INTERMETALLIC COMPOUND AT COPPER WIRE-ALUMINUM BOND PAD INTERFACE IN THERMOSONIC WIRE BONDING

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A thesis submitted
in fulfilment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "Intermetallic Compound At Copper Wire – Aluminum Bond Pad Interface In Thermosonic Wire Bonding " results from my own research except as cited in the references. Therefore, the thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature	:	
Name	:	Sivapriya A/P Ratha
Date	:	11 January 2023

APPROVAL

I hereby declare that I have read this thesis, and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours.

Signature	:	T. J. S. Anand.
Supervisor Name	:	Profesor Ts. Dr. Joseph Sahaya Anand Thangaraj
Date	:	11 January 2023

DEDICATION

To my beloved family for raising me and providing me with a lifetime of love and support.

To my supervisor Profesor Ts. Dr. Joseph Sahaya Anand Thangaraj for mentoring and supporting me during the completion of this thesis.

ABSTRACT

The main objective of this research is to study the Intermetallic Compound at the Copper Wire – Aluminum Bond Pad Interface in Thermosonic Wire Bonding. In Semiconductor / Electronic industry the Au-Al intermetallic replaced with this Cu-Al combination due to the increasing price of Gold. While replacing the Cu-Al as wire bonding materials it is found of void formation that affects the quality of the discrete compounds. In general, excessive IMC growth in wire bonding systems will reduce bond reliability. This study provides an insight at the production of voids during the formation of Intermetallic (IMC) in the Cu wire Al pad interface. In addition, a theoretical stress model based on IMC development at the Cu wire–Al bond pad contact was developed. The specimens will be treated by High Thermal Storage (HTS) of 0, 500 and 1000 hours. Based on measurements of IMC thickness and volume change, this model was used to estimate stress generation. The effect of volume changes and thickness on stress development will result in the formation of voids. There have been a few investigations on the identification of Cu-Al IMC using different methods like as Scanning Electron Microscope (SEM) and Energy dispersive X-Ray (EDX). Basically, EDX is used as a selective technique to detect the Cu-Al IMC phase because it has high resolution and can reveal ultrafine features of material microstructure. Although, because of various constraints, the X-ray Diffraction (XRD) method was used to substitute EDX in the investigation to detect the Cu-Al IMC phase at the bonding interface. However, there are several problems to utilizing this method. As a result, this research will focus on the two sample preparation procedures, powder method and etching process. One of these two ways would be the selected method, which would determine the success of both procedures at the end of the experiment.

ABSTRAK

Objektif utama penyelidikan ini adalah untuk mengkaji Sebatian Antara Logam pada Antara Muka Pad Wayar Tembaga – Pad Ikatan Aluminium dalam Ikatan Wayar Termosonik. dalam industri Semikonduktor / Elektronik, Au-Al intermetallic digantikan dengan kombinasi Cu-Al ini disebabkan oleh kenaikan harga emas. Semasa menggantikan Cu-Al sebagai bahan ikatan dawai didapati pembentukan lompang yang menjejaskan kualiti sebatian diskret. Secara amnya, pertumbuhan IMC yang berlebihan dalam sistem ikatan wayar akan mengurangkan kebolehpercayaan bon. Kajian ini memberi gambaran tentang penghasilan lompang semasa pembentukan Intermetallic (IMC) dalam antara muka pad Al wayar Cu. Di samping itu, model tegasan teori berdasarkan pembangunan IMC pada hubungan pad ikatan wayar Cu-Al telah dibangunkan. Spesimen akan dirawat oleh Penyimpanan Terma Tinggi (HTS) 0, 500 dan 1000 jam. Berdasarkan ukuran ketebalan IMC dan perubahan volum, model ini digunakan untuk menganggar penjanaan tegasan. Kesan perubahan isipadu dan ketebalan terhadap perkembangan tegasan akan mengakibatkan pembentukan lompang. Terdapat beberapa penyiasatan mengenai pengenalpastian Cu-Al IMC menggunakan kaedah berbeza seperti Mikroskop Elektron Pengimbas (SEM) dan Sinar-x Penyebaran Tenaga (EDX). Pada asasnya, EDX digunakan sebagai teknik selektif untuk mengesan fasa Cu-Al IMC kerana ia mempunyai resolusi tinggi dan boleh mendedahkan ciri ultra halus struktur mikro bahan. Walaupun, kerana pelbagai kekangan, kaedah Sistem Pembelauan Sinar-x (XRD) digunakan untuk menggantikan EDX dalam penyiasatan untuk mengesan fasa Cu-Al IMC pada antara muka ikatan. Walau bagaimanapun, terdapat beberapa masalah untuk menggunakan kaedah ini. Hasilnya, kajian ini akan memfokuskan kepada dua prosedur penyediaan sampel iaitu kaedah serbuk dan proses goresan. Salah satu daripada dua cara ini ialah kaedah yang dipilih, yang akan menentukan kejayaan kedua-dua prosedur pada akhir percubaan.

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Finally, a special thanks to my beloved mother, father, siblings, and my colleagues for all their moral support in pushing me to continue working on this final year project and offering financial support to help us meet all the costs associated with finishing this research.

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LIST OF SYMBOL AND ABBREVIATION

IMC	-	Intermetallic Compound
SEM	-	Scanning Electron Microscope
XRD	-	X-ray Diffraction
HTS	-	High Temperature Storage
OM	-	Optical Microscope
EDX	-	Energy Dispersive X-ray
BSE	-	Backscattered Electrons
EDS	-	Energy-Dispersive X-Ray Spectroscopy
FAB	-	Free Air Ball
HTSL	-	High temperature storage life
STEM	-	Scanning Transmission Electron Microscopy
EFO	-	Electro Flame OFF
FC	-	Flip Chip
US	-	Ultrasonic
IC	-	Integrated Circuit
LED	-	Light Emitting Diode
TRC	-	Twin-Roll Casting
HAST	-	Humidity Stress Test (With Bias)
uHAST	-	Humidity Stress Test (Unbiased HAST)
THB	-	Temperature Humidity Bias
USL	-	The maximum value

WPT	-	Wire Pull Test
BPT	-	Ball Pull Test
PCT	-	Pressure Cooker Test
HTST	-	High Temperature Storage Test
TC	-	Temperature Cycle
RCA	-	Root Cause Analysis
APS	-	Average Peel Strength
HF	-	Hydrofluoric Acid
JCPDS	-	Joint Council Powder Diffraction Society
σ	-	Tensile Stress
P	-	Load or Force
A	-	Area

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

Corrosion and wear resistance for a single material have become increasingly difficult to fulfil as modern industry has developed. Because of their high corrosion resistance, ductility, heat conductivity, and electric conductivity, copper and aluminium have been frequently employed in engineering structures (Zhang et al., 2015). The semiconductor industry has used thermosonic bonding of copper (Cu) wire to an aluminium (Al) bond pad (CuAl) as a keyway to put together parts. Cu wire, on the other hand, is stiffer, which makes it easier to move the wire during transfer moulding and lets it be used for multi-tier ultra-fine pitch (40 m) interconnection. Cu-Al connections have a lot of problems, like too much Al deformation and damage under bond pad structures, which makes the process window smaller (Yau et al., 2020).

According to Pelzer et al., (2012), Any microelectronic component relies heavily on wire bond interconnections, which have a considerable influence on dependability. When it comes to wire bonding, a variety of techniques have been employed. Thermocompression, ultrasonic, and thermosonic bonding are the methods used. Wire bonding as a means of connecting the substrate to the ICs and other external circuitry on the board. Coucoulas first introduced thermosonically bonded balls in 1970, he improved a process that is currently included in nearly all wire-bonded devices. Ultrasonic, bonding force, and thermal energy are all used in this kind of bonding (Yen, 2016). This bonding technique is appropriate for the production of aluminum-gold intermetallic complexes (IMCs). These types of IMCs are linked to the formation of Kirkendall voids, which lower the dependability of components, particularly in high-power devices and electronic applications requiring fine-pitch spacing (Jahangiri et al., 2020). When it comes to thermosonic ball bonding, Cu wire has various benefits over Au wire, including considerable cost savings, greater electrical and thermal conductivity, which results in quicker die functioning, and superior mechanical qualities. Cu-Al bonds may have a longer lifetime than Au-Al bonds due to the considerably slower growth of IMC between copper wire and aluminium metallization. This is because IMC growth is significantly slower between copper wire and aluminium metallization (Xu et al., 2010).

The most common way to connect chips in the microelectronics industry is through thermosonic (thermal and ultrasonic) wire bonding on Al bond pad. Gold wires are still used most of the time, but copper wires are being used more and more, especially in cost-conscious applications. Manufacturers of wire are always making improvements to their products so that they can meet the growing demands on bond contact lifetime caused by use conditions that are hard on reliability, like those found in automotive applications (März et al., 2014). Thermosonic bonding was chosen since it's the easiest. Despite being fast, this procedure produces a lot in a short time. In this approach, thermal and ultrasonic energy are used to link two materials. Gold (Au) wire is chosen for thermosonic bonding with an aluminium (Al) bond pad (Srikanth et al., 2004).

Furthermore, the "Electro Flame Off" (EFO) procedure melts the wire tip to generate a free air ball (FAB). The FAB is capillary-compressed against the bond pad while vibrating laterally. Ultrasonic vibration deforms the FAB. Then, ultrasonic vibration cleaning eliminates surface contaminants and oxides. The bonding contact produces a new intermetallic phase. Intermetallic phase bonds FAB and bond pad. Wire looping and stitch bonding complete wire bonding on a finger pad. (Anand et al., 2013).

Hug & Bellido, (2011) mentioned Al/Cu interphases have already been studied in other fields, such as microelectronics and metal laminates. All of these studies agree that there is an ideal thickness for the intermetallic layer in terms of its mechanical properties. The goal of this study is to find out which annealing conditions give CCA wires the best mechanical properties when put through a tensile test. First, the materials and methods of the experiments are described. Then, the results on the interphase composition and mechanical properties are given. These results are talked about in terms of a competition between two main effects: how IMC strengthens the interface and how their brittleness makes them less flexible.

Copper wire bonding was tested carefully at massive semiconductor companies, and many problems with long-term reliability were fixed. When compared to gold ball bonding, which is the industry standard for high yields and reliability, the process was less effective and yields were unstable. However, this is quickly changing ((Levine & Consulting, 2016). Pelzer et al., (2012) stated that increasing the temperature improves diffusion-based reliability testing. Temperatures outside the required range might create stress test artefacts such differing phase compositions, void formation, or interlayer stress, over- or underestimating stress readings. Understanding the physical changes at the wire bond and pad metallization interface permits estimate of the unconsumed Al thickness under the IMC under specific stress conditions. The bond interface must sustain thermomechanical stress following IMC development to fulfil lifetime requirements. With this information, you may define the needed initial metal remnant thickness under the ball bond, bond process circumstances, or required pad metal thickness (Moisy et al., 2020).

1.2 Problem Statement of the Research

Copper wire is frequently utilised in fine pitch applications due to its lower cost in comparison to gold wire. Copper wire oxidised to form quickly, and tests have shown that it is resilient under moulded humidity and electrically biassed situations; nonetheless, this raises concerns about the dependability of packaged goods (Yen, 2016). Due to the initial absence of oxidation in the copper wire material, the thermosonic bonding of copper wire to an aluminium bond pad was a popular technique. On the other hand, an excessive production of the Cu-Al intermetallic compound (IMC) as well as voids can lead to deterioration and failure of the bonding. In thermosonic Cu wired Al bond pad systems, it is not uncommon to notice void formation following a predetermined amount of time spent in HTS annealing. There is a widespread presumption that void formation is brought on by the volumetric shrinkage of newly generated IMC between the parent metals (Cu & Al). The production of voids can be attributed to volumetric shrinkage, which happens when the magnitude of the stress is greater than the strength of the material. The performance or dependability of the microchip can be impacted by the IMC phase at the bonding interface, which is measured in nanometers (nm). IMC growth at the thermosonic Cu-Al bonding contact is very thin (on the order of a few tenth to one hundredth of a nanometer) (Chen et al., 2011). However, direct measurement of the IMC that is generated at the bonding contact is difficult to do. In this work, a comparison of two different sample preparation procedures is used in order to identify the minor peaks associated with the Cu-Al IMC phases. X-ray diffraction, often known as XRD, is a technique that is frequently utilized for characterizing both thin films and bulk objects. However, direct measurement of the IMC that is generated at the bonding contact is difficult to do. In order to locate the lesser-known peaks of the Cu-Al IMC phase, this research analyses and contrasts two different sample preparation procedures.

1.3 Objectives of the Research

The study's aim was to identify IMC development at the thermosonic wire bonding contact between the copper wire and the aluminium bond pad.The following objectives are as follows:

a) To investigate the formation of voids during the formation of Intermetallic (IMC) in Cu wire Al pad interface that undergo High Thermal Storage (HTS) treatment.
b) To analyze the effect of the thickness that will be affected the stress development of IMC.
c) To prepare the sample preparation method for SEM-EDX and XRD analysis by High Thermal Storage process for Cu-Al IMC samples.

1.4 Scope of Research

Scope of this research:

- Study the IMC behaviour and thermosonic Cu wired Al bond pad.
- Study of the data for the research is generated and prepared using a thermosonic wire bonder and an HTS chamber from the semiconductor industry.
- Study the the development is based on some observational information correlation between IMC thickness and composition change.
- Study about the IMC phase at the bonding interface for Cu-Al IMC phases.
- Study the various tools used in analysing the microstructure of IMC behaviour after the HTS process, such as an optical microscope, SEM, XRD, and many more.