EFFECT OF DIFFERENT COOLING RATE ON INTEGRATED CIRCUIT(IC) PACKAGE

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ABSTRACT

Currently, electronic products have shrunk into smaller size and in order to increase the input/output (I/O) counts as well as to improve performance. The goal of this study is to determine the reliability and strength of the solder joint formed at the integrated circuit (IC) interconnection with the board. The strength of the joint is based on the intermetallic compound (IMC) formation at the joint. Free lead based solders have been used nowadays due to the environmental and health hazard effect of the lead based solder. Two types of surface finish have been used in this study which was electroless/nickel immersion gold (ENIG) and bare copper substrate as the reference in the research. All specimens will be subjected to reflow soldering with slow and fast cooling rate apply on the sample. Then, all specimens will undergo isothermal ageing at 150°C for 250 hour and 500 hour. The IMC formed at the solder joints of all specimens were studied in terms of thickness and cooling rate applied on it. Characterization on the specimen is done by the cross section of the joint to see the IMC formation on the solder joint. It can be concluded that, the fast cooling rate forms large IMC compared to slow cooling rate which is much thinner than fast cooling rate. Besides that, it was found that IMCs thicknesses are proportional with ageing durations. However, thicker IMC was found on the bare copper substrate joint compare to ENIG surface joint after ageing treatment, indicating higher growth rate of IMCs formed at the bare cooper substrate.

ABSTRAK

Pada masa kini, saiz produk elektronik menjadi semakin kecil dan peningkatan masukan/keluaran (I/O) adalah fokus utama dalam meningkatkan prestasi produk elektonik. Matlamat kajian ini adalah untuk mengukur kebolehpercayaan dan kekuatan penyambungan pateri yang terbentuk pada litar bersepadu (IC) antara sambungan dan papan litar. Kekuatan sendi adalah berdasarkan pembentukan sebatian intermetallik (IMC) pada penyambungan tersebut. Pateri berasaskan bebas plumbum sebagai pilihan pada masa kini kerana pateri berasaskan plumbum memberi kesan buruk kepada alam sekitar dan kesihatan penguna. Dalam kajian ini, dua jenis permukaan papan litar telah digunapakai iaitu tanpa elektrik / nikel rendaman emas (ENIG) dan substrat tembaga sebagai rujukan dalam penyelidikan. Semua spesimen akan melalui pematerian reflow dan kemudian melalui penyejukan dengan kadar perlahan dan cepat. Kemudian, semua sampel akan menjalani penuaan isoterma pada 150 ° C selama 250 jam dan 500 jam. IMC yang terhasil pada penyambungan pateri pada semua spesimen telah dikaji dari segi ketebalan disebabkan kadar penyejukan berbeza yang dikenakan pada sampel. Pencirian pada spesimen itu dilakukan oleh keratan rentas yang sama untuk melihat pembentukan IMC pada penyambungan pateri. Berdasarkan kajian, dapat disimpulkan bahawa kadar penyejukan cepat membentuk IMC bersaiz besar dibandingkan dengan kadar penyejukan perlahan yang lebih nipis daripada kadar penyejukan cepat. Selain itu, ia telah mendapati bahawa ketebalan IMC adalah berkadar dengan jangka masa penuaan. Walau bagaimanapun, lebih tebal IMC ditemui pada permukaan substrat tembaga berbanding dengan permukaan ENIG selepas rawatan penuaan, menunjukkan kadar pertumbuhan yang lebih tinggi IMC pada substrat tembaga.

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LIST OF SYMBOLS

Symbols

A_S	Heat transfer surface area
h	Convections heat transfer coefficient
Q	Heat Transfer
T_s	Temperature of surface
T_∞	Temperature of the fluid sufficiently far from the surface

LIST OF ABBREVIATIONS

Ag	Silver
Au	Gold
Cu	Copper
DIG	Direct Immersion Gold
EN	Electroless Nickel
ENIG	Electroless Nickel Immersion Gold
ENIGEG	Electroless Nickel Immersion Gold Electroless Gold
ENEPIG	Electroless Nickel Electroless Palladium Immersion Gold
H_2SO_4	Sulfuric Acid
IC	Integrated Circuit
ILB	Inner Lead Bonds
IG	Immersion Gold
ImAg	Immersion Silver
IMC	Intermetallic Compound
I/O	Input/Output
ISn	Immersion Tin
$KauCN_2$	Potassium Cynoaurate
NaOH	Sodium Hydroxide
Ni	Nickel
OLB	Outer Lead Bonds
OSP	Organic Solderability Preservatives
Pb	Lead

RoHS	Restriction of use of Hazardous Substances
SEM	Scanning Electron Microscope
Sn	Tin
TAB	Tape Automated Bond

CHAPTER 1

INTRODUCTION

1.1.1 INTRODUCTION

Heart of electronic system control is integrated circuit (IC), and since they are sensitive to electrical, mechanical, physical and chemical influences, they require special considerations by the packaging industry. Today‘s demand on high performance, high reliability and low cost of circuit and system level requirements make the packaging industry to have better understanding of existing and emerging IC packaging technologies. Before board mounting, the plastic package is exposed to humidity.

Lead based solders have been widely used in the electronic industry for a considerable time. Nowadays, free lead based have been used in industry due to the environmental and health hazard issues, lead-based solders are being phased out from the industry. Initiatives, both by governmental and non-governmental agencies have been taken to gradually replace lead-based solders such as Sn-Pb solders with lead-free solders such as Sn-Ag and Sn-Ag-Cu solders.

Reliability issues are usually related to the solder joint intermetallic compounds. The IMC is formed between the solder and substrate surface finish and functions to provide mechanical, thermal, and electrical connections through the solder joint. During reflow soldering, due to the high temperature conditions, a reaction usually occur between the solders and the surface finish layers which in turn form layers of intermetellic compound at the interface of the solder joints. The formation of solder joint requires intermetallic compounds. However, excessive thickness of IMCs will embrittle the solder joint due to its hard and brittle properties. The brittle property of IMCs caused the strong stress concentration effect during the thermal cycles, and cracks were found to initiate and propagate near the IMC layers (Jene et al., 2011). So, study and characterization on the IMCs formed are essential in order to achieve a good and reliable solder joint.

1.1.2 OBJECTIVES

The objectives of this research are:

i. To determine the effect of various cooling rates on IMC formation using Ni-Au/Cu coating
ii. To investigate the effect of ageing treatment on thickness of the IMCs formed at the solder joints.

1.1.3 SCOPE

In this research, different cooling rates on the IC package are conducted. Through these different cooling rates, the solder joint reliability will be tested. To create the joint, formation of IMC is necessary at the joint. The characterization of intermetallic formation at the interface, from the aspect of thickness composition is observed. However, excessive growth of IMC may lead to degradation of solder joint strength. Therefore, the formation of IMC needs to be controlled to produce strong and reliable older joint. Thus, the work is focuses on effect of cooling rates to control the IMC formation and grain size. Besides that, investigation of isothermal ageing effect on intermetallic formation at the solder joint.

CHAPTER 2

LITERATURE REVIEW

2.1 ELECTRONIC PACKAGING

In the globalization era, electronic components or gadget play big parts in advanced world. The advanced country in the world can be classified through their advanced gadget. These advanced gadgets became high demand and made the manufacturers continuous develop the electronic gadget to meet the market needs.

With increasing demand of electronic devices in every field, electronic packaging is gaining more importance, particularly for high-density applications. To ensure the optimum performance of an electronic device a good electronic device is essential. Electronic packaging compiles five functions which are (Harper, 2000):

i. A structure to support and protect the chip
ii. Connections for providing electrical current that powers the circuits on the chip
iii. Connections for signal lines leading onto and off the silicon chip
iv. A wiring structure for signal and power interconnections within a system and for input/output I/O
v. A meant for removing the heat generated by circuits

2.2 CHIP LEVEL INTERCONNECTS

There are three main methods for the chip-to-carrier connection assemblies which are widely deployed in the electronic industry. They are the chip and wire (wire bonding), tape automated bonding (TAB) and flip chip attachment.

Table 2.1: Interconnections in Electric Systems

Interconnection level	Characterization	Interconnection technology
Zero Level	Intrachip interconnections	Built up layers of metal and dielectric materials
First Level	Chip to package	Wire bonding, Tape Automated Bond, Flip Chip
Second Level	Packaged chip to substrate	Solder, sockets, conductive adhesives, printed circuit board
Third Level	Board to board	Sockets, edge card contacts

Source: Tummala (2001)

2.2.1 Wire bonding

In the ball-wedge wire bonding process, the gold wire is ball bonded to the chip bond pad surface as shown, and wedge bonded to a substrate pads as shown in Figure 2.1. Wire bonding materials used in a ball bonding process mainly include the bonding wire and bonding tool. Axial symmetric ceramic tools with vertical feed holes are called capillaries for ball bonding tools. (Harper, 2000).

In the bonding process, the ball is formed at the tip of the capillary and then pressed against the chip. The pressure and the thermosonic action result in bonding the ball to the chip. The wedge bond can then be placed anywhere on a 360° arc around the ball bond, using the capillary tip (Harper, 2000). This is the main advantage that makes this process attractive for high speed automated bonding where the bonding head or package table does not have to rotate to form the wedge bond.

Another type of bonding is wedge-to-wedge bonding process where the direction of the wire that terminates in the package wedge bond is determined by the orientation of the wedge bond at the chip. Usually aluminium wire is used in this process (Harper, 2000). The drawback is the bonding head and the work holder requires motion and this result in a slower wire bonding process. Wire bonding can be split into three options: thermosonic and thermocompression ball-to-wedge using gold wire, and ultrasonic wedge-to-wedge using either gold or aluminium wire (Otter, 2001). Table 2.2 demonstrates the comparison of these three bonding process.

Table 2.2: The comparison of three wire bonding process

Wire bonding method	Normal type of metal wire	Force applied to form the bond	Type of the first bond
Thermocompressions	Gold wire Wire diameter: 0.0007''-0.0002''	Heat and pressure	Ball bond
Thermosonic	Gold wire Wire diameter: 0.001'' or less	Heat pressure and ultrasonic energy	Ball bond
Ultrasonic	Aluminium wire Wire diameter: 0.0007''-0.0002'' And 0.005''-0.02'' for high current applications (gold wire can also be used with wire diameter of 0.002'' or larger	Pressure and ultrasonic energy	Wedge bond

Source: Otter (2001)

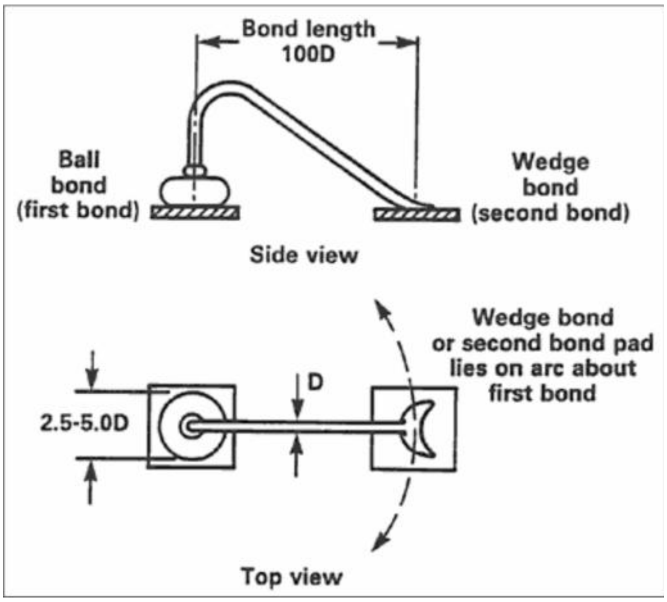

Figure 2.1: Schematic representation of the geometry of a ball/wedge

Source: Otter (2001)

2.2.2 Tape Automated Bonding (TAB)

TAB is the process of mounting a polymer material die on a flexible tape, such as polyimide. The mounting is done as the bonding sites of the die, usually in the form of gold or solder of bumps or balls, are connected to fine conductors on the tape, which offer the means that of connecting the die to the package or directly to external circuits. Sometimes the tape bonded tape is already contains the actual application circuit of the die (Siliconfareast, 2001).

The TAB bonds connecting the die and the tape are known as inner lead bonds (ILB), while those that connect the tape to the package or to external circuits are known as outer lead bonds (OLB). Single-sided tape usually used in TAB, although two-metal tapes are also available. A commonly-used metal in tapes is copper; it can be electrodeposited on the tape or attached to the adhesives tape. Photolithography is used to see the metal image of the tape patterns onto the circuit.

To facilitate the connection of the die bumps or balls to their corresponding leads on the TAB circuit, holes are punched on the tape wherever the die bumps are going to be positioned. The conductor traces of the tape are then cantilevered over the punched holes to meet the bumps of the die.

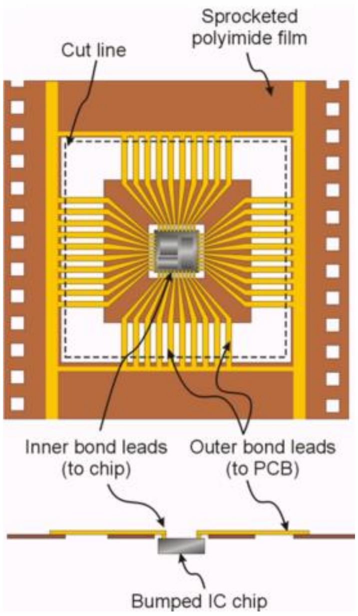

Figure 2.2: TAB

Source: Al-Sarawi (1997)

2.2.3 Flip Chip Bonding

High-density and high-speed electronic packaging technology is progressing rapidly, and has become indispensable for optimizing electrical products. Recently, in the field of high-density and high-speed packaging, flip-chip interconnection technology was developed. The flip-chip interconnection is the connection of an integrated circuit (IC) chip to a carrier or substrate with the active face of the chip facing toward the substrate. The flip-chip technology is generally considered the ultimate first level connection, because the highest density can be achieved and the path length is shortest, so that optimal electrical characteristics are achieved.

The term “flip-chip” refers to an electronic component or semiconductor device that can be mounted directly onto a substrate, board, or carrier in a ‘face-down’ manner. Electrical connection is achieved through conductive bumps built on the surface of the chips. During mounting, the chip is flipped on the substrate, board, or carrier, (hence the name ‘flip-chip’), with the bumps being exactly positioned on their target locations. Because flip chips do not require wire bonds, their size is much smaller than their conventional counterparts.

The flip-chip concept is not new; having been around as early as the 1960’s when IBM used them for their mainframes. Since then, various companies have developed the flip-chip to be utilized in thousands of various applications, taking advantage of the dimension and cost benefits offered by this assembly technique. Flip chips have likewise eliminated performance problems associated with inductance and capacitance connected with bond wires.

In electronics the main intentions within the development of packaging is to lower price, increase the packaging density, and improve the performance wheres still maintaining or perhaps up improving the reliability of the circuits. Flip chip is a process that facilitates direct attachment and electrical interconnection of the chip to the substrate circuitry. Thus flip chip is as ideal concept of interconnection to fulfill these visions as this kind of bonding requires only one level of connections between the chip and the connection board. Table 2.2 will summarize the advantages and limitations of wire, tape automated and flip-chip bonding.

Table 2.3: Comparison between interconnection

	Advantages	Disadvantages
Wire Bonding	• Highly flexible interconnection process • High yield interconnection • High reliability structure • Large industry infrastructure	• Low I/O count due to limitations of space on chip perimeter edge • Bond geometry variations • Potential wire sweep during encapsulation moulding
Tape Automated Bonding	• Small bond pads and finer pitches • High I/O counts • Reduce weight • Better heat transfer than thermal management	• Provide only peripheral interconnection • Package size increases with I/O counts • Process inflexibility • Difficulty in assembly rework
Flip Chip Bonding	• High density I/O connection • Superior electrical performance due to small bump joint • Low cost assembly • Light weight • Reliability determined from fatigue life of solder	• Limited inspection because die is facing down • High cost for low volume assembly

2.3 SOLDERING

2.3.1 Introduction

Nowadays, there are only two main classifications for soldering methods: mechanical or non-electrical (using primarily acid flux) and electrical (using primarily rosin flux). While advances in transistors, resistors, capacitors, diodes, and particularly integrated circuits have revolutionized the world, these devices are of very little value as individual components. As this component to be useful, they must be electrically connected to each other and to mechanical devices. Majority of these electrical connections are made by soldering. The solder does not only make electrical connections, it also used to provide a physical connection between the component and supporting printed circuit board. Throughout the years solder has been used in various applications; however it was the invention of electronic devices in the latter part of this century that led to rapid advances in soldering technologies. The advances in electronics would not have resulted in today's mass production of electronic equipment without accompanying advances in soldering technology.

2.3.2 Materials

Soldering is a method of making a permanent electrical and mechanical connection between metals. Compare to glue which forms a solely physical adhesive bond. Solder are chemically reacts with other metals to form a different alloy. While there are various processes utilized in soldering, virtually all of them involve four basic elements: base metals, flux, solder, and heat (Elenius, 1997).

2.3.2.1 Base Metals

Any metal that contacts the solder and forms an intermediate alloy are called base metal. When attaching electronic components to a printed circuit board, the component's leads or pins and board's metallic circuitry are the base metals which will contact the solder. Many metals, such as copper, bronze, silver, brass, and a few steels, without delay react with solder to create strong chemical and physical bonds.

Other metals, such as aluminium, high alloy steels, cast iron, and titanium, range from vary from difficult to not possible to solder. The fact that there are metals that don't react with solder is important; these materials are used in the development of soldering machinery. These metals can even be used as temporary covers for components that do not seem to be soldered (Hoban and Lunt, 1997). Also of importance to the electronic industry is the fact that ceramics do not react with solder. The level of surface oxidation on the base metal and how solder will react with it is a direct relationship between it. The more oxidation is present, the weaker the solder bond. Most metals oxidize at a much accelerated rate when heated creates a particular problem is the fact of soldering, since the chemical reactions associated with soldering require high temperatures.

2.3.2.2 Flux

Flux is often applied as a liquid to the surface of the base metals prior to soldering. Though flux really encompasses a range of functions, the primary and first purpose of flux is to prevent the base metals from oxidizing while they are being heated to the soldering temperature. The flux covers the surface to be soldered, shielding it from oxygen and thereby preventing chemical reaction throughout heating. Metal most fluxes also have and acidic component that is used to remove the oxidation already present on the base. Applying a strong acid, it would be possible to virtually completely clean off the oxidation layer. However, the use of strong acids presents a heavy drawback. Oxidation layer is not limited to the oxidation layer the corrosives of acids desirable to get rid of. Very strong acids can be damaging to electronic components and a residue continues to corrode after the soldering process is complete even the mild acids leave. There is a definite tradeoff between applying a flux with a strong acid that removes a good deal of oxidation and applying a flux with a mild acid that is not as corrosive. In any case, most fluxes in common use are corrosive enough that their residue must be cleaned off after soldering.

When the liquid solder is applied, the flux must readily move out of the way so the solder can come into direct contact with the base metal. During this method some of the flux inevitably combines with the solder. Flux decorator typically take advantage of this fact and style the flux to bring down the surface tension of the solder upon contact, thereby permitting a more efficient wetting.

2.3.3 Type of Solder

2.3.3.1 Lead Based Solder

Tin, lead and their alloys, due to their low melting temperatures and wide convenience, are the most commonly used solder materials in today's flip chip technology. To determine the appropriate tin composition in the solder, the mechanical properties of various compositions (%) of tin is observed. From table 2.4, the 63% tin 37% lead solder alloy (Sn/Pb) ends up within the maximum tensile strength, shear strength, impact strength, and resistance to creep. This 63-37 composition is additional referred to as the eutectic purpose of the alloy (Rahn, 1993).

Table 2.4: Mechanical Properties of Tin at different wt (%)

Tin (wt. %)	Tensile Strength (Mpa)	Shear Strength (Mpa)	Elongation (%)	Elastic Modulus (%)	Izod Impact Strength (J)	Stress tp produce 0.01%/day creep rate (kPa)
0	12	12	55	18.0	8.1	1700
5	28	14	45	18.5	9.5	100
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	

Source: Rahn (1993)

Referring to the phase diagram of tin-lead (Figure 2.3), the Sn/Pb alloy only has a single solidification temperature at the eutectic point. This means that once the solder melts on application of heat, it solidifies immediately from liquid state to solid