THE EFFECT OF PRE-TINNING PROCESS WITH RESPECT TO GOLD EMBRITTLEMENT ISSUE FOR GOLD PLATED PINS

by

Mohammad Noor Bin Md Yassin

Dissertation submitted in partial fulfilment of

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(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

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BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

____

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TRONOH, PERAK

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHAMMAD NOOR BIN MD YASSIN

ABSTRACT

This project is a study of interaction between tin-lead solder with gold that associated with intermetallic compound IMC. Alloy $Sn_{63}Pb_{37}$ solder is used as a control for the experiment. Effect of IMC formation to joint reliability is studied by varying the gold thickness through pre-tinning process. A rough guide of implementation to prevent gold embrittlement to $Sn_{63}Pb_{37}$ solder is given at the end of the research. Physical analysis equipment X-ray fluorescence (XRF) and high power optical scope for IMC microstructure investigation are utilized. It is found out in this study that the time of pre-tinning process where the pins are submerge into solder bath contribute to the magnitude of IMC formation. Thus greater IMC formation will decrease the joint reliability for the long term. It is also important to periodically inspect the solder bath purity since through daily pre-tinning process the solder bath will be contaminated with Au that was dissolved from the plating pin. Au contamination will deteriorate the ability of the solder bath to do pre-tinning process since if it's saturated Au, instead of removing the Au layer it will contaminate more the solder joint with Au.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Gold possesses a unique combination of properties of particular value in the construction and operation of electrical and electronic equipment. These properties include high resistance to tarnish and corrosion, low electrical resistivity and contact resistance, ease of thermal compression and ultrasonic bonding and, particularly in the case of certain gold-based alloys, high resistance to mechanical wear.

Most efficient use is made of these properties by employing gold, usually in the electroplated form, either as an intermediate layer in certain microelectronic devices, or as a finish on such components as connectors, terminations, and printed circuits as per Figure 1.1. Components coated in this way are frequently required to be assembled by soft soldering, but although gold is very easily wetted by molten tin-lead alloys using non-corrosive rosin fluxes the joints so formed are often to be mechanically weak.

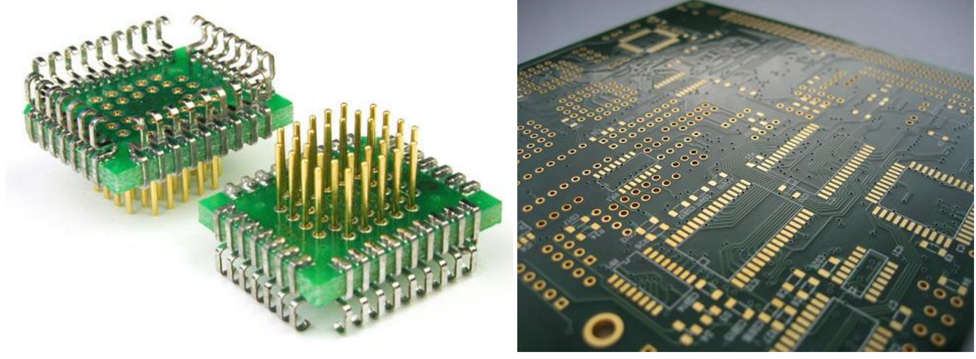


Figure 1.1: Gold Plated Connectors and PCB

Published information on the reliability of soldered joints on gold is confusing, apparently contradictory results having been reported by different authors, and the

purpose for this project is therefore to review the factors influencing joint properties and the conditions under which reliable joints may be made.

Gold dissolves extremely rapid in molten tin-lead solders, values quoted in the literature for the rate of solution in 60 per cent tin - 40 per cent lead at 250ºC, for example, varying from 4 µm/s for pure gold wire to 10 µm/s for an electroplated gold of unspecified composition. The solid solubility of gold in both tin and lead is, however, very small, and the addition of even than 0.5% gold to tin-lead solders results in the appearance of the intermetallic compound $AuSn_4$ in the solid alloy. This compound is hard and brittle and has a strong tendency to grow from the melt in the form of coarse plated or needles. Consequently, when present in sufficient quantities the compound embrittles the solder, the ductility and impact strength of a tin 40% lead-gold alloy, for example, falling rapidly when the gold content exceeds 4 to 5% and reaching a very low level with 8 to 10% gold.

Clearly, if rapid solution of the gold during soldering causes the gold content of the solder to raise above about 5% the joint itself will be very brittle. Moreover, a continuous layer of $AuSn_4$ forms during soldering at the solder-gold interface and when this increase in thickness beyond a certain very low value the bond between the compound and the gold substrate is considerably weakened, thus further reducing joint strength.

It will be apparent from the foregoing that the properties of soldered joints on gold-plated surfaces are likely to be affected by a number of factors including the time and temperature of soldering and the characteristics of the gold plate.

1.2 Problem Statement

Soldering gold-plated parts can be problematic as gold is soluble in solder. Solder which contains more than 4-5% gold can become brittle. The joint surface is dull-looking. Gold reacts with both tin and lead in their liquid state, forming brittle intermetallics. When eutactic 63% tin - 37% lead solder is used, no lead-gold compounds are formed, because gold preferentially reacts with tin, forming the $AuSn_4$ compound. Particles of $AuSn_4$ disperse in the solder matrix as per Figure 1.2, forming preferential cleavage planes, significantly lowering the mechanical strength and therefore reliability of the resulting solder joints. If the gold layer does not completely dissolve into the solder, then slow intermetallic reactions can proceed in the solid state as the tin and gold atoms cross-migrate. Intermetallics have poor electrical conductivity and low strength. The ongoing intermetallic reactions also cause Kirkendall voiding, leading to mechanical failure of the joint, similar to the degradation of gold-aluminium bonds know as purple plague. A 2-3 µm layer of gold dissolves completely within one second during typical wave soldering conditions. Layers of gold thinner than 0.5 µm also dissolve completely onto the solder, exposing the underlying metal usually nickel to the solder. Impurities in the nickel layer can prevent the solder from bonding to it. Electroless nickel plating contains phosphorous. Nickel with more than 8% phosphorus is not solderable. Electrodeposited nickel may contain nickel bydroxide. An acid bath is required to remove the passivation layer before applying the gold layer, improper cleaning leads to a nickle surface difficult to solder. A stronger flux can help, as it aids dissolving the oxide deposits. Carbon is another nickel contaminant that hinders solderability.

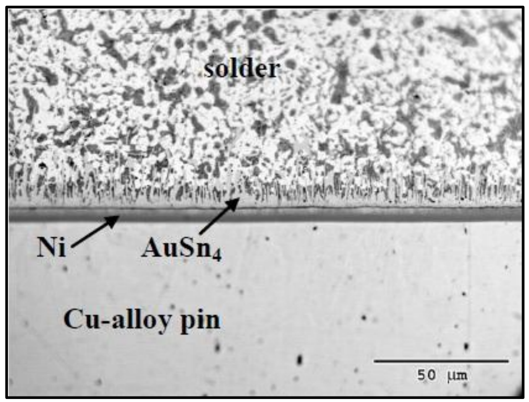


Figure 1.2: Gold Embrittlement

1.3 Objective and Scope of Study

The objectives of the project being run are as follows:

i. To study the effect of Au thickness on tin-lead solder joint characteristic in terms of IMC formation.

1.4 Scope of Study

The project of determining the effect of pre-tinning process for gold plated component's pin will be focusing on the microstructure area. Pre-tinning in the context described here refers to the process of applying a fresh coat of solder to component pins before mounting them on a circuit board. This is done to enhance solderability by removing/replacing oxidized material on the pins. All the evaluation will be made on the solder joints cross section area between solder and the pin. Five components will be prepared for five different soaking times (pre-tin). Each and every soldered part will be cut in cross-sectional for microstructure evaluation and mechanical testing.

To examine the microstructure characteristic of the solder joints at different condition (resulting different gold coated thickness), Optical Microscope (OM) will be used to observe and evaluate the microstructure. X-ray fluorescence (XRF) will also be used for elemental identification.

CHAPTER 2

LITERATURE REVIEW

2.1.0 Effect of tin-lead on solder system

2.1.1 Effect of Lead (PB)

By appearance in Figure 2.1, lead is a bluish-gray metal with a bright metallic luster when the surface is freshly exposed. In ordinary air, the surface deteriorates rapidly, taking on the dull gray appearance. This tarnish is very tenacious and protects the metallic surface from further environmental attack, which is why lead were preserved for thousand so years in the ground or other relative corrosive environment. Lead is very soft metal with great ductility and can be easily formed. It can form eutectic alloy with tin with melting point at 183°C, low enough for most industries application.

As one of the primary components of eutectic solders, lead imparts many technical advantages to tin-lead solders (Mulugeta and Guna, 1998), including the following:

- It reduces the surface tension of pure tin and lower surface tension of solder which facilitates wetting (Vianco, 1993)
- As an impurity in tin at levels as low as 0.1% lead prevents the transformation of white or beta tin to gray or alpha tin upon cooling. The reaction results in a 26% increase in volume, and the transformation causes loss of structural integrity to the tin. (Vianco, 1993)
- Pb serves as a solvent metal to enable other joint constituents, such as Sn and Cu, to rapidly form intermetallic bonds.

Figure 2.1: Lead Ore

These factors, combined with lead being a readily available and low cost metal, make it an ideal alloying element with tin. However, despite the advantages, it's also well substantiated that the common thermal fatigue failure for solder interconnects is linked with the Pb-rich phase. Because of limited solubility and precipitation, Sn solute atoms cannot affectively strengthen the Pb-rich phase. At room temperature, the limited solubility of Pb in Sn matrix renders it incapable of improving the plastic deformation slip. Under temperature cycling (thermomechanical fatigue) condition, this Pb-rich phase tends to coarsen and eventually, lead to a solder crack (Hwang, 2001).

2.1.2 Effect of Tin (Sn)

From Figure 2.2, it can be seen that tin is silvery, malleable poor metal is not easily oxidized in air and is used to coat other metals to prevent corrosion. Because of its ability to wet and spread on a wide range of substrates using mild fluxes, tin has become the principal component of most solder alloys used for electronic applications. Tin exists in two different forms with two different crystal structures. White or β tin has a body centered tetragonal crystal structure and is stable at room temperature. Gray tin or α tin, which has a diamond cubic crystal structure, is thermodynamically stable below 13°C. The transformation of β to α tine, also called "tin pest", takes place when the temperature falls below 13°C, and results in a large increase in volume that can induce cracking in the tin structure.

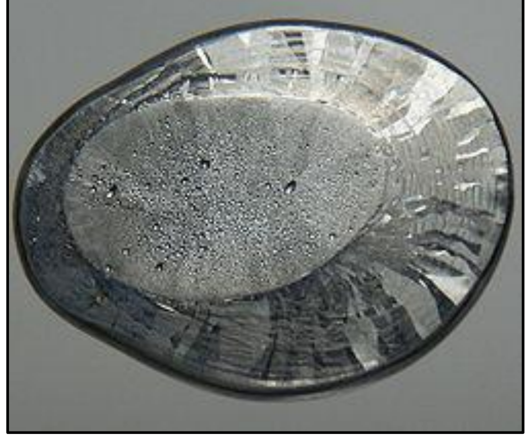


Figure 2.2: Tin

2.2.0 Solder Characteristic

Soldering is well-known metallurgical joining a filler metal (the solder) with a melting point below 425°C. In order to form a proper metallurgical bond between two metals, wetting must takes place. This means that a specific interaction must take place between liquid solder and the solid surface of the parts to be soldered as shown in Figure 2.3. Solders can be classified as soft (melting point between 190 to 425°C). The performance characteristics that are important include the melting temperature, the microstructure, IMC (intermetalliic) formation and its inherent mechanical strength e.g. shear strength, fatigue behavior and creep behavior.

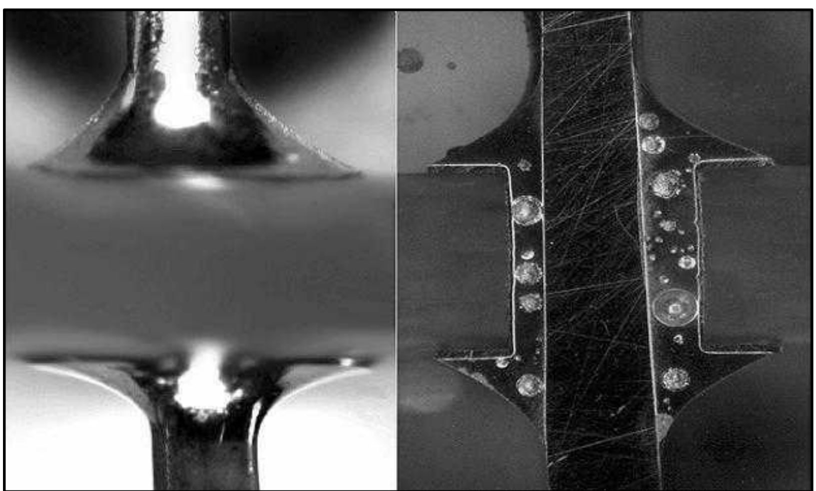


Figure 2.3: Solder Characteristic

2.3.0 Melting Temperature

One of the fundamental performance characteristic of solder for industrial applications is melting temperature. For these applications, the melting temperature of the solder determines the maximum allowable temperature a product can be exposed to in service and the maximum processing temperature that devices and substrates can withstand during soldering. And, it is always desirable to have one same solidus and liquidus point that is called eutectic point. This eutectic point is desired in order to minimize the plastic region that is sensitive to mechanical movement or vibration that can lead to rejectable solder joint.

2.4.0 Microstructure

The useful properties of materials are strongly dependent on their microstructure, which describes the grain structure and the combination of phases present in a material, as well as its defects, morphology and distribution. Generally, for a material of a given chemical composition, the microstructure is not constant and varies greatly, depending on processing and service conditions as shown in Figure 2.4. In soldering assembly, the time-and-temperature-dependent soldering profile affect the microstructure of the solder joints, including the intermetallic layer thickness and the number of intermetallic phases present in the solder joint. The microstructure variation can drastically affect the fatigue life of the solder joint. Because operating temperature is a high homologous temperature for the solder, the initial eutectic microstructure evolves over time. Homologous temperature is the ration of operating temperature to melting temperatures, e.g. 0.5 (=90°C/183°C). The lesser homologous temperature the better (Mulugeta and Guna, 1998)

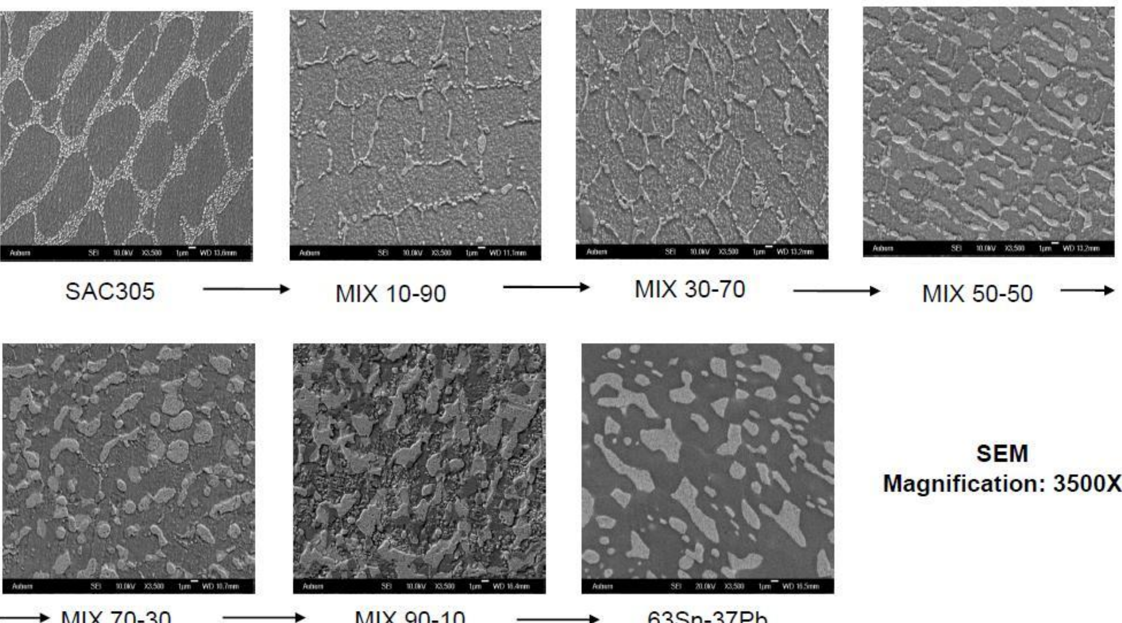


Figure 2.4: Microstructure Variations upon Solder Composition

2.5.0 Intermetallic Compound (IMC)

Intermetallic compound (IMC) is defined as a distinguishable homogeneous phase having a relatively narrow range of compositions with simple stoichiometric proportion (Manko, 1979). The intermetallic compounds that are formed at the solder substrate interface as per Figure 2.5 continue to grow over time and increases with rising temperatures. This growth is a result of a solid-state reaction driven by an energy differential. The solder substrate reaction is exothermic, which means that the intermetallic compounds that are formed have lower energy content than the reacting metal. Example IMC's are $AuSn_4$, Cu_6Sn_5, Cu_3Sn, Ni_3Sn_4 and etc.

Each solder joint forms an intermetallic layer with each of the surfaces being joined together with the malleable tin-lead solder in between. The malleable nature of the tin-lead solder absorbs some thermal shock and mechanical stress, like a rubber bumper. This is ideal for the durable solder joint. But solder joints age. The intermatallic compounds grow through time and with temperature. They often work together, but they can work independently. As time goes by, the intermetallic compound grows. Therefore, the tin-lead solder itself becomes a part of the intermetallic layer. Eventually, all thats's left is intermetallic layer, which is both brittle and non-solderable. It is now susceptible to thermal and mechanical stress and can easily crack (Frear, 1974).

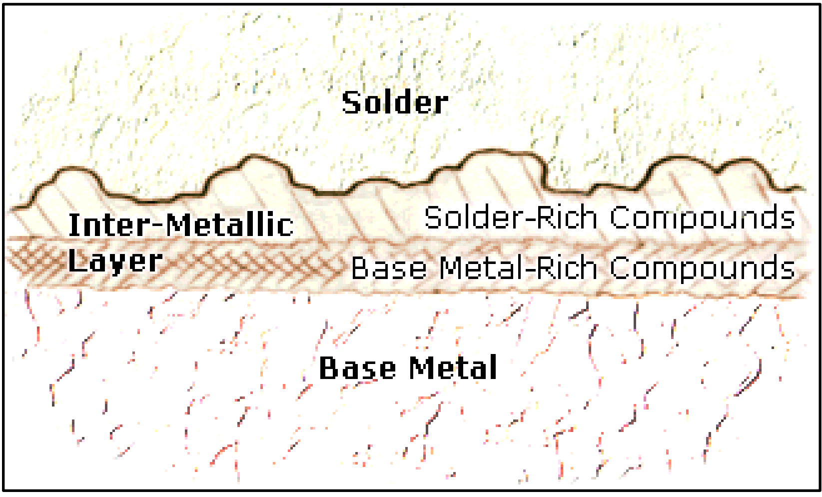


Figure 2.5: InterMetallic Layer

2.6.0 Mechanical Properties

The mechanical properties of solder joints represent some of the most critical factors in soldering. The application of mechanical forces to a solid body causes the body to deform and may be even to fracture. Of special importance are the stresses and strains that are used to characterize the behavior of material under different types of mechanical loading.

The mechanical property of a solder joint defines the response of solder joints to imposed strains and stresses. The properties of major concern for solder application are shear strength (UTS), ductility, creep and fatigue resistance. From Table 3.1, we will be concerning on 63Sn-37Pb eutectic solder alloy.

Imposition of stresses and strains can be divided into three broad categories: time independent monotonic deformation, time- dependent monotonic deformation and cyclic deformation (Mulugeta and Guna. 1998)

Table 3.1: Mechanical Properties

Table I
Melting temperatures and mechanical properties of solder alloys

Solder	Melting temperature (°C)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Hardness	Creep exponent (*n*)	Structure
95Pb–5Sn	270	20	11.8	28.5	9.5 HV	5.9[d]	Solid solution
63Sn–37Pb	183	32	18.1	39.7	12.4 HV	8[e]	Eutectic
Sn–3.5Ag	221	51	18.9	37.5	11.0 HV	6.05[f]	Eutectic
Sn–3Ag–0.5Cu	217	54	25.3	41.8	13.3 HV		Near-eutectic
Sn–3Ag–0.5Cu–1Bi	213	52	50.6	61.5	18.3 HV		Near-eutectic
Sn–3Ag–0.5Cu–3Bi	207	53	48.1	81.3	28.6 HV		Near-eutectic
Sn	232	50[a]	–	–	3.9 HB[b]		bct
Pb	327	16[a]	6–8[b]	16–19[b]	4–6 HB[b]		fcc
Bi	271.4	32[b]	–	–	7 HB[b]		rhom
Ag_3Sn	480	80[c]	–	–	–		ortho
Cu_6Sn_5	415	125[c]	–	–	–		hex

[a] Brandes, 1983.
[b] Cubberly *et al.*, 1979.
[c] Subramanian *et al.*, 1999.
[d] Vaynman *et al.*, 1998.
[e] Frost and Ashby, 1982.
[f] Hua and Glazer, 1997.

2.6.1 Time-Independent Monotonic Deformation

The deformations in this category are tensile and shears. When solid materials are subjected to small stresses they usually respond in an elastic fashion, i.e. the strain produced by the stress is reversible and the magnitude of the strain is proportional to the magnitude of the stress. This reversible deformation, where stress and strain is held constant, is called elastic deformation. With increased stress, the material starts to undergo plastic deformation. With increased stress, the material starts to undergo plastic deformation. Once plastic deformation takes place, the material is deformed permanently and will recover its original shape when the stress is removed.

2.6.2 Time Dependent Monotonic Deformation

This deformation is commonly referred to as "creep", a measure of the time required for a material to fail when it is under a constant load at a constant temperature. Creep involves deformation mechanisms, such as grain boundary sliding, vacancy diffusion, etc, which require a thermal driven diffusion process. Therefore, creep deformation becomes critical only when the temperature exceeds half the absolute melting temperature of the material. For most soldering alloys, operating temperature is well above half their absolute melting temperature. Consequently, for soldering, creep is considered the most important deformation mechanism.

2.7.0 Cyclic Deformation or Fatigue

Fatigue, a measure of resistance to cyclic loading, can be isothermal or "thermal". Isothermal fatigue is where imposed cyclic displacement occurs at a constant temperature. Thermal fatigue, on the other hand, is a condition where cyclic displacement occurs due to a change in temperature, because of the joining of two materials with dissimilar thermal coefficients of expansion.

Fatigue in solder joints leads to crack initiation and crack propagation; the fatigue life of a solder joint is determined by the number of stress cycles it endures before a crack is initiated and propagates. Even when the cyclic stress is well below the yield stress of the material, fatigue failure can occur due to defects and irregularities in the microstructure that may serve as crack initiation sites.

Failure in solder alloys involves both fatigue and creep. For eutectic tin-lead solder, the failure mode in creep and in fatigue appears to be the same (Mulugeta and Guna, 1998). There is a scarcity of fatigue-resistance data for most of the Pb-free alloys.

The point was well made in the early 1970s by David Boswell that surface mount assemblies have many issues in common with civil engineering. For example, although there are major differences in scale and dimensions, the stress analysis of a chip component mounted at opposite ends has parallels with the stresses imposed by the environment on a bridge, and there are benefits from thinking in terms of the ability of both structures to withstand those stresses.

In the construction shown in Figure 2.6, the thermal expansions of the component and the printed board can be assumed to be different, and the thermal mismatch Δu is given by:

$$\Delta u = \Delta e \times L \times \Delta T \quad \text{.......................................(1.0)}$$

where,

Δe = the difference in CTE between the materials

L = the longest dimension of the component (often the diagonal)

ΔT = the temperature change

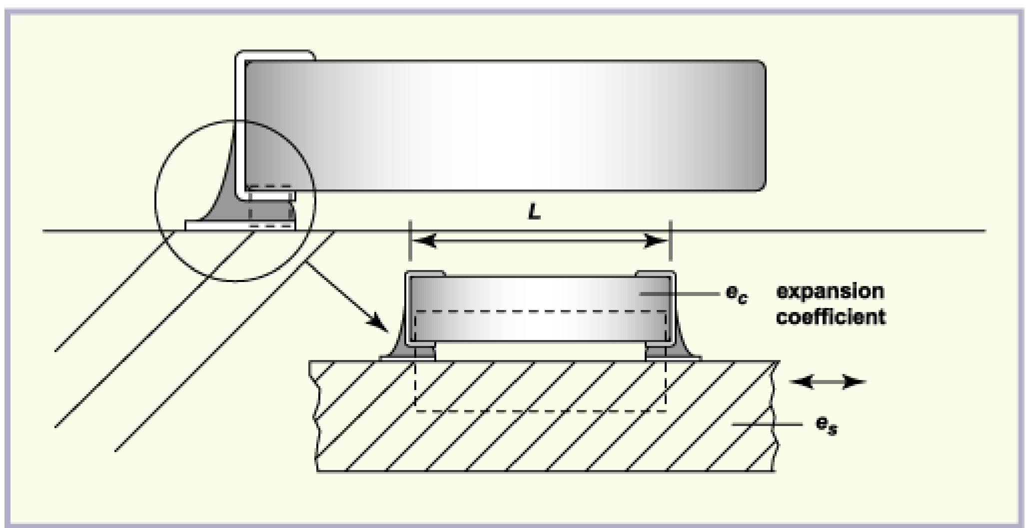


Figure 2.6: Thermal mismatch in solder joints

In most mechanical structures, such thermal mismatch would be accommodated by elastic deformation, resulting sometimes in a high stress in the structure. With soldered assemblies, however, the situation is different, as the strength of the solder is low compared with that of the usual engineering materials. With leadless components, the materials of component and substrate are comparatively so rigid that a large part of the mismatch has to be accommodated by plastic deformation in the solder joints. In this case, repeated movement due to temperature changes produces a cyclic stress (Figure 2.7), and fatigue failure may eventually follow.

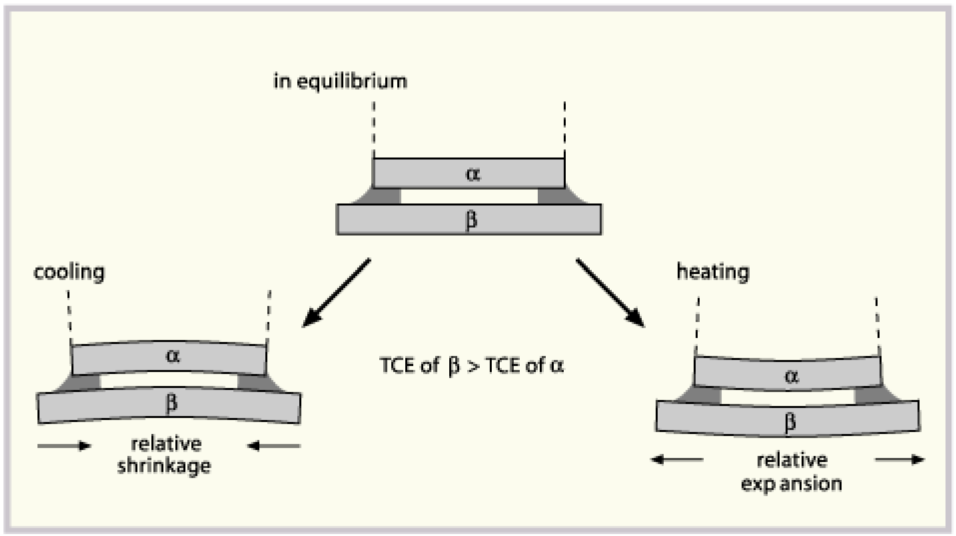


Figure 2.7: CTE mismatch producing cyclic stress

The shear strain experienced depends on the CTE mismatch between the materials and the length: height ratio of the joint. As CTE mismatch increases, so do the strain, and thus the thermal cycling life decreases. If rigid solder joints are to survive cycling during the specified life, the component size may have to be limited or the stand-off height increased to withstand large temperature fluctuations and CTE mismatch. The Column Grid Array is an example of a package where the stand-off height is deliberately made higher than a normal BGA (by using columns of high-melting solder) in order to accommodate CTE differences between its ceramic body and a PCB substrate.

2.8.0 Why Gold is used?

The high electrical conductivity of gold, the low contact resistance and the good solderability, combined with constancy of these properties due to the chemical inertness of the metal, makes gold the ideal choice for many items of electrical and electronics hardware. Contacts, terminals, connectors, chaises, printed circuit board are routinely plated with gold or gold alloy. The good electrical properties combined with the excellent ductility of gold make it ideal for flexing or vibrating current carrying components. The resistance of gold to the formation of oxides, sulphides and other corrosion products suits it to application on safety devices, alarm and high reliability switches. Gold is used on waveguides and other RF conductors, grid wires and glass seal. Transistors make used of both pure and doped gold for eutectic bonding, resistance welding, formation of beam leads and making ohmic contacts to semiconductors. In spite of its major cost and consequent higher component cost, gold is still required because of its many desirable properties. Metal component piece parts are plated to protect the metal during the processing, testing and life of the device. Gold facilitates chip bonding (die attachment) and wire bonding due to its softness. It also provides tarnish, oxidation and corrosion resistance, good solderability, weldability and resistance to chemical etchants and low electrical contact resistance.

2.8.1 Thick Au versus Thin Au

Thick gold plated to 100micro inches (2.5μm) or more while thin gold plated generally range from 20-60 micro inches (0.5-1.5μm) or less (Frank, 1974). The justification for this classification rests historically in the attitude of the design engineer to porosity in gold plate. It takes 100-200 micro inches (2.5 to 5μm) to have substantially pore-free gold. Pore-free gold is important in controlling contact reliability. Therefore, probably the most important application for thick deposits is on the edge contacts of printed circuit board and on the mating surfaces of their connector.

Thin Gold deposits are specified when a good level of corrosion resistance is necessary, but where a pore-free deposit is not required. The bulks of connectors having gold plated contacts which serve general purpose application are plated with minimum 30-50 micro inches (0.75-1.25μm) of gold, the underlying being 30-150 micro inches (0.75-3.75μm) of copper or nickel. Nickel is more popular and normally used as a diffusion barrier between copper/gold with 2μm as safe specification (Don, 1998).

In more recent findings, as soldering to gold deposits of 30-100 micro inches (0.75-2.5μm) resulted in some commonly associated problems of "embrittlement", gold thickness becomes ultimately important and critical. For tight hermetic requirement product however example in optoelectronic industry, gold on fiber metallization cannot be too thin (<1μm) because of porosity and short shelf life. The Au dissolution and $AuSn_4$ IMC formation will embrittle the joint and result in losing hermeticity (Jin, 2003). With the emergence of plating process that can produce denser, less porous deposits, a thinner gold deposits of 5015 micro inches (0.125-0.375μm) is becomming popular now for most application (Ronald, 1998).

2.8.2 Gold Embrittlement Issue

It is well known that soldered connection made to gold plated surfaces can lead to unreliable or mechanically weak bond, due to the rapid formation of intermetallic compound during soldering (Cotts(1), 1999). A very careful control of the gold thickness and the soldering conditions is needed in order to have a satisfactory low failure incidence. It is generally reported that there is apparently lower mechanical strength of soldered connections on gold plating when gold content is 3.5-5.0% (Frank, 1974). Gold has the highest dissolution rate in solder compared to metals like Ag, Cu Pd and Ni and this has led to high formation of intermetallic (IMC) formation.

CHAPTER 3

METHODOLOGY

3.1 Process Flow Chart

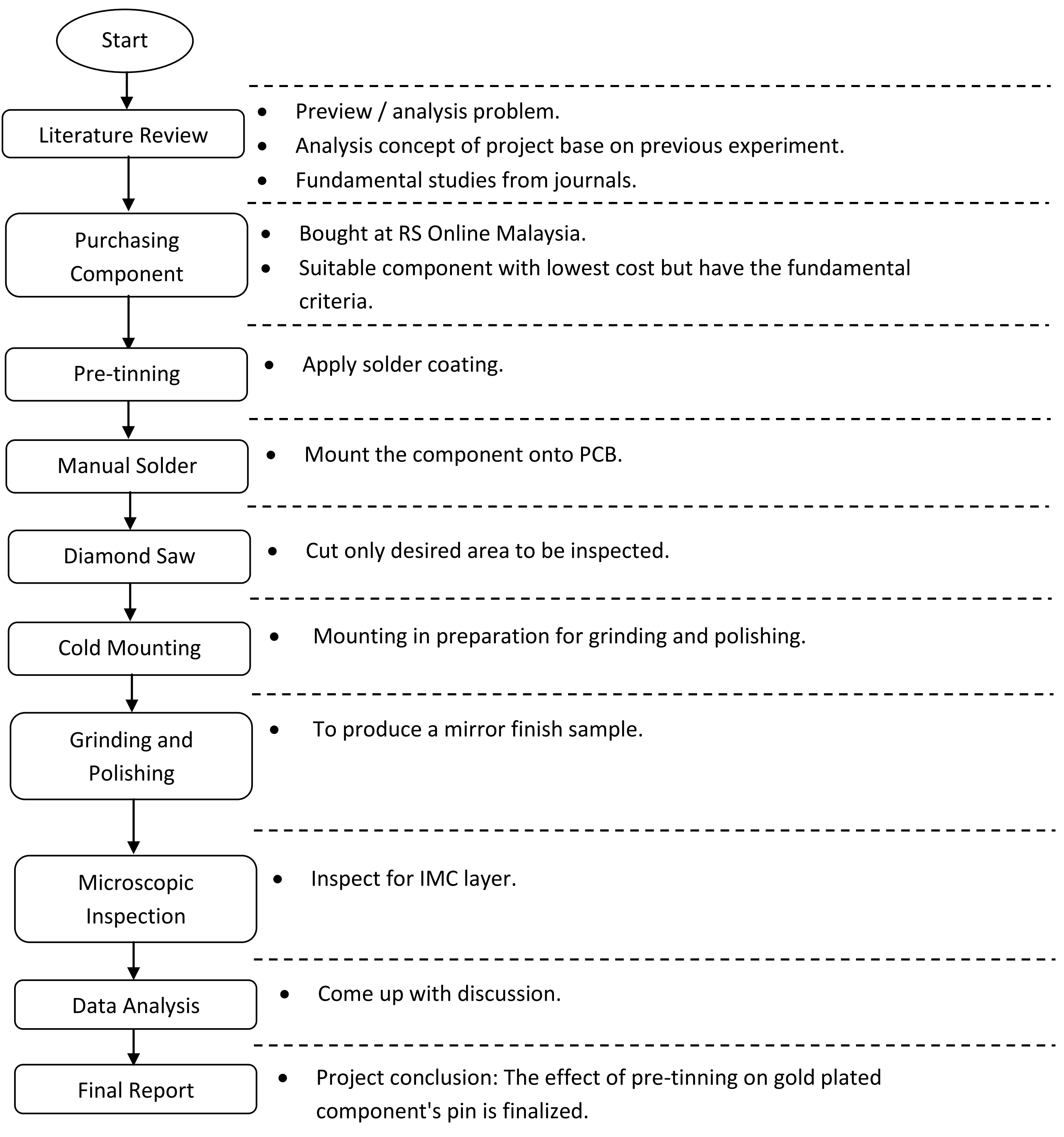


Figure 3.1: Process Flow Chart

3.2.0 Sample Preparation

3.2.1 Jumper Switch™

Jumper Switch™ (Figure 3.2) is switchable jumper on 0.1" pitch that securely switches ON and OFF PCB track signals with a positive contact action. It has a reliable switching of the gold over plated phosphor bronze contacts assured with 4 point wiping contact design. The contacts never rub over any plastic part and every single part is tested before dispatch. The positive detent action ensures good shock resistance. Jumper Switch™ has been designed for use on hand or flow soldered and washable PCBs. The tight pin fit prevents any wicking. This component was purchased from RS Malaysia at malaysia.rs-online.com/ through online order. Since it is only cost cheap, very suitable to purchase in large amount for various experiment as long as the desired specification is present.

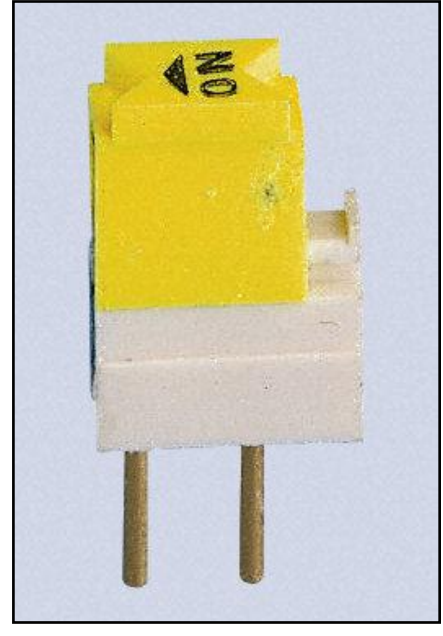


Figure 3.2: Jumper Switch

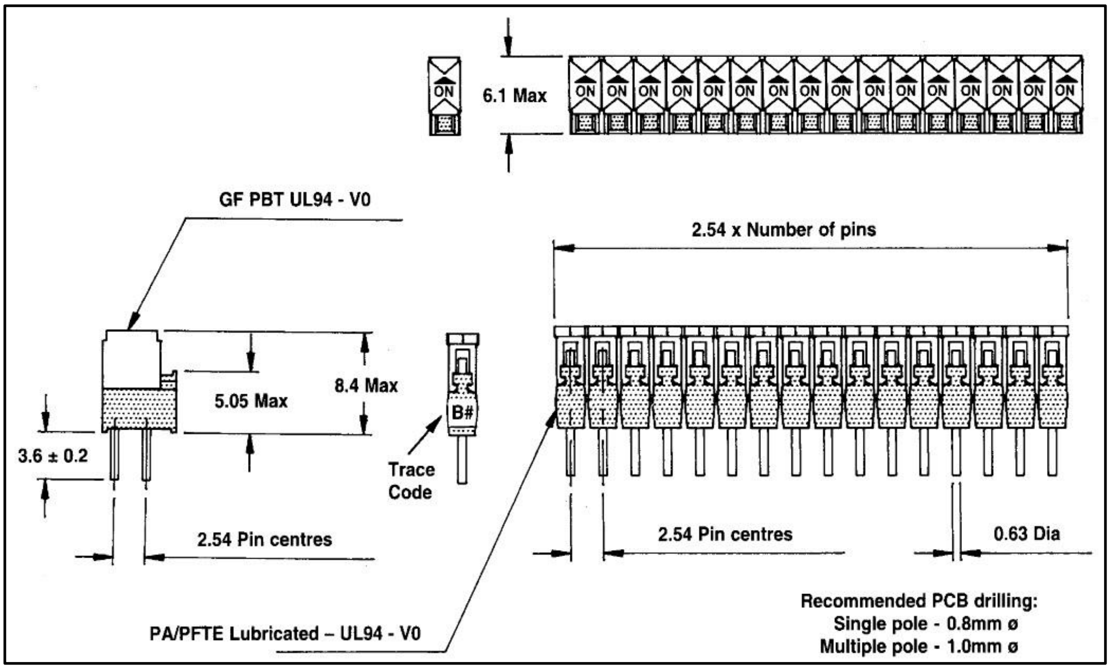


Figure 3.3: Mechanical Details

Table 3.1: Jumper Switch™ Principal Electrical and Performance Data at 20°C, 70% RH

Criteria	Description
Contact ratings - Non Switching	100Vac, 5A
Switching	1µV to 100V, 1µA to 1A, 10VA Default in "ON" position
Initial Contact Resistance	(at 10VA, 10mA max) Typical: 10mΩ Max: 15mΩ
Insulation resistance	(at 500Vdc min) 1,000MΩ
Life	Minimum 1,000 operations
Dielectric Strength	1 minute: 500Vrms 50Hz
Capacitance between open contacts	<5pf. at 1 KHz
Temperature	Operating range for continuous electrical use and manual operation is restricted to -55°C to +85°C for standard products.
Operating Force	Per pole Max 5N
Humidity	Damp Heat Steady State : 56 days

3.2.2 Printed Circuit Board (PCB)

A printed circuit board, or PCB (Figure 3.4), is used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces etched from copper sheets laminated onto a non-conductive substrate. It is also referred to as printed wiring board (PWB) or etched wiring board. A PCB populated with electronic components is a printed circuit assembly (PCA), also known as a printed circuit board assembly (PCBA).

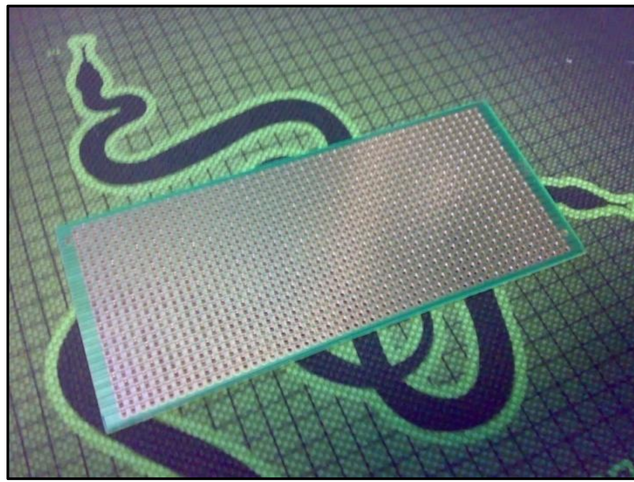


Figure 3.4: Bare Board

Since this board only have one sided terminal pads and not both side pads the solder joints created will be much smaller as Figure 13.b below but still sufficient for analysis.

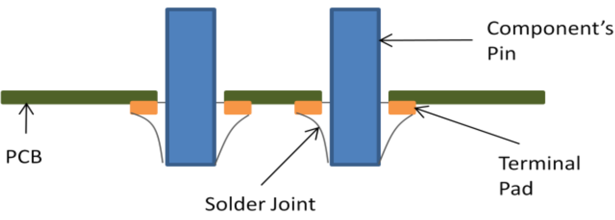


Figure 3.5a: One side pad

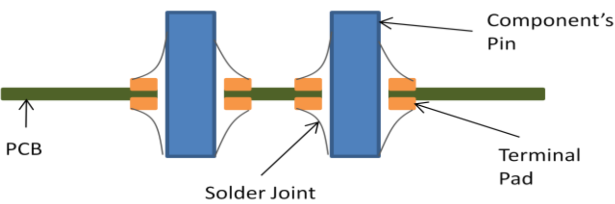


Figure 3.5b: Two side pad

3.3.0 Pre-tinning Procedure

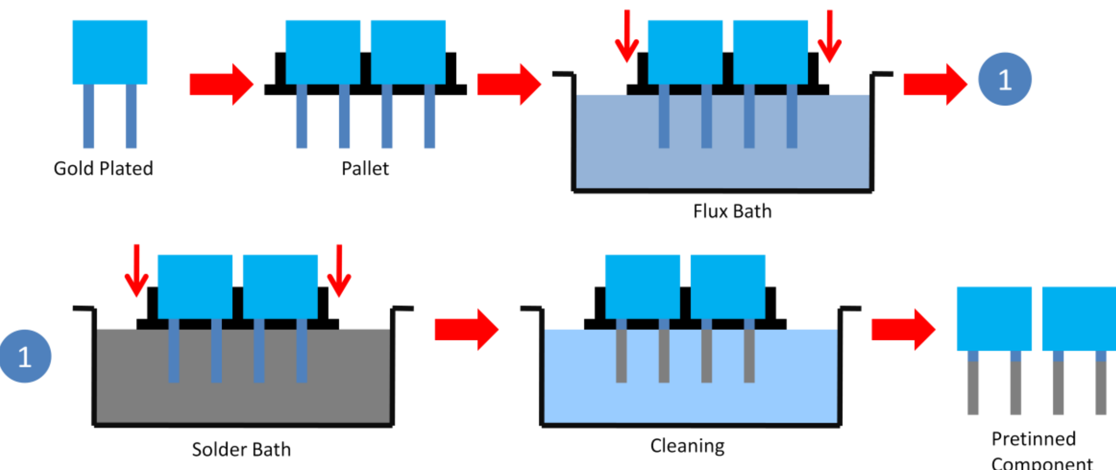


Figure 3.6: Pre-tinning Procedure

For the pre-tinning process, four components will be used and undergone each procedure in Figure 3.6. The experiment varies between the dipping time from one second, three seconds, five seconds and ten seconds. 1 component will not undergo the pre-tinning process to stimulate the effect of not having it. For this process, a digital timer is needed to monitor the dipping time and record it.

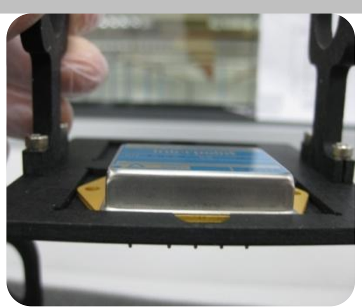
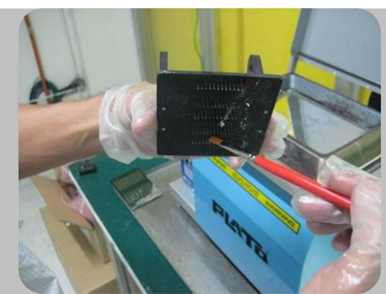
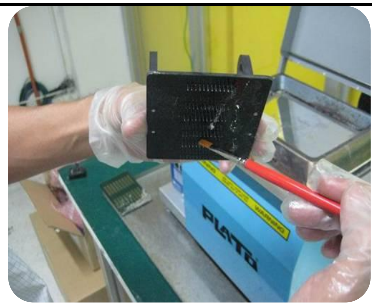
Pictures	Method
	• A specific pallet will be required for each component that has different design. • The purpose of this pallet is to prevent the molten solder from damaging the component's body.
	• Insert the component pins through the holes on the pallet. • The component must be make sure perfectly fits into the holes without any tilting so that every pins will be pre-tin evenly.
	• Apply flux to the component's pin. • This will be done using a brush by brushing through all the pins.
	• Dip the pallet with the component onto the solder bath. • While dipping, it is important to do it carefully so that the component won't be tilted.
	• Leave the pallet onto the solder bath for 5 sec for gold stripping process. • This is to remove the gold layer.

Figure 3.7a: Pre-tinning Details



- Apply flux again for the second time.

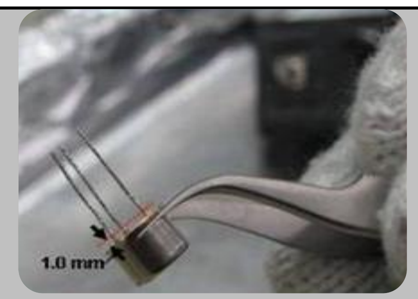
- Dip the pallet with the component onto the solder bath.
- While dipping, it is important to do it carefully so that the component won't be tilted.

- Leave the pallet onto the solder bath for 5 sec for pre-tinning process.
- This is to prepare the solder layer to the component's pins.

- Take out the component form the pallet using appropriate apparatus.
- Make sure to give time to the solder cool down and solidified fully.

- Soak the component into the IPA for flux residue cleaning.

Figure 3.7b: Pre-tinning Details



- Visual inspection on the component's lead.
- Make sure that there is no irregularity at the pre-tinned area.

3.4.0 Solder Type SnPb 63-37

Table 3.2: Mechanical Properties

Tin (wt.%)	Tensile Strength (MPa)	Shear Strength (MPa)	Elongation (%)	Elastic Modulus (GPa)	Izod Impact Strength (J)	Stress to produce 0.01%/day creep rate (kPa)
0	12	12	55	18.0	8.1	1700
5	28	14	45	18.5	9.5	1400
10	30	17	30	19.0	10.8	
20	33	20	20	20.0	15.0	
30	34	28	18	21.0	16.3	790
40	37	32	25	23.7	19.0	
50	41	36	35	26.9	20.3	860
60	52	39	40	30.0	20.3	
63	54	37	37	31.5	20.3	2300
70	54	36	30	35.0	19.0	

As can be seen from the above Table 3.2, the 63% tin 37% lead solder alloy results in the maximum tensile strength, shear strength, impact strength, and resistance to creep. This 63-37 composition is also known as the eutectic point of the alloy, where the alloy behaves like a pure metal having a single melting (solidification) temperature (176ºC / 349ºF). This is a good operational feature. Once the solder melts on application of heat, it solidifies immediately on removal of heat, without going through a pasty stage like other alloys. This allows for predictable soldering and fast cycle times.

Table 3.3: Physical Properties

Tin (wt.%)	Specific Gravigy	Electric Resistivity (10^{-9}ohm-m)	Thermal Conductivity (W/m-K)	Thermal Expansion Coefficient (10^{-6}/°C)
0	11.34	212	34.8	29.3
5	10.80	207	35.2	28.4
10	10.50	204	35.8	27.9
20	10.40	192	37.4	26.6
30	9.66	180	40.5	25.6
40	9.28	166	43.6	24.7
50	8.90	153	47.8	23.6
60	8.52	145	49.8	21.6
63	8.34	144	40.9	21.4
70	8.17	134	30.0	20.7

From Table 3.3 above, SnPb 63-37 has the lowest electric resistivity (144 10^{-9}ohm-m) compared with other composition. This is a very good criterion for electronic industry since lower resistivity means the lower power lost due to heat generated through solder joints. Lower thermal expansion coefficient will contribute in reducing the fatigue stress as per explain in the literature review.

3.5.0 Manual Soldering

Manual soldering is accomplished by quickly heating the metal parts to be joined, and then applying a flux and a solder to the mating surfaces. The finished solder joint metallurgically bonds the parts - forming an excellent electrical connection between wires and a string mechanical joint between the metal parts. Heat is supplied with a soldering iron (Figure 3.8). The flux is a chemical cleaner which prepares the hot surfaces for the molten solder. Listed below are suggestions and preventive maintenance techniques to extend life and wettability of tips and desoldering tiplets.

Figure 3.8: Manual Solder

1. Keep working surfaces tinned, wipe only before using, and retin

immediately. Care should be taken when using small diameter solder to assure that there is enough tin coverage on the tip working surface.

2. If using highly activated rosin fluxes or acid type fluxes, tip life will be reduced. Using iron plated tips will increase service life.
3. If tips become unwettable, alternate applying flux and wiping to clean the surface. Smaller diameter solders may not contain enough flux to adequately clean the tips. In this case, larger diameter solder or liquid fluxes may be needed for cleaning. Periodically remove the tip from your tool and clean with a suitable cleaner for the flux being used. The frequency of cleaning will depend on the frequency and type of usage.
4. Filing tips will remove the protective plating and reduce tip life. If heavy cleaning is required, use a Weller WPB1 Polishing Bar available from your distributor.
5. Do not remove excess solder from a heated tip before turning off the iron. The excess solder will prevent oxidation of the wettable surface when the tip is reheated.
6. Anti-seize compounds should be avoided (except when using threaded tips) since they may affect the function of the iron. If seizing occurs, try removing the tip while the tool is heated. If this fails, it may be necessary to return the tool to Weller for service. Removing the tip from the tool on a regular basis will also help in preventing the tip from seizing.

3.5.1 Recognizing the Reliable Solder Connection

Two easily measured indicators in the soldering process that can determine the reliability of the solder connection are the soldering iron's tip temperature and the solder's wetting characteristics. The tip's temperature during the soldering process is an indicator of the amount of heat being transferred from the tip to the connection. The optimum rate of heat transfer occurs if the soldering iron tip temperature remains constant during the soldering process.

Another indicator for determining reliability is the solder's wetting action with the lead and board materials. As operators transfer heat to the connection, this wetting

characteristic can be seen visually. Of the molten solder quickly wick up sides of the component on contact, the wetting characteristic is considered good. If the operator sees the solder is flowing or spreading quickly through or along surface of the printed circuit assembly, the wetting is also characterized as good.

3.5.2 Right Amount of Solder (Figure 3.9)

a) Minimum amount of solder
b) Optimal
c) Excessive solder

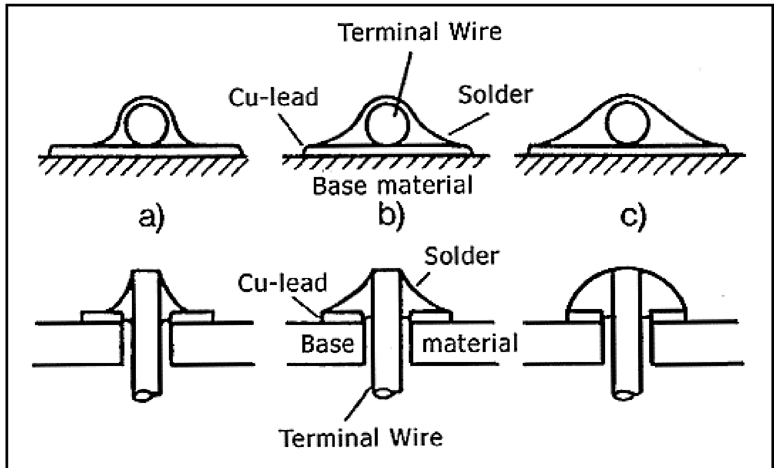


Figure 3.9: Types of Solder joint

3.5.3 Solderability

a) Bad solderability of terminal wire
b) Bad soldering of PCB
c) Bad soldering of terminal wire and PCB

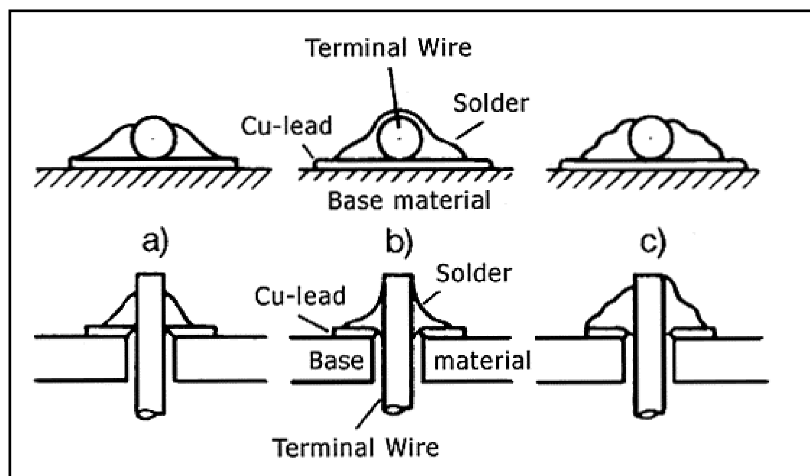


Figure 3.10: Types of Solder joint

3.6.0 Diamond Wire Saw

Diamond wire cutting (DWC) is the process of using wire of various diameters and lengths, impregnated with diamond lust of various sizes to cut through materials. Because of the hardness of diamonds, this cutting technique can through almost any material that is softer than the diamond abrasive. One of the advantages of DWC is that it produces less kerf and wasted materials compared to solid blades. On very expensive materials, this could save hundreds or thousands of dollars of waste. On the other side, using diamond wire for cutting have the problem of being less strong and possible more dangerous because when the wire breaks and whips.

Figure 3.11: Diamond Wire Saw

Table 3.4: Standard Operating Procedure for DWC

No.	Description
1.	Adjust and secure the sample to be cut on the working table with special fixtures provided. Make sure the line of cut is correctly set.
2.	Attach the Feeding weight with wire on the pin below the worktable and guide the wire to either the front or the back pulley (depending on whether the cutting is to be on the inside or outside of the Diamond wire).
3.	Move the sample and work table away from the Diamond wire. Hold its movement using the Stopper provided.
4.	Adjust and set the cutting limit switch accordingly.
5.	Adjust the upper and lower guiding pulley with added tension as necessary.
6.	Install the Splashguard on the upper guiding pulley.

7.	Install the Moistening pulley.
8.	Install and filled the Pan with WELL cutting liquid/water mixture.
9.	Turn key on the main switch to "ON" position.
10.	Press the "Green" button to start the automatic mode driving the wire.
11.	Adjust the linear wire speed (about 0.8 ~ 1.1 m/s) by turning slowly the potentiometer until the desire speed is reached.
12.	Carefully release the Stopper and feed the working table with sample towards the Diamond wire.
13.	Observe the cutting sequence and stop the machine of any adjustment is to be made.
14.	Press the "Red" button to stop the machine once the cutting is completed.
15.	Remove sample from the working table.
16.	Clean the machine after job completion.
17.	PPE is required while using the system such as glove and mask.

3.6.1 Cutting Design

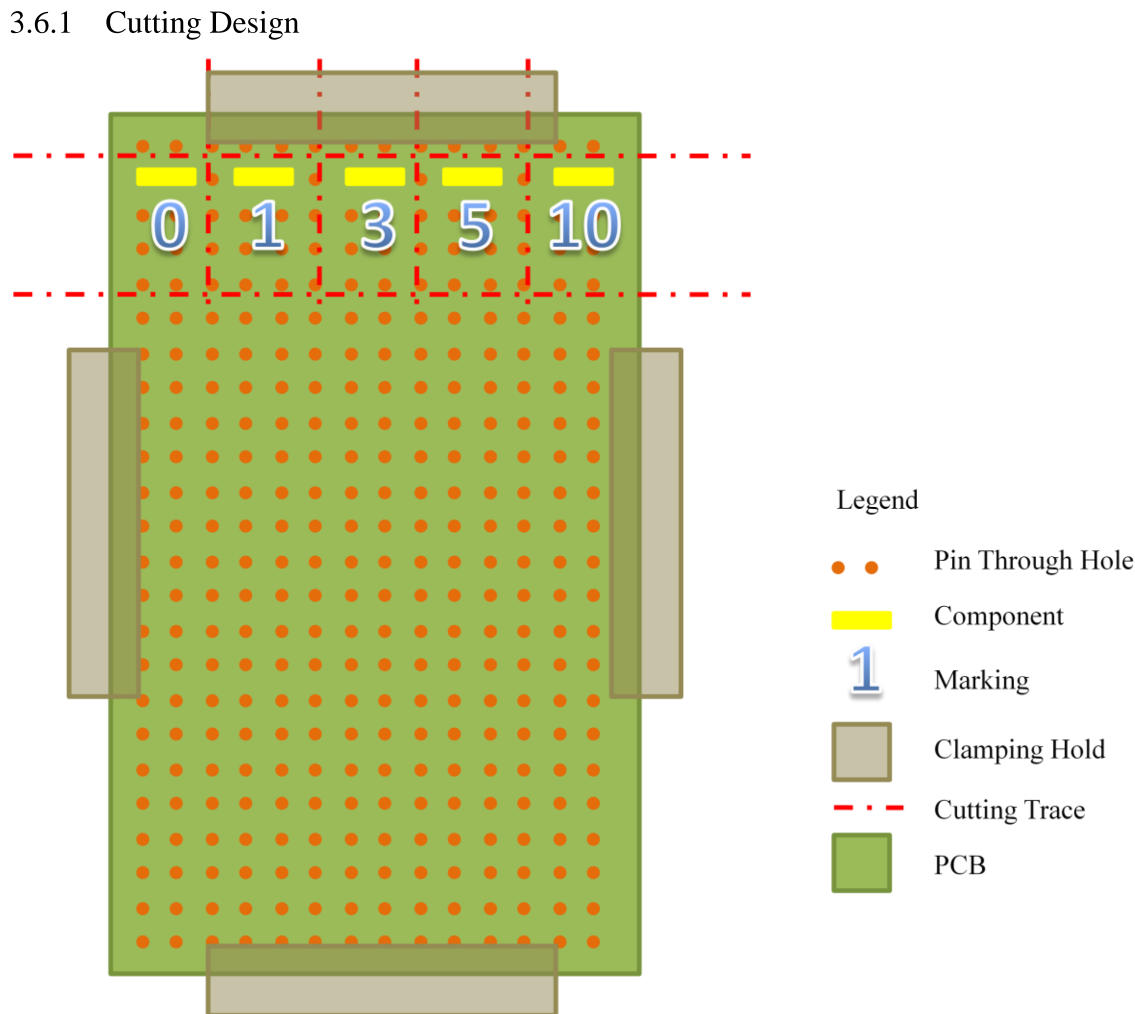


Figure 3.12: Cutting Design

Before cutting the sample from PCB it is appropriate to design the cutting trace first so that no unnecessary damage can occur to the sample. The design is as show in Figure 3.12. The size of the sample must also compatible with the available mould for cold mounting in the next procedure including the marking sign for easier identification between samples. Starts by marking the sample with 1, which means 1 seconds dipping time. Marking the sample must be in same side for all samples since only one side will be gone during grinding and polishing process. After that, clamp the PCB with the special fixtures on the working table by ensuring the correct orientation to the line of cutting trace.

3.7.0 Cold Mounting

The purpose of mounting is to protect fragile or coated materials during preparation and to obtain perfect edge-retention. Mounting also allows for a safer, more convenient handling of e.g. small, sharp or irregularly shaped specimens or when the protection of layers is imperative. Cold mounting offers specific advantages depending on the number of specimens and the quality required:

- Excellent results with porous, fragile and heat sensitive specimens
- Well suited for vacuum impregnation
- Fast curing of large specimen volumes

There are 2 different types of cold mounting resins, epoxy and acrylic. The choice of resin is determined by a number of factors such as type of material, specimen characteristic, quantity of specimens, and the quality requirements. For electronic components such as the Jumper Switch the most suitable resin is the Epoxy Resins (Figure 3.13). Epoxies are ideal for vacuum impregnation and porous specimens. It is also for high edge retention requirements. Epoxy Resins was chosen also after meeting all the criteria in Table 3.5.

Figure 3.13: Cold Mounting Ingredient

Table 3.5: Cold Mounting Resin Selection Guide

Curing Time	Shrinkage	Cold Mounting Resin	Application area /Special features
10 - 20 min	●	DuroCit	Contains special aluminium silicate filler for execellent workability. For coated specimens and high edge-retention and planeness requirements.
	● ●	ClaroCit	Universal use. Provides clear, transparent specimens (extreme clear when cured under pressure).
	● ●	VersoCit	Routine examination of soft to medium hard materials.
	● ●	ViaFix	Excellent for filling of microvias. Provides clear, transparent specimens (especially when cured under preassure). ViaFix is affected by alcohol. When using diamond products or lubricants containing alcohol, the surface will be affected and the structure of the polymer beads will appear.
1 - 4 hours	●	CaldoFix-2	Cures in 1½ hours in an oven at 75°C / 167°F. Long pot life. For vacuum impregnation of porous specimens and plasma spray coatings.
	●	SpeciFix-40	Epoxy with curing time of 3½ hours. Cures in oven or DryBox. For vacuum impregnation of porous specimens and plasma spray coatings. Extremely good adhesion.
> 4 hours	●	SpeciFix-20	Curing time 8 hours. Ideal for small specimens. For vacuum impregnation of porous specimens and plasma spray coatings. Extremely good adhesion.
	●	EpoFix	Curing time approx.12 hours. Epoxy with very low viscosity. Very well suited for vacuum impregnation of porous specimens and plasma spray coatings. Can be used on all types of specimens. Superior penetration of cracks and pores. Excellent adhesion.

*from 1-5 and 1 is best

3.7.1 Vacuum Impregnation

Materials like copper base or electronic specimens for failure analysis require special care during preparation. Porosity, gaps, cracks and loose particles can easily be altered or even removed during preparation if the specimens are not mounted properly. In these cases, vacuum impregnation is used to reinforce and protect the materials. With vacuum system, impregnation is carried out quickly and efficiently. After curing the resin reinforces the fragile materials like pull-outs and unopened or smeared pores can be avoided. The epoxy resins are suitable due to their low viscosity and the negligible shrinkage.

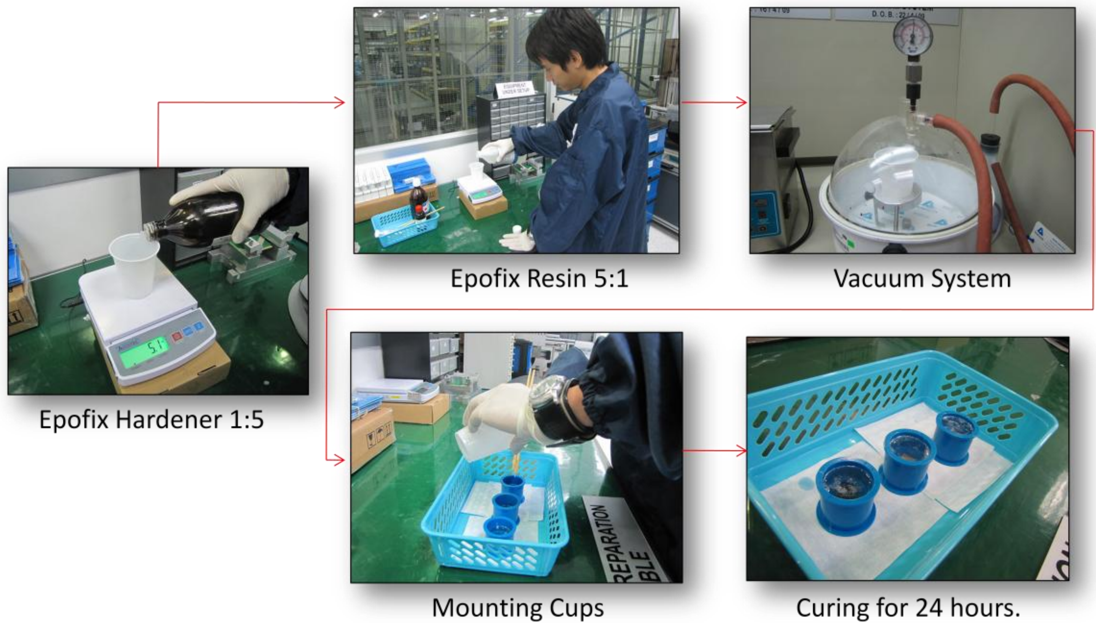


Figure 3.14: Cold Mounting Steps

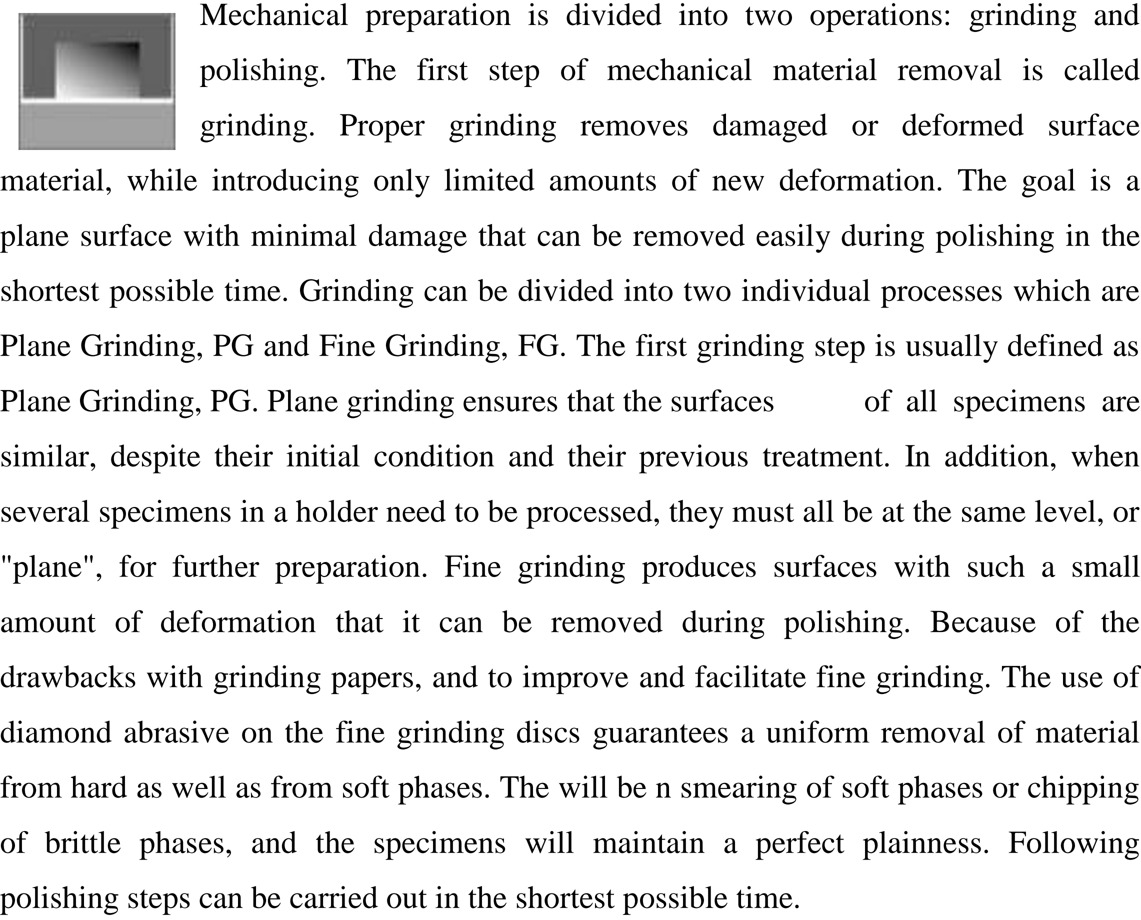
Using a digital weighing machine, 5g of Epofix Hardener is poured into a cup. Since the ratio of the composition is 1:5 another totals of 25g Epofix Resins will be added to the cup. After that, stir the solution for 2 minutes so that the chemical will mix together perfectly. At this stage bubbles will be visible in the solution and that is not desired because it will create porosity in the curing process later. The solution then is put into a vacuum system where all the bubbles were sucked out leaving no bubbles in it. After the solution is fully prepared, a suitable size of mould was chosen that able to fit the specimens properly. Here it is important to put the specimen in the desired orientation because one side will be destroyed during grinding session. Make sure that the marked area is on the upper side. Pour the solution into the mould until all parts of the specimen is submerged as shown in Figure 3.14. It takes approximately 24 hours for the solution to cure.

3.8 Grinding and Polishing

Mechanical Preparation

Mechanical preparation is the most common method of preparing materialographic samples for microscopic examination. Abrasive particles are used in successively finer steps to remove material from the surface until the required result is reached.

Definition of Processes



Mechanical preparation is divided into two operations: grinding and polishing. The first step of mechanical material removal is called grinding. Proper grinding removes damaged or deformed surface material, while introducing only limited amounts of new deformation. The goal is a plane surface with minimal damage that can be removed easily during polishing in the shortest possible time. Grinding can be divided into two individual processes which are Plane Grinding, PG and Fine Grinding, FG. The first grinding step is usually defined as Plane Grinding, PG. Plane grinding ensures that the surfaces of all specimens are similar, despite their initial condition and their previous treatment. In addition, when several specimens in a holder need to be processed, they must all be at the same level, or "plane", for further preparation. Fine grinding produces surfaces with such a small amount of deformation that it can be removed during polishing. Because of the drawbacks with grinding papers, and to improve and facilitate fine grinding. The use of diamond abrasive on the fine grinding discs guarantees a uniform removal of material from hard as well as from soft phases. The will be n smearing of soft phases or chipping of brittle phases, and the specimens will maintain a perfect plainness. Following polishing steps can be carried out in the shortest possible time.

Like grinding, polishing must remove the damage introduced by previous steps. This is achieved with steps of successively finer abrasive particles. Polishing can be divided into two different processes which are Diamond Polishing, DP and Oxide Polishing, OP. Diamond is used as an abrasive to accomplish the fastest material removal and the best possible plainness. There are no other abrasive available, which can produce similar results. Because of its hardness, diamond cuts extremely well through all materials and phases. Certain materials, especially those that are soft and ductile, required a final polish for optimum quality. The combination of chemical activity and fine, gentle abrasion produces scratch-free, deformation-free specimens. Polishing is carried out on polishing cloths. For diamond polishing, lubricant must be used. The choice of cloth, diamond grain size and lubricant depends on the material to be polished. The first steps are usually done on cloths with low resilience and, for soft materials, with low viscosity lubricant. For final polishing, cloths with higher resilience and a lubricant with high viscosity are used.

Figure 3.15: Grinding and Polishing

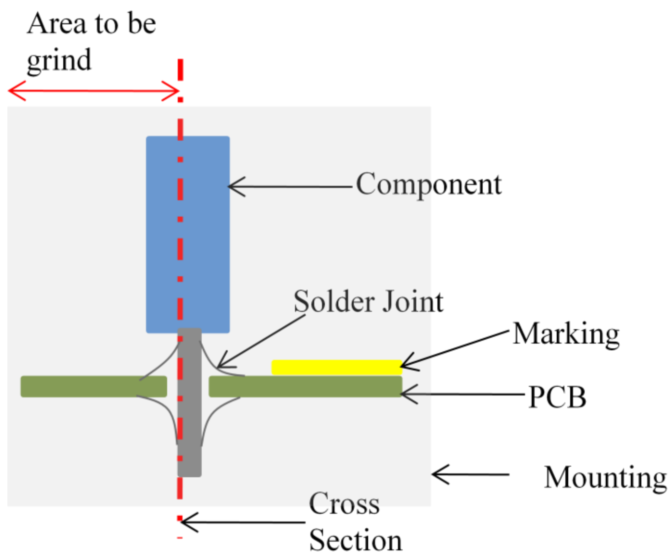


Figure 3.16: Cross Section

Table 3.6: Sand Paper

Sand Paper No	Force	Time(min)	Speed	Rotation Dimention	Water
320	5	Reach target point	200	Contra	On
600	5	10	200	Contra	On
1200	5	10	200	Contra	On
3um	5	20	150	Comp	Off
1um	5	20	150	Comp	Off

Table 3.6 above shows the stages during grinding and polishing for sand paper number 320 which is the coarsest paper to the final polishing using sand paper number 1µm. Extra careful attention is needed when using the first sand paper since it is easily to over grind the specimens from the desired location. Make sure to grind it bit by bit and always check whether the grinding has reached the location or not as shown in Figure 3.16.

3.9 Microstructure Examination

As discussed before, the specimens will undergo microstructure examination after all are perfectly polished. It is important for the component to be in mirror finish so that during the microstructure analysis it is easier to indentify the difference between each sample. This microstructure examination will be done using Optical Microscope (Figure 3.17) under 150 x magnifications.

Figure 3.17: Optical Microscope

CHAPTER 4

RESULT AND DISCUSSION

Five cross section of component have been grinded and polished. The conditions of the specimens are as below:

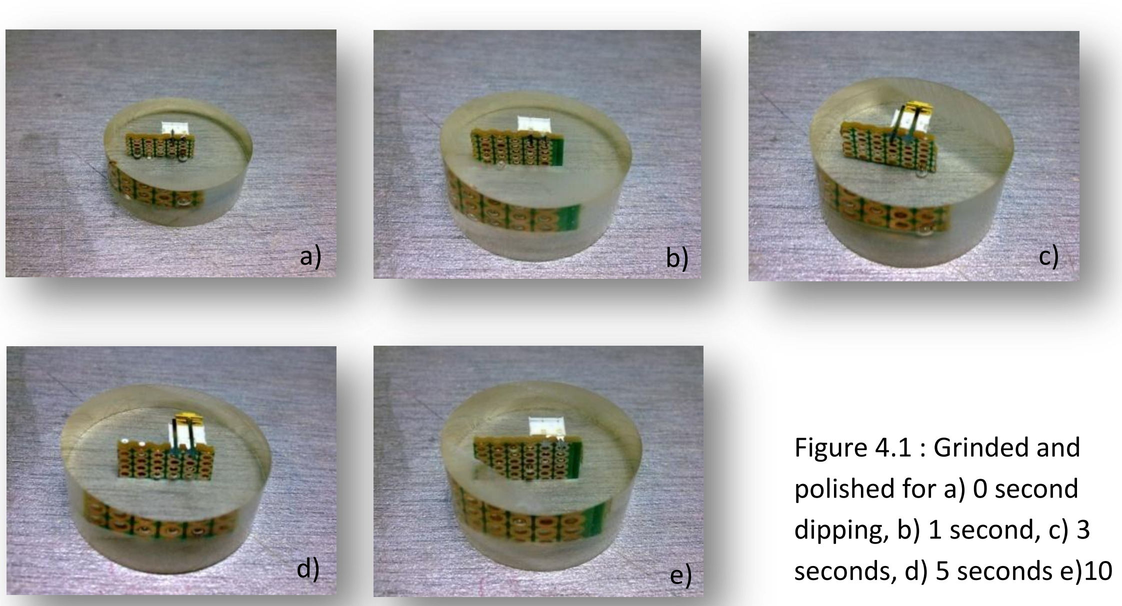


Figure 4.1 : Grinded and polished for a) 0 second dipping, b) 1 second, c) 3 seconds, d) 5 seconds e)10

There are no significant different in naked eyes between all the specimens (Figure 4.1) since the intermetallic (IMC) layers we are looking for is in the range of 1µm to 5µm. Using the high power optical microscope with magnification at 150x the results are in Figure 4.5-4.9. Along with these figures is the average intermetallic (IMC) AuSn4 thickness included. But first of all it is important to check the initial gold thickness. Even though the specification did say the gold thickness is around 1µm including some porosity with it. Figure 4.2 shows the gold thickness in average of 1.06 µm almost the same as per claim in the specification.

4.1.0 Gold Thickness

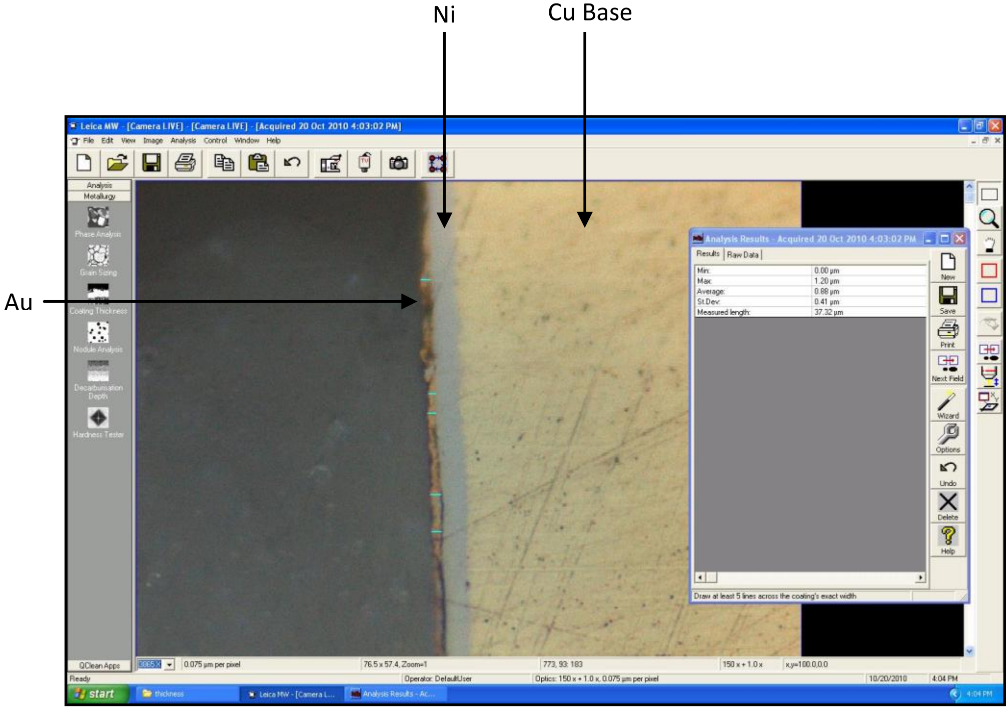
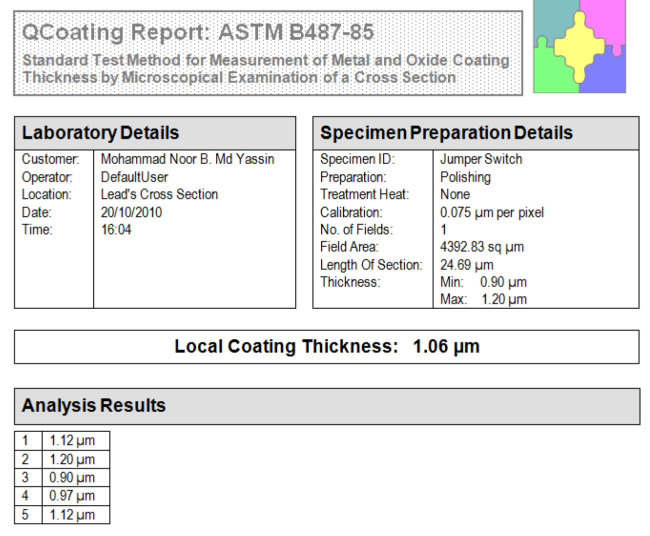


Figure 4.2: Gold Thickness

Using the Optical Microscope coating thickness software, the average gold thickness for all components can be measured. After taking an image from the scope five lines are made on top of the gold layer. Five lines represent five thickness lengths and from that, value an average thickness is obtained. Figure 4.3 below shows the result.



QCoating Report: ASTM B487-85

Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of a Cross Section

Laboratory Details	
Customer:	Mohammad Noor B. Md Yassin
Operator:	DefaultUser
Location:	Lead's Cross Section
Date:	20/10/2010
Time:	16:04

Specimen Preparation Details	
Specimen ID:	Jumper Switch
Preparation:	Polishing
Treatment Heat:	None
Calibration:	0.075 μm per pixel
No. of Fields:	1
Field Area:	4392.83 sq μm
Length Of Section:	24.69 μm
Thickness:	Min: 0.90 μm Max: 1.20 μm

Local Coating Thickness: 1.06 μm

Analysis Results

1	1.12 μm
2	1.20 μm
3	0.90 μm
4	0.97 μm
5	1.12 μm

Figure 4.3: Result of Average Au Thickness

4.2.0 Elemental Identification

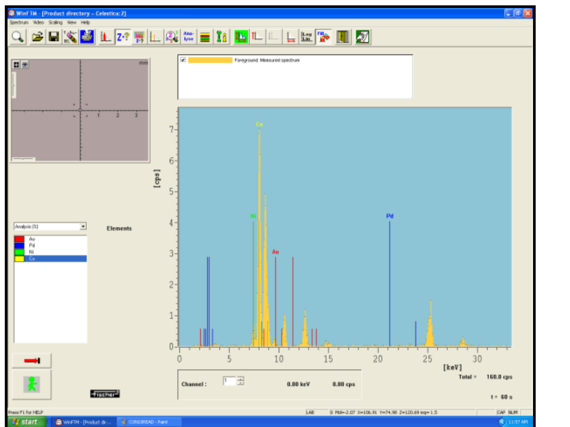
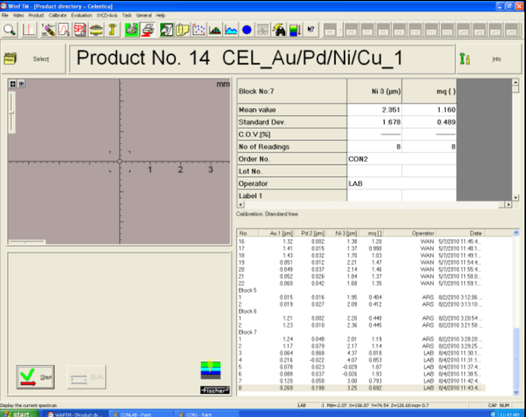



Figure 4.4: XRF Graph

After all the samples are fully prepared, X-ray Fluorescence (XRF) is used to identify what compositions consist on the sample. This process is important since the Optical Microscope cannot identify elemental composition in the solder joints. Before starting the test, a suitable recipe needs to be prepared. In this case, only an existing recipe can be choose from the Celestica XRF where it usually used in everyday operation. By selecting Product No. 14 CEL_Au/Pd/NiCu_1 consisting all the desired composition need to be verified. Even though this test result in thickness but this method cannot be used to determining the intermetallic (IMC) thickness. The purpose is specifically only to make sure that the Au element is present in the solder joint. From the data sheet in Figure 4.4, it shows that the Au thickness is 0.269 µm.

4.3.0 $AuSn_4$ Thickness

0 Second Pre-tinning

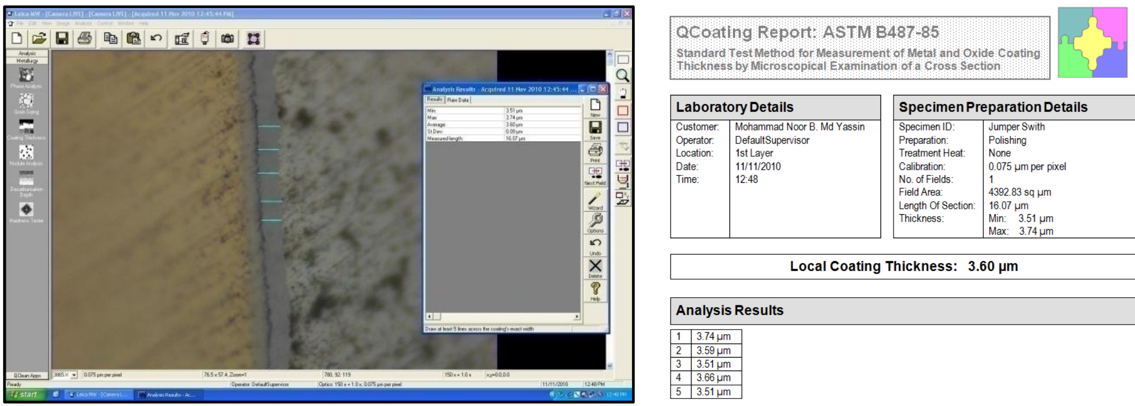


Figure 4.5: Second Pre-tinning

1 Second Pre-tinning

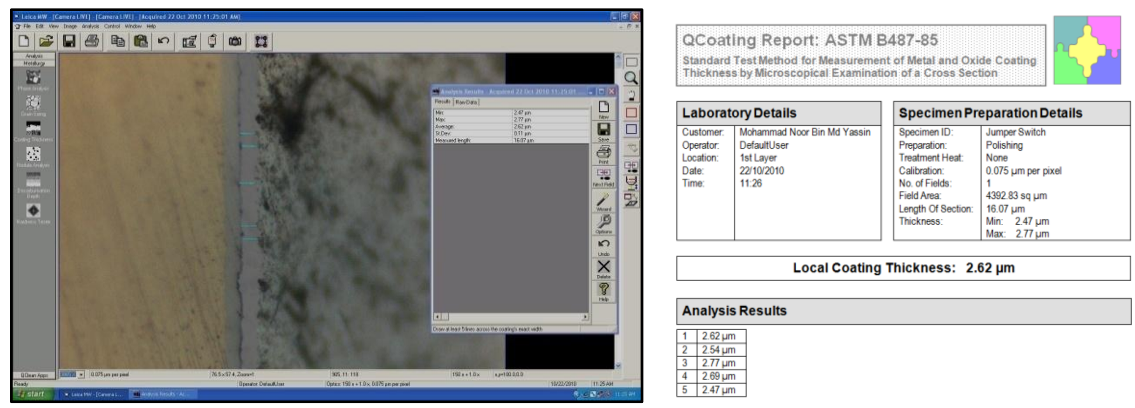


Figure 4.6: Second Pre-tinning

3 Seconds Pre-tinning

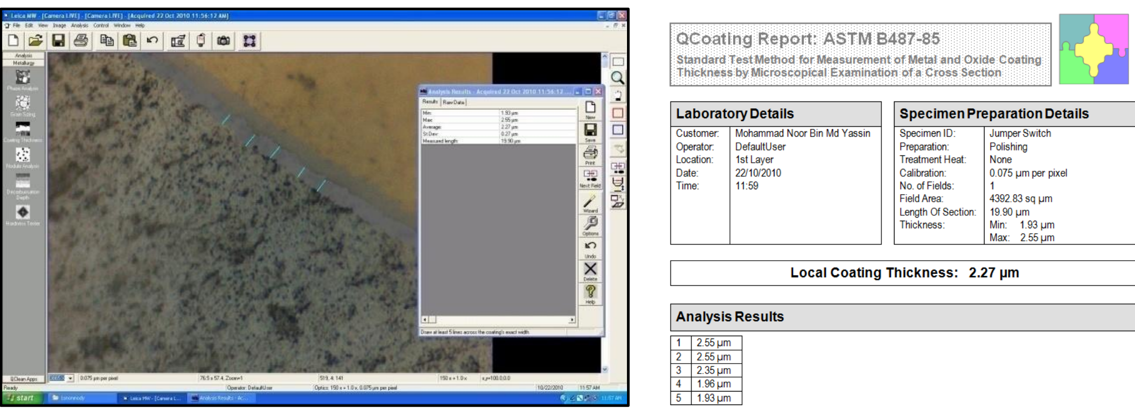
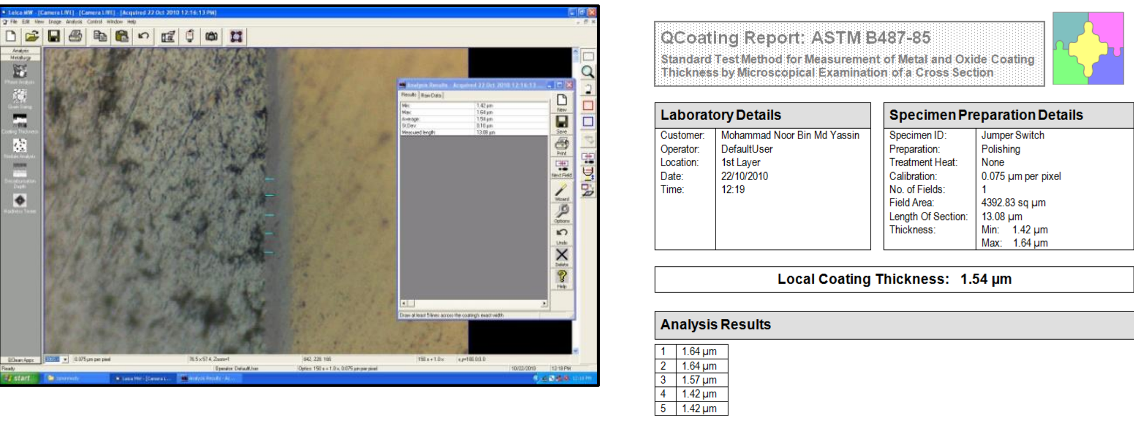


Figure 4.7: Second Pre-tinning

5 Seconds Pre-tinning



QCoating Report: ASTM B487-85

Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of a Cross Section

Laboratory Details	
Customer:	Mohammad Noor Bin Md Yassin
Operator:	DefaultUser
Location:	1st Layer
Date:	22/10/2010
Time:	12:19

Specimen Preparation Details	
Specimen ID:	Jumper Switch
Preparation:	Polishing
Treatment Heat:	None
Calibration:	0.075 µm per pixel
No. of Fields:	1
Field Area:	4392.83 sq µm
Length Of Section:	13.08 µm
Thickness:	Min: 1.42 µm Max: 1.64 µm

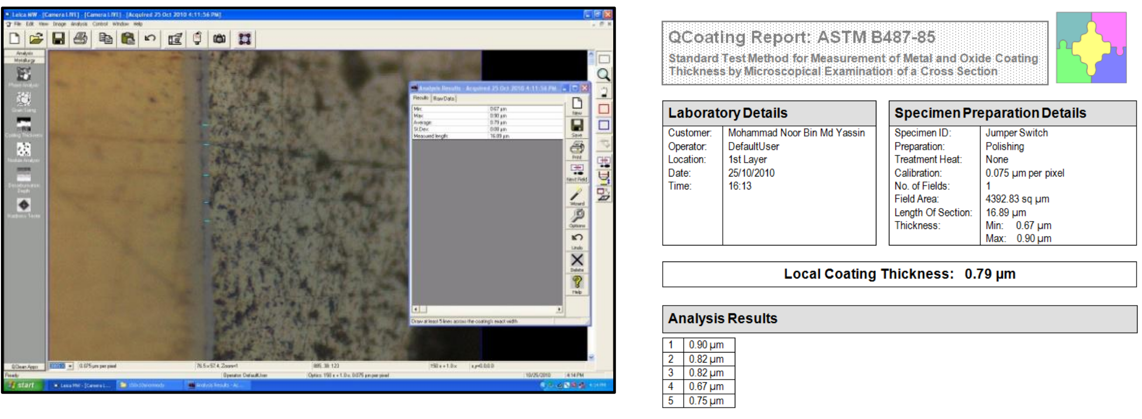
Local Coating Thickness: 1.54 µm

Analysis Results

1	1.64 µm
2	1.64 µm
3	1.57 µm
4	1.42 µm
5	1.42 µm

Figure 4.8 Second Pre-tinning

10 Seconds Pre-tinning



QCoating Report: ASTM B487-85

Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of a Cross Section

Laboratory Details	
Customer:	Mohammad Noor Bin Md Yassin
Operator:	DefaultUser
Location:	1st Layer
Date:	25/10/2010
Time:	16:13

Specimen Preparation Details	
Specimen ID:	Jumper Switch
Preparation:	Polishing
Treatment Heat:	None
Calibration:	0.075 µm per pixel
No. of Fields:	1
Field Area:	4392.83 sq µm
Length Of Section:	16.89 µm
Thickness:	Min: 0.67 µm Max: 0.90 µm

Local Coating Thickness: 0.79 µm

Analysis Results

1	0.90 µm
2	0.82 µm
3	0.82 µm
4	0.67 µm
5	0.75 µm

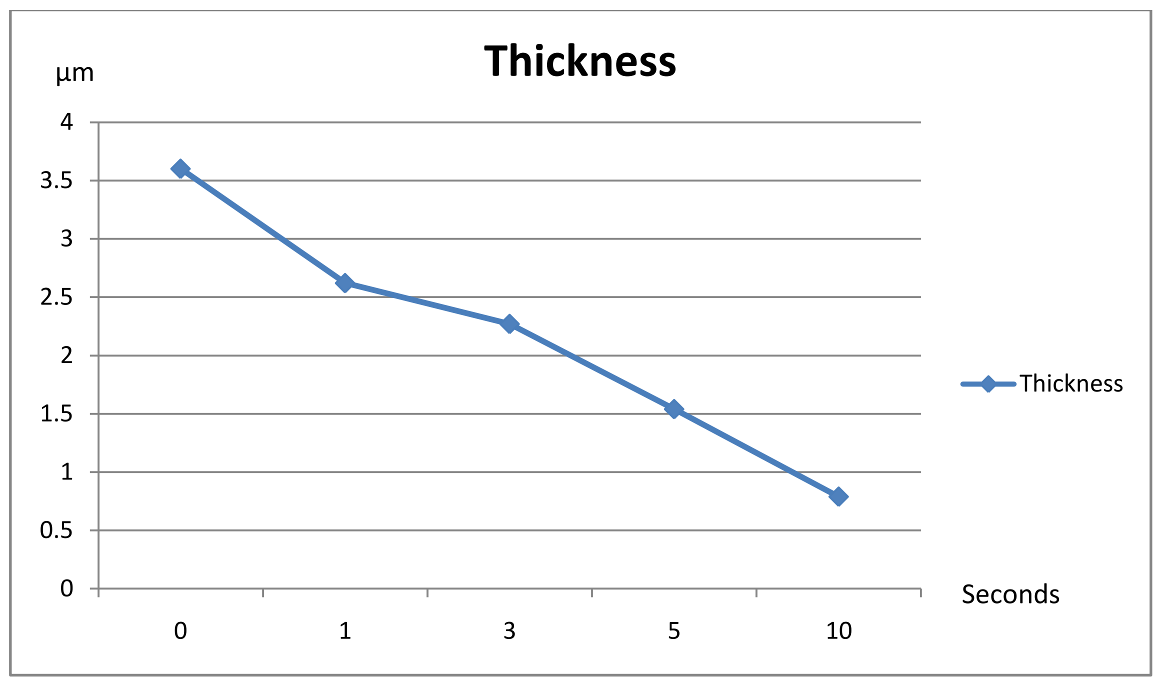
Figure 4.9 Second Pre-tinning

4.4.0 Pre-tinning Time VS IMC Thickness

Pre-tinning Time (seconds)	IMC Thickness (µm)
0	3.60
1	2.62
2	2.27
5	1.54
10	0.79

Table 4.1: Pre-tinning Time VS IMC Thickness

Table 4.2: Pre-tinning Time VS IMC Thickness



4.5.0 Discussion

From the results obtain, it shows that the initial IMC $AuSn_4$ thickness is as high as 3.6 µm. This high thickness is due to the thick gold layer thickness which is 1.06 µm since this component never undergoes pre-tinning process. Even though 1.06 µm is not that thick according to Frank, 1974, stating thick gold plated to 100micro inches (2.5µm) or more while thin gold plated generally range from 20-60 micro inches (0.5-1.5µm) or less. But the IMC thickness that it creates after manual soldering is quite thick under the optical microscope. This intermetallic (IMC) have characteristic such as unreliable or mechanically weak solder joint. The thicker the intermetallic (IMC) the more it contribute to weaker the solder joint. Moving to the next specimen where it under go 1 second pre-tinning time, the intermetallic (IMC) thickness reduces dramatically to 2.62 µm. The reduction is more than 1 µm shows that pre-tinning process gives an impact by reducing the resulting IMC thickness. This is because during the pre-tinning process a small amount of gold layer is dissolved into the solder bath. It is reminded that the solder bath used for pre-tinning process must be in large volume so the dissolved gold will not deteriorate the ability for future pre-tinning. Periodic inspection also must be done to monitor the gold contamination. At Celestica Kulim, this is done by taking a solder sample from the solder bath and the sample was sent to Cookson Electronics Assembly Materials located in Taiwan. The analysis could be easily done from local vendor but due to customer requirement it must be done from specific company. This shows how strictly the pre-tinning process was monitored because without proper inspection instead of reducing the gold thickness, the solder joint will be contaminated with more gold due to impurities in the solder bath. The report analysis is shown in Appendix 2. As the dipping time increase the graph shows that the intermetallic (IMC) thickness is reduce until as thin as 0.79 µm. The thin intermetallic (IMC) layer compared to the sample without pre-tinning process are much better in terms of microstructure and solder joint reliability.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1.0 Conclusion

From this research, it can be concluded that the pre-tinning process affects the solder joint of gold plating components in terms of intermetallic (IMC) layer growth. The relation between dipping time and intermetallic (IMC) growth are the longer the dipping time the lower the intermetallic (IMC) growth. Different component will have different thickness of gold plating. With different gold plating thickness it will require different dipping time for pre-tinning process. So, it is crucial for each part to have undergone this analysis to determine the safety intermetallic (IMC) growth by having the appropriate dipping pre-tinning time.

5.2.0 Recommondation

For future purpose, it is recommended for the next research to use strain gage to investigate more deeply on the solder joint reliability. Strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical to change.

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APPENDIX

FYP 2 Gantt Chart

Appendix 1: FYP 2 Gantt Chart

Milestone for Final Year Project 2

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Cold Mounting Process	■	■						Mid-semester Break							
2	Grinding			■	■											
3	Submission of Progress Report 1															
4	Polishing					■	■	■								
5	Submission of Progress Report 2									▲						
6	Seminar									▲						
7	Microscopic Analysis									■	■	■				
8	Refine Result												■	■	■	■
9	Poster Exhibition											▲				
10	Submission of Dissertation Final Draft															
11	Oral Presentation															
12	Submission of Dissertation (hard bound)															▲

Appendix 2: Solder Bath Inspection

REPORT OF ANALYSIS

CUSTOMER: CELESTICA
客户

SAMPLE NO: PRE TIN(R) SN#188609
樣品名稱

TEST RESULT:(%BY WT.)
分析結果

Program: Sn-400
Comment: 63 Alloy Sn/Pb Solder 14056/01
Single spark(s)

05/05/2010 03:30:09 PM

Elements: Concentration

Sample No:
Sample Id:

Quality:

No	Sn %	Pb %	Sb %	Ag %	As %	Bi %
1	62.7	REM.	<0.0001	0.0010	0.0065	0.0057

No	Cd %	Cu %	Fe %	Ni %	Zn %	Au %
1	0.0018	0.0781	0.0028	0.0023	0.0003	0.0504

No	In %	Al %	P %	S %
1	<0.0001	<0.0001	0.0038	0.0053

CONTAMINATION ALERT LEVELS

	WEIGHT %		
Sn	-	-	-
Pb	-	-	-
Sb	.50	-	.50
Cu	.25	-	.30
Au	.10	-	.20
Ag	.10	-	.10
Al	.005	-	.005
As	.03	-	.03
Bi	.25	-	.25
Cd	.005	-	.005
Fe	.02	-	.02
Ni	.01	-	.01
Zn	.005	-	.005
Cu+Au+Cd+Zn+Al	.40	-	.40

*Note: Sn +/- 1.50%

COMMENTS:
建議事項

☐ The purity of solder is normal.
焊錫純度正常。

☑ Cu is present but is with in the normal working range.
元素存在，但仍於安全的作業區間。

☐ ______ is high, Monitor soldering and replace solder if problem occure.
元素含量太高，請調整焊錫或更換焊錫。

☐ ______ is low, Monitor soldering and replace solder if problem occure.
元素含量太低，請調整焊錫或更換焊錫。

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2.受測樣品由委託者自行取樣，所列結果僅對樣品負責。

徐[illegible]

Q.C. Supervisor

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