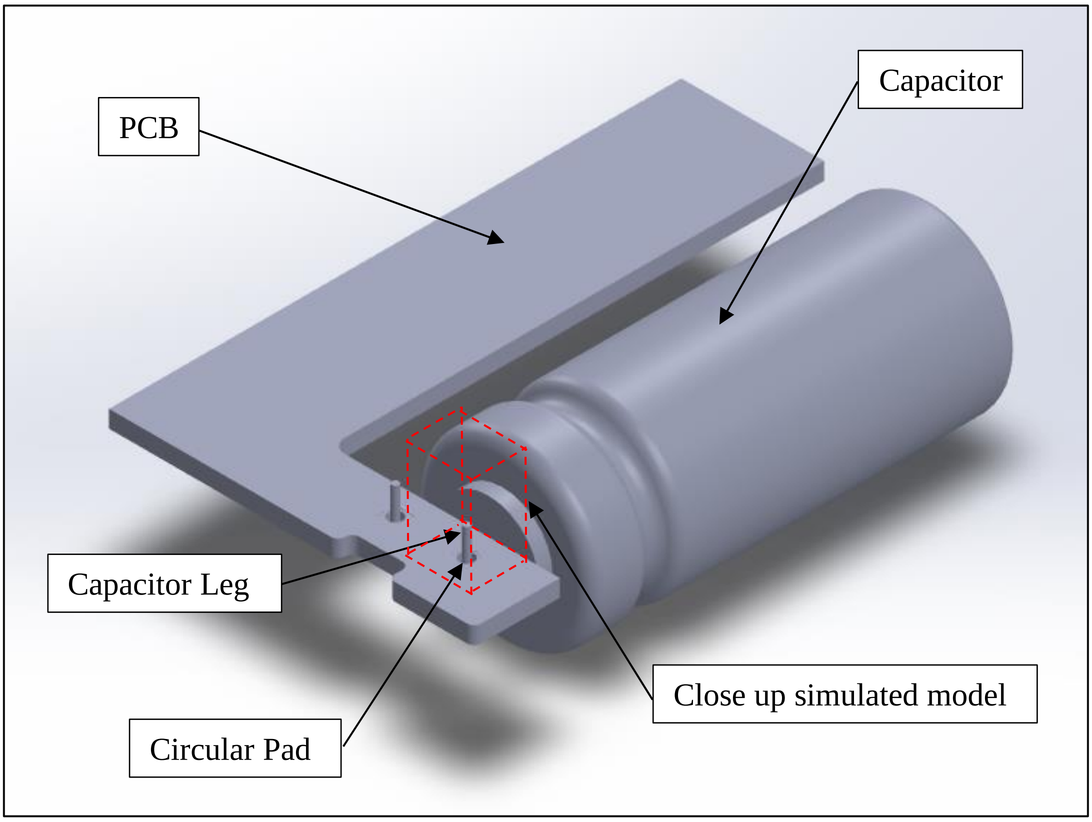

Figure 3.6 Full assembly of simulated model

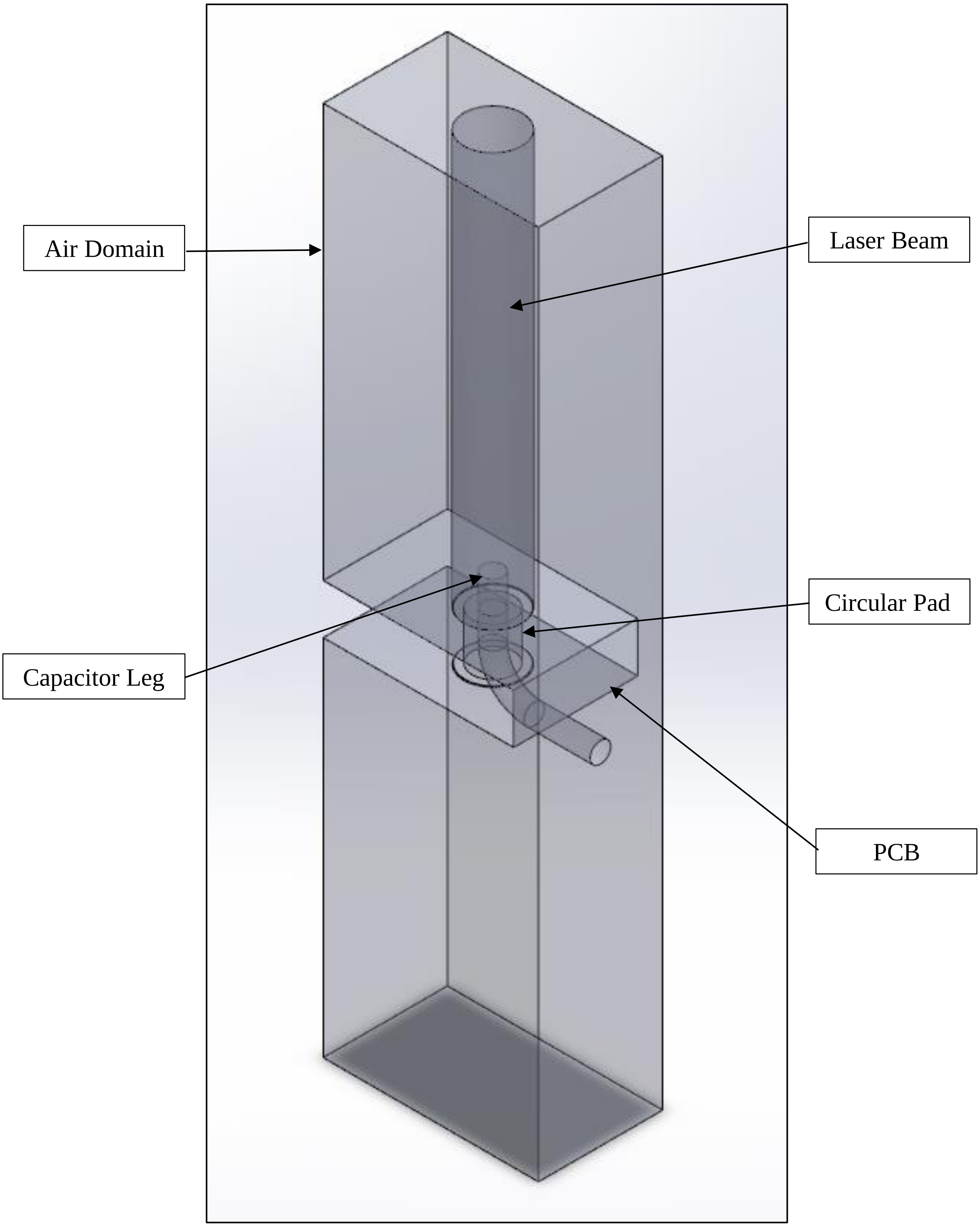

Figure 3.7 Close up simulated model