MEAM 5990: Master's Independent Study Report

Semiconductor Die Attach Procedure on Paper Substrates

by

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TABLE OF CONTENTS

SECTION 1

INTRODUCTION

1.1. Electronic System and Die Attach Method

An electronic system can be viewed as shown in Figure 1.1. When an integrated circuit needs to be connected with the other electronic components such as inductors and capacitors to form a functional product it is referred to as 'System on Board' (SoB). In some cases an integrated circuit serves the function of a system as a whole, it is called 'System on Chip' (SoC). When a bare silicon chip/ die is packaged to be used for a desired application, it is called 'Packaged Device'. The focus of this study is to form a SoB, which involves die attach of a Silicon MEMS (Microelectromechanical System) resonator on a soil moisture sensor screen printed on Kapton and Paper substrates.

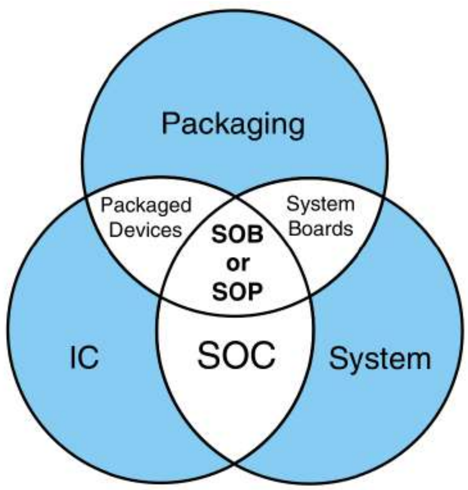


Figure 1.1: Overview of Electronic System [1]

Die Attach or IC assembly is the first processing step after wafer fabrication and singulation that enables ICs to be packaged for systems use [1]. However, die attach can also be used to attach a bare IC directly on a application circuit board which then can be packaged as a single system. IC assembly process involves three interfaces: (1) metallurgical bond pad interface on the IC; (2) metallurgical bond pad interface on the package; and (3) electrical interconnection between these two interfaces, Figure 1.2 [1].

This study investigates the methods to attach a bare silicon chip having metal pads onto a paper (Figure 1.3) and Kapton substrates. The substrates are screen printed using Silver/ Copper nano inks to make a soil moisture sensor [2], the chip is mechanically attached to the substrate and electrically to the sensor electrodes. The soil moisture sensor is wireless [2] and the chip serves to amplify the the signal for the sensor. Referring to the Figure 1.1, the said soil moisture sensor can be termed system on board (SOB), in which the paper/ Kapton serves the function of both board and substrate for the IC.

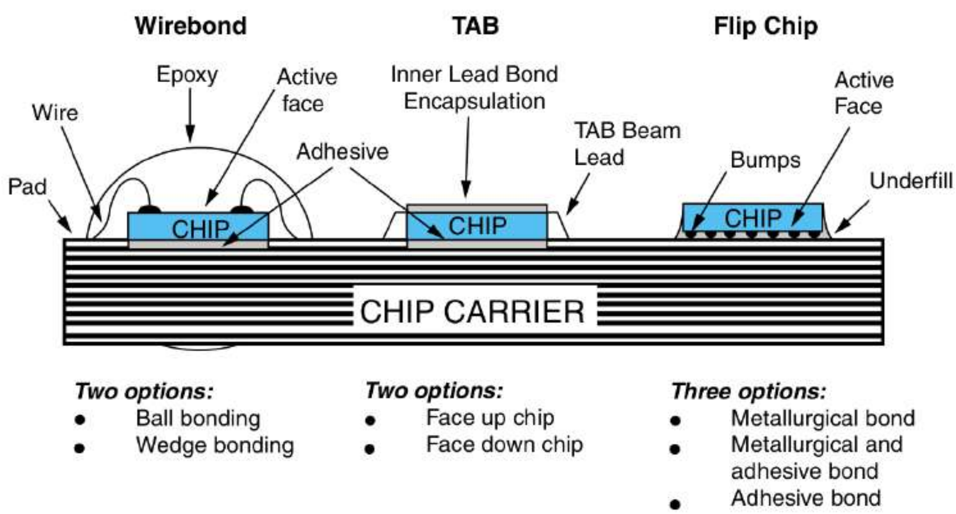


Figure 1.2: Chip to Package or Susbstrate Interconnection Techniques [1]

The methods for die attach studied here are: wire bonding as explained in Section 2, and flip chip bonding as explained in Section 3. Traditional high temperature die attach methods such as C4 (Controlled Collapsed Chip Connection) flip chip bonding technique involves forming solder bumps on the chip and melting the solder (reflow) during die attach process to form a metallurgical bond with the substrate electrical contact pads which can expose the entire system to temperatures as high as 200°C [1]. Thus it is necessary to use an alternate die attach techniques which don't need melting of the bonding material for the typical flexible and low temperature electronics substrates owing to their low working temperatures.

1.2. Die Attach Methods for Printed Electronics

Flexible-hybrid printed electronics is a rapidly growing field because it provides high throughput manufacturing of electronics that enables economies of scale resulting in more affordable products [3]. Paper, which is made of renewable, recyclable, biodegradable, and non-toxic cellulose materials, is an attractive substrate for printed electronics [3]. But paper is both temperature- and pressure-sensitive and can stand only processes with low temperature and pressure budgets [4]. Therefore, anisotropic conductive paste (ACP) and non-conductive paste (NCP) are currently the main approaches for fine-pitch bonding on paper and other low temperature substrates [4]. For the application considered here, the fine pitch requirements are not a concern, and the flip chip technique has been selected considering the temperature, bonding pressure, time and the number of process step required.

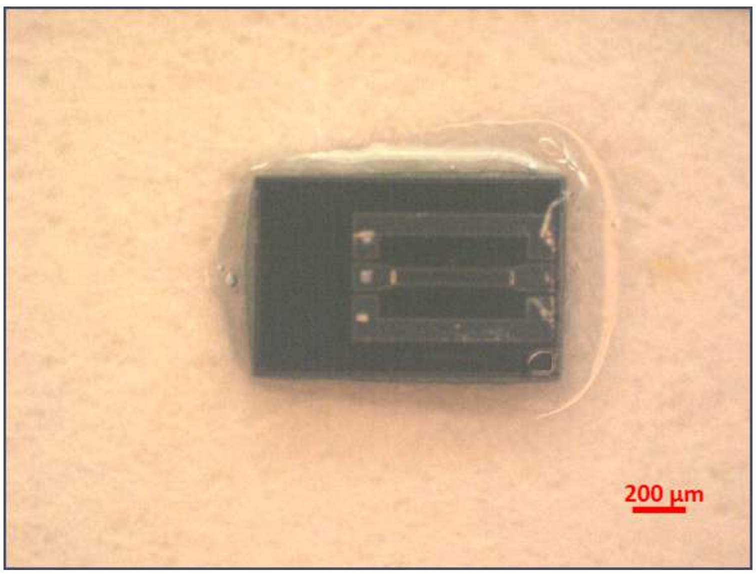


Figure 1.3: A Silicon MEMS Resonator Attached on Paper using Epoxy

In case of wire bonding, the die can be attached to the substrate using room temperature curing adhesives as shown in Figure 1.3; and to form the electrical connections on the contact pad, low temperature techniques such as ultrasonic bonding are effective. Next chapter discusses in details the wire bonding process and its application.

SECTION 2

WIRE BONDING

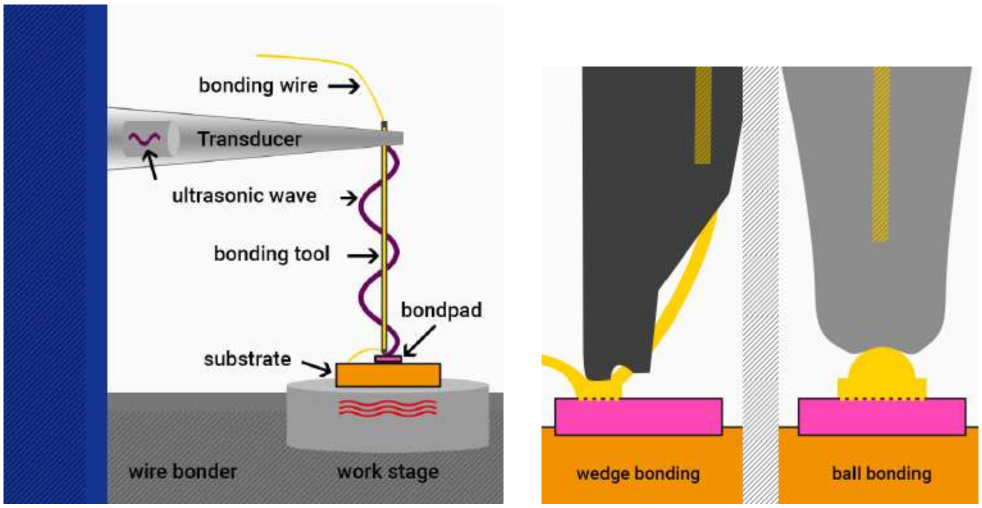
Wirebonding is a chip-to-package interconnection technique where a fine metal wire is attached between each of the I/O pads on the chip and its associated package pin, one at a time [1]. However, for the application presented here, wire bonding has been used to connect the aluminium pads of bare silicon die to a 33 μm aluminium wire using wedge bonding technique. The other ends of the wires have been bonded to the sensor electrodes using Silver epoxy conductive paste. There are two types of wirebonds: gold ball bonding; and gold or aluminum wedge bonding [1]. Table 2.1 shows the comparison of the two bonding methods.

Parameter	**Wedge Bonding**	**Ball Bonding**
Material	Gold and Al wires	Only Gold wires
Pad Size	Small Pad ($\sim$ wire dia.)	Large Pads (4 $\times$ wire dia. [5])
Bond Strength	Lower bond strength	Greater bond strength
Heating	No active heating	Active heating required to form ball
Bond Flexibility	Unidirectional bonding	360° bonding
Pitch	Fine pitch ($<$ 102 μm [6])	Fine pitch limited by ball dia.
Bonding Speed	Slower bonding	Faster bonding
Techniques	Ultrasonic bonding	Thermocompression and Thermsonic bonding
Capability	Can bond in deep cavity	Not suitable for deep cavity

Table 2.1: Wedge Bonding and Ball Bonding [6]

2.1. Mechanism of Wire Bonding

Figure 2.8a shows construction of a typical wire bonding tool. It consists of a ultrasonic transducer which excites the bonding tool connected to its end. The bonding tools are different for wedge and ball bonding and the wire is passed through the tool tip as shown in Figure 2.3. For ball bonding, the wire end is melted using an attachment called Electronic Flame Off (EFO). The tool used for the experiments presented is TPT HB100 Wire Bonder (figure 2.2) [7].



(a) Principle (b) Types

Figure 2.1: Principles and Types of Wire Bonding [8]

The mechanism of wire bonding is shown in Figure 2.5 [8], there are three different techniques among the two major types of wire bonding which are explained below.

Figure 2.2: TPT HB100 Wire Bonder [7]

2.1.1. Ultrasonic Bonding

In U/S bonding, the wire is guided to the bonding site, then pressed onto the surface by a stylus ("bonding wedge") [9].

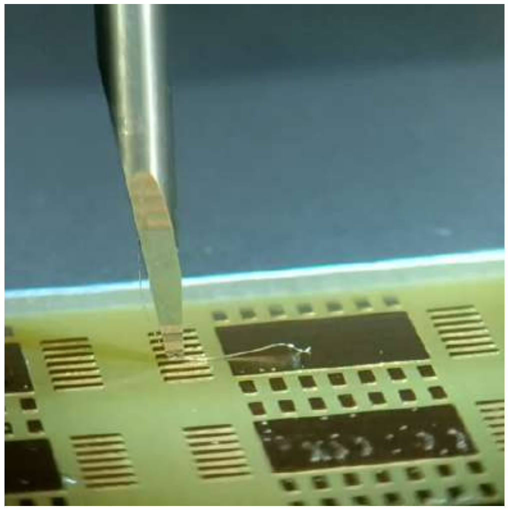


Figure 2.3: Wire bonding tool and wire bond

The details of the mechanism by which the ultrasonic bond is accomplished have long been a source of speculation. The explanation given by G. G. Harman and his colleagues [10] at the National Bureau of Standards is plausible. The function of the ultrasonic energy is to enhance wire deformation and break up the surface oxides at the bonding site [9]. This happens in first few milliseconds of US action [11]. These massive plastic deformations expose atomically clean fresh metal which cold welds very readily [9].

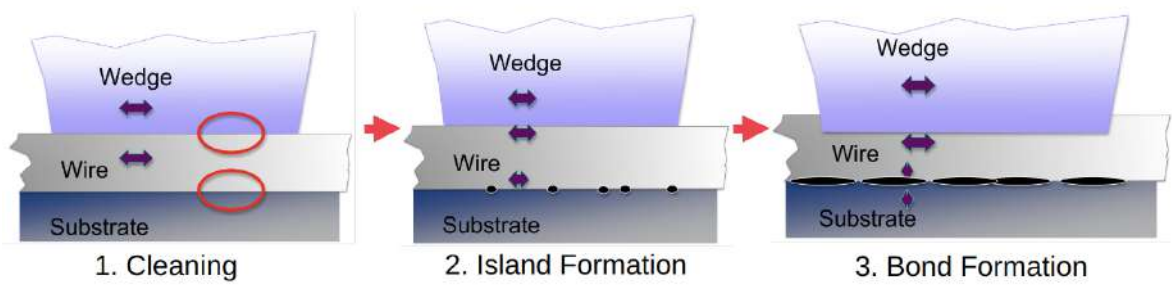
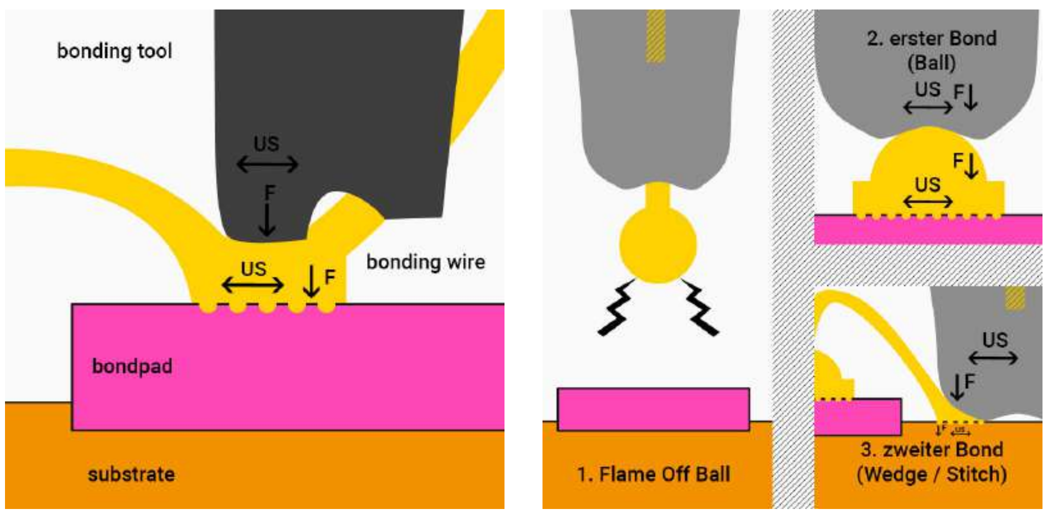


Figure 2.4: Ultrasonic Wedge Bonding Mechanism [11]

In the case of **Aluminum wire and bondpads**, this is helped by the fact that Aluminum is always covered by an oxide layer which is both very thin and very hard [11]. It therefore acts as a sort of grinding powder which helps to expose the atomic lattices very quickly, but does not generate much debris because there is so little abrasive material (oxide) due to its thinness [11]. This is the underlying reason why Aluminum wire can so easily be bonded at room temperature without additional thermal activation (such as is required by gold wire). Au, Cu, and other metals are used in special applications [9].

2.1.2. Thermocompression Bonding

Thermocompression bonding is accomplished by pressing the wire against the bond site metallization at an elevated temperature [9]. Practically all T/C bonding is performed using Au wire, and practically all wire loops are formed using a "ball bond" at the first bond site, and a "stitch bond" at the second [9]. The bonding tool is a capillary of alumina, tungsten carbide, or other refractory material, and the bonding surface is heated to 300-400° C [9]. Gold wire is particularly suitable for T/C bonding because it deforms readily under the bonding capillary at elevated temperatures, exposing clean metal, and no surface oxide on the wire inhibits its joining [9].



(a) Wedge-Wedge Bonding (b) Ball-Wedge Bonding

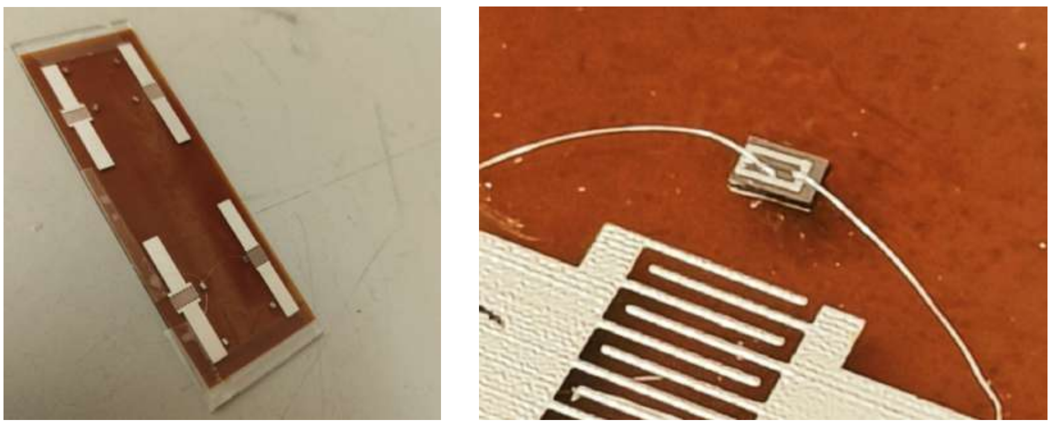
Figure 2.5: Closer look of wire bonding mechanism [8]

2.1.3. Thermosonic Bonding

The principal features of U/S and T/C bonding are married in T/S bonding (figure 2.5) [9]. Gold wire ball-and-stitch bonds are made, as in the T/C technique, but the capillary is driven by a burst of ultrasonic power at each bond to augment metal joining [9]. As a consequence, the substrate temperature may be lower than in T/C bonding [9]. Thermosonic bonding has been particularly successful in attaching wires to hard-to-bond thick-film hybrid substrate metallizations [9].

2.2. Wire Bonding Bare Silicon Die on Paper and Kapton Substrates

The screen printed soil moisture sensor on Kapton and Paper substrate was attached on a glass slide to have a rigid support during wire bonding owing to flexibility and low hardness of Kapton and Paper. If there remains a gap underneath the substrate and wire bonder workstage, it is very difficult to exert sufficient bonding force since no reaction force is generated from the surface. Thus the sensor was attached to a glass slide using BONDiT™ epoxy as shown in the Figure 2.6a. Then the same epoxy was used to attach the bare die to the substrate as shown in the Figure 2.6b.



(a) Sensor attached to glass slide

(b) Bare die on sensor

Figure 2.6: Sample preperation for wire bonding

For attaching the bare die to the substrate, special care had to be taken to avoid scratches and damage to the die. The distance of the die from the sensor electrode is also important, since longer distance cause wire sagging. Wire length around 15-20 mm worked without excessive sagging.

Figure 2.7 shows a bonded bare Silicon die, the other ends of the wire are connected to the sensor electrodes using silver epoxy since the wire bonding attempts were not successful as discussed next. Figure 2.8 shows the 10X magnification optical microscope images of the wire bonds. It can be observed that the wire at the substrate metallization has been plastically deformed during the bonding, the wire width after deformation should not be greater than 1.2 times the wire diameter to avoid excessive deformation and weakening of the bond.

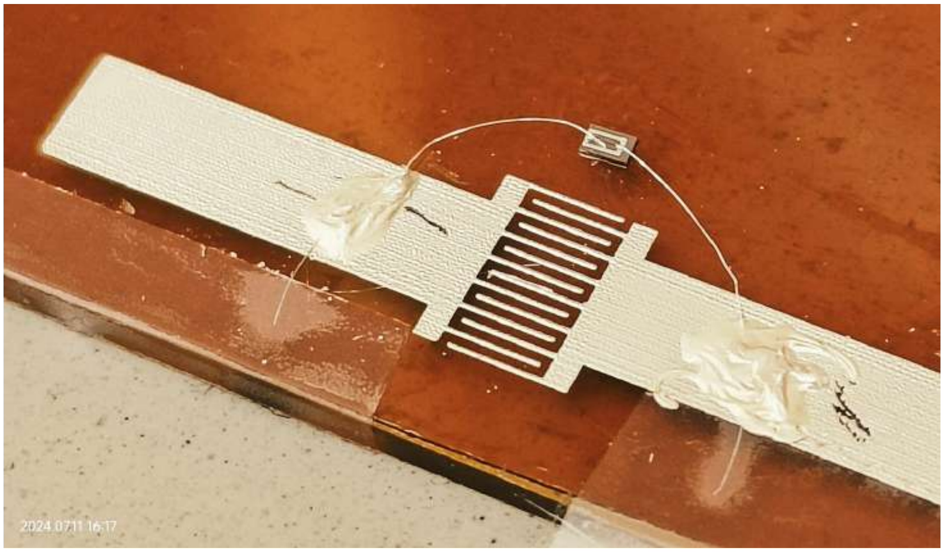
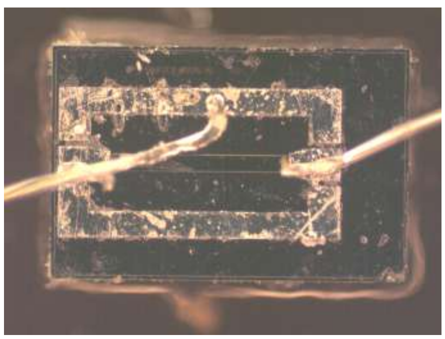
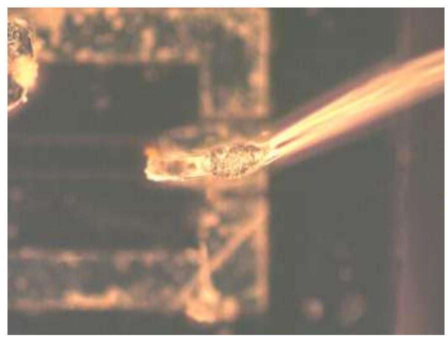


Figure 2.7: Wire Bonding and Epoxy Bonding



(a) Wedge bond



(b) Wedge bond leg and tail

Figure 2.8: Wedge bonds inspected under microscope

Figure 2.9 shows the same silicon die attached to a sensor on with paper substrates using the same epoxy. No differences were observed between the paper and kapton substrate during die attach and wire bonding.

2.3. Wire Bonding on Screen Printed Silver Metallization

Wire bonding on the silver metallization was not successful for both the substrates, which might be because of the porosity and low hardness of the screen printed silver electrodes. The hardness was tested on the Hysitron Nanoindentor and the hardness of silver substrate was found about an order of magnitude smaller than the hardness of aluminium metallization on the silicon. Silver paste was applied on glass substrate and annealed at 150°for 75 minutes. The the wire bonding trials were conducted on the annealed silver substrate metallization, which too were unsuccessful.

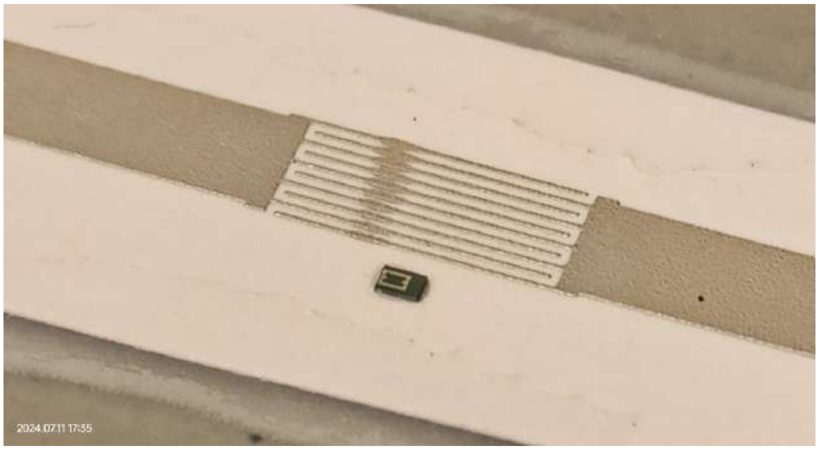


Figure 2.9: Bare Si die attached to paper substrate

Annealing at elevated temperature is to be tried, so that at the elevated temperatures (300 °C) the silver particles fuse together and recrystallize to form a less porous homogeneous substrate with increased hardness.

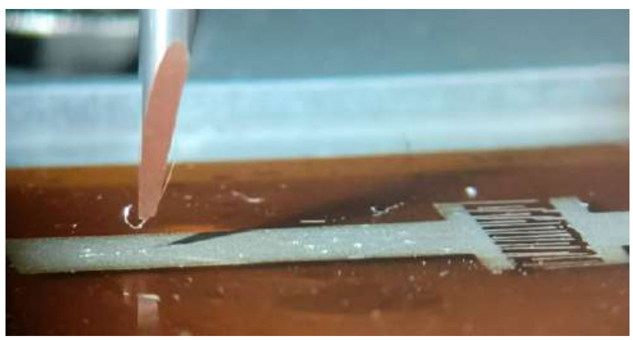
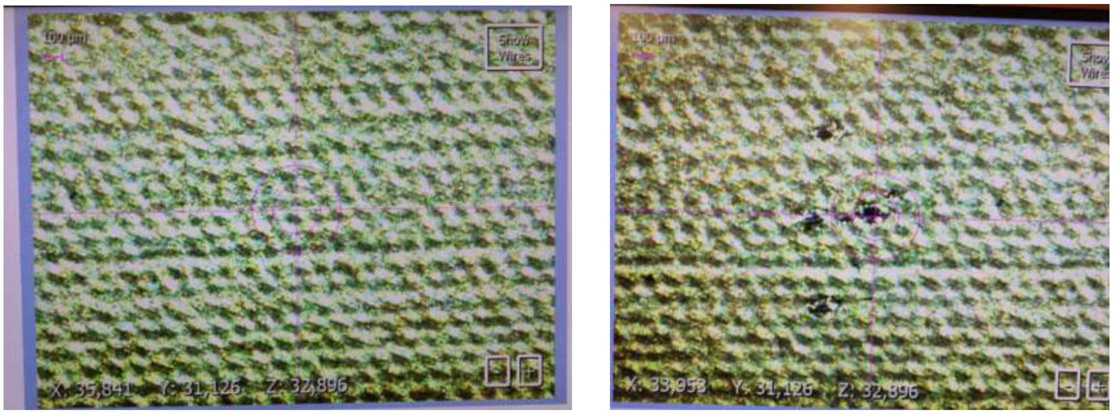


Figure 2.10: Wire bonding on silver metallization

During the wire bonding, the ultrasonic oscillations of the tool scratch the silver particles off the substrate and expose the substrate beneath, which observed in the Figures 2.11a and 2.11b. This might be due the hardness of the silver metallization being too low to break the aluminium oxide and expose the clean aluminium surface to Silver. Parameters for wire bonding as shown in the figure were tried but none of the parameter combination seemed to work on the silver nanopaste.



(a) Before Bonding (b) After Bonding Attempt

Figure 2.11: Silver scratched off by the bonding tool

The next chapter discusses the flip chip bonding method with focus on flexible and printed electronics.

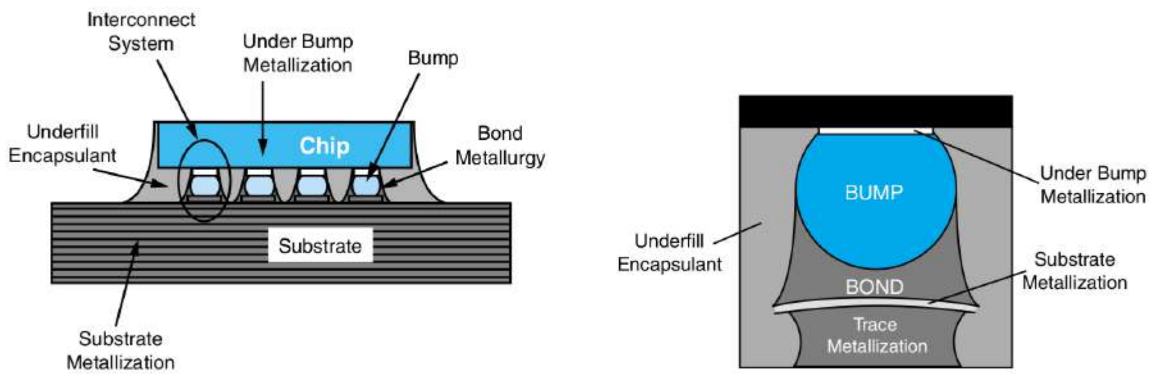
SECTION 3

FLIP CHIP BONDING

Flip chip interconnection is the connection of an integrated circuit chip to a carrier or substrate with the active face of the chip facing toward the substrate. Interconnection between the chip I/O and substrate is achieved using a bump structure on the chip and a bonding material, typically on the substrate, forming an electrical interconnection between the chip and the substrate [1]. Flip chip bonding typically involves solder interconnections that make the electrical and mechanical connection between the chip and the carrier, although alternate material systems such as conductive adhesives can also be used [1]. In contrast to wirebonding, which is a peripheral and time consuming bond technique, in which bonds are formed sequentially, the flip chip allows all I/Os to be connected simultaneously [1].

3.1. Basic Structure of a Flip Chip Interconnection

The interconnection system can be subdivided into four functional areas: under bump metallization (UBM); chip bumps, bond materials between the bump and substrate me tallization; encapsulant; and substrate metallization. A representative structure is shown in Figure 3.1. The IC bond pad interface metallization for flip chip applications consists of the UBM, chip bump, and bond materials.



(a) Flipchip Structure (b) Bond Structure

Figure 3.1: Flipchip Interconnection System

Following figures shows the process flow of conventional flip chip bonding technique:

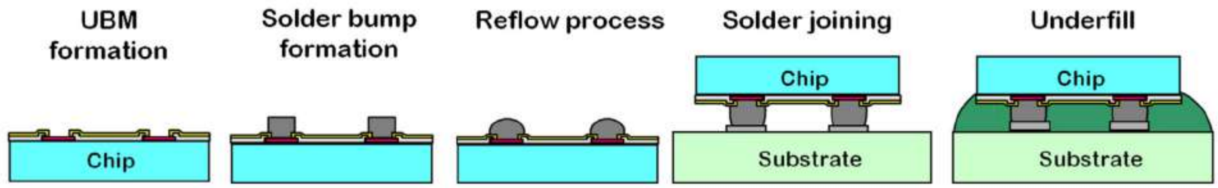


Figure 3.2: Conventional flipchip process [12]

3.2. Solderless Flip Chip Bonding

Briefly, claimed advantages of adhesives for flip chip joining include not only the environmental issues, but also fine pitch requirements (no solder masks) and the possibility of polymerizing at much lower temperatures in a reasonable time [13].

3.2.1. Isotropically Conductive Adhesives

Isotropically conductive adhesives (ICA) are pastes of epoxy resins which are statistically filled with silver or gold particles to a content that assures conductivity in all directions (up to 80 weight-%). The conductivity between the particles is grounded on touching each other. Process Flow [13]:

- Application of the ICP precisely onto the points to be electrically connected.
- Alignment of the bumps to the electrodes on the substrate.
- Bonding the chip by curing the adhesive typically @ 175°C for 2 minutes.
- Applying an underfill material for compensating thermal mismatch.
- Curing of the underfill material.

3.2.2. Anisotropically Conductive Adhesives

Anisotropically conductive adhesives (ACA) are pastes of epoxy resins or films of b-stage epoxies or thermoplastics (or blends). They are filled with massive gold particles or gold coated polymer spheres to a content that assures electrically insulation in all directions before but electrically conduction in z-axis only after bonding (up to 20 weight-%). The process flow can be divided into three steps [13]:

- Application of the ACA onto the whole substrate.
- Alignment of the bumps to the electrodes on the chip.
- Bonding the chip by curing the adhesive typically @175°C & 2 minutes and a load of 20 kg/cm2.

3.2.3. Anisotropically Conductive Film ACF

ACFs are cut with a chip-size, and then prelaminated on the substrate. Finally, the contact is established between the chip and the substrate by thermal compression bonding. When the compressive force is applied in the vertical direction or Z-axis, the conductive particles are trapped between the bumps on the chip and the corresponding pads on the substrate, making the electrical connections only in the vertical direction, as shown in Figure 3.3 Next, the heat or the energy is applied to cure the adhesive and maintain the mechanical connection.

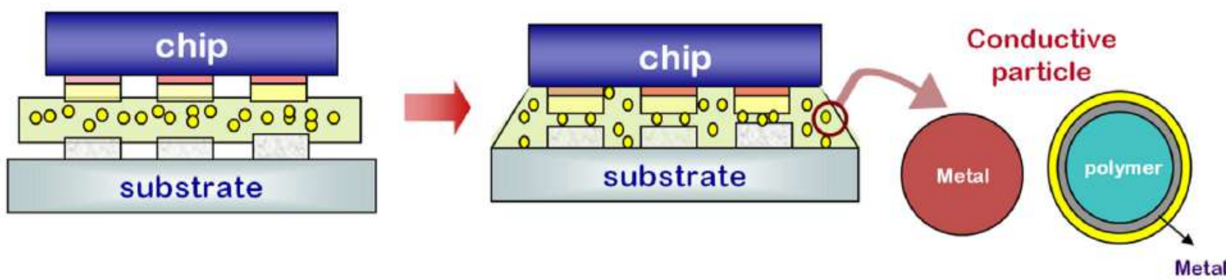


Figure 3.3: Flipchip Bonding using ACF [12]

3.2.4. Non Conductive Adhesives NCA

Non-conductive adhesives (NCA) are films of thermoplastics or b-stage epoxies(or blends) which are not filled with any particles [14]. The conductivity after bonding is grounded on direct contact between bump and substrate metallization. The process flow can be divided into three steps:

- Application of the NCF onto the whole substrates.
- Alignment of the bumps to the electrodes on the chip.
- Bonding the chip by curing the adhesive typically @75°C for 10 and a load of 20 kg/cm2 or 70 to 100 g/bump respectively.

The load has to be kept up until the adhesive is cooled down to a temperature lower than glass transition.

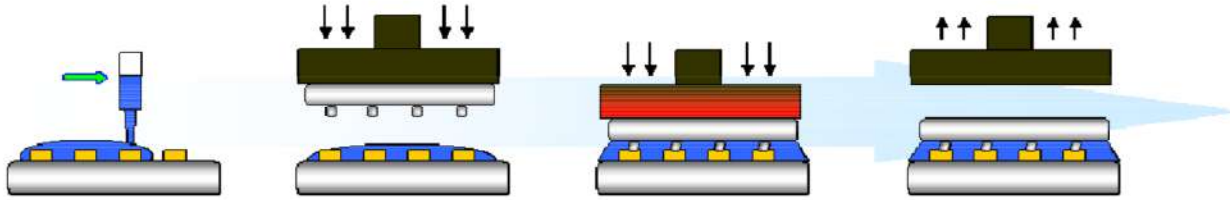


Figure 3.4: Process flow of Flipchip Bonding using NCA [15]

In order to penetrate the film there is a need for special formed so-called gold stud bumps. They can be achieved by thermosonic bonding of gold wire onto the chip 4.5 and tearing up the wire. The result is a mechanical ball bump with a ductile top region. This effect can be used to compensate nonplanarities between substrate and IC.

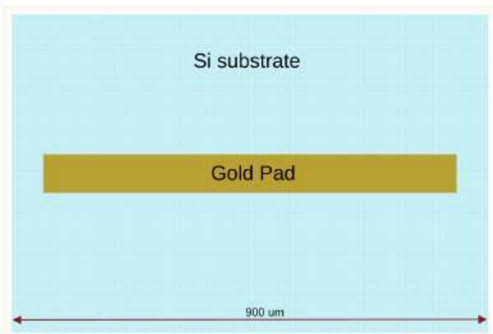
To determine the effectiveness of electrical connections in flip chip it is necessary to measure the electrical contact resistances at the bump-pad interfaces. Which is done using daisy chain chips as disucussed in the next section.

SECTION 4

FUTURE WORK

4.1. Daisy Chain Dies Layout

The flip- chip interconnects resistance is usually tested through the use of daisy chain chips [16]. The aim of these test structures is to probe the average electrical resistance that will clearly depend on the chosen Flip-chip technology [16]. Figure 4.1 shows the layout of the daisy chain chip to be fabricated. The chip with single pad is for measuring two contact and with double pad is for measuring four contacts.

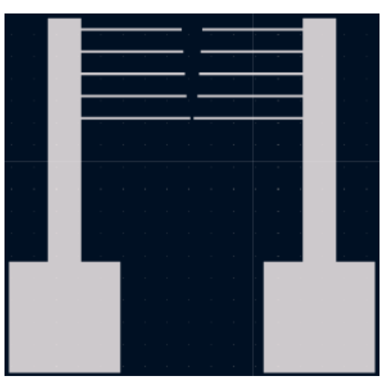


(a) Single Pad

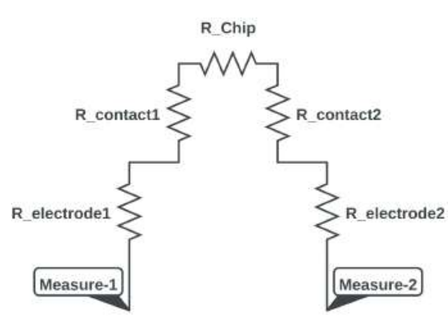
(b) Double Pad

Figure 4.1: Daisy Chain Chip Layout

The circuit to measure the resistances in two contact pads and four contact pad structures is illustrated in the Figure 4.2 and Figure 4.3, respectively.

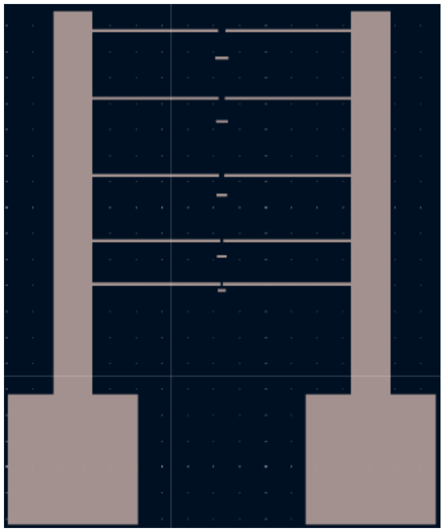


(a) Screen Print Layout

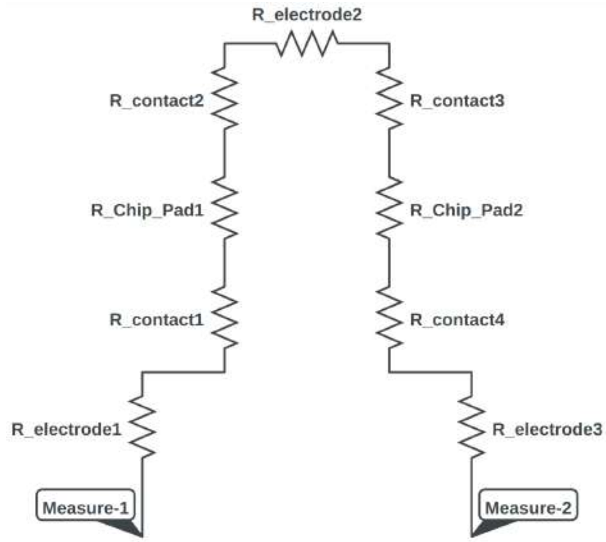


(b) Electrical Circuit

Figure 4.2: Setup to measure two contact resistances



(a) Screen Print Layout



(b) Electrical Circuit

Figure 4.3: Setup to measure four contact resistances

4.2. Fabrication Steps

4.2.1. Lift Off

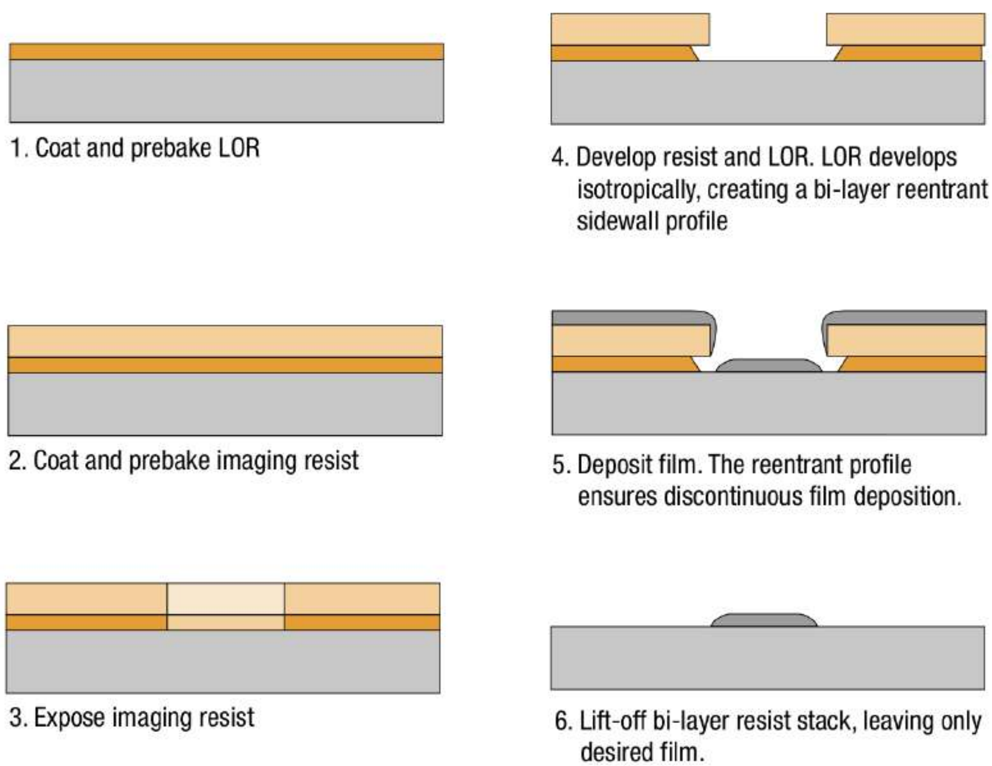


Figure 4.4: Lift Off Process for Chip Fabrication [17]

4.2.2. Dicing

To dice the wafer, (Advanced Dicing Technologies Ltd.) ADT 7120 / 7130 dicing tool available at the Packaging Lab at Singh Center for Nanotechnology will be used.

4.3. Bump Formation

The TPT HB100 wire bonder has a facility to form the gold bumps as shown in the Figure 4.5.

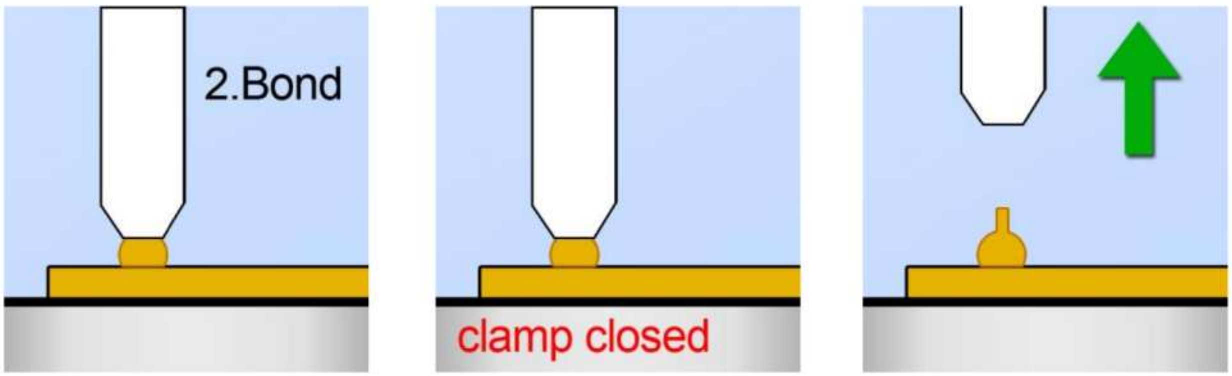


Figure 4.5: Forming gold bump [18]

4.4. Screen Printing

The layout as shown in the Figures 4.2a and 4.3a will be screen printed on the paper and Kapton substrates.

4.5. Flip Chip Bonding

For flip chip bonding, FineTech Fineplacer Pico2 Flipchip Bonder will be used. From the study of adhesives, Anisotropically Conductive Adhesive Paste is a promising and viable technique.

4.6. Contact Resistance Measurement

From the circuits shown in the Figures 4.2b and 4.3b:

$$\begin{aligned} R_{measured} &= 2 \cdot R_{electrode} + 2 \cdot R_{contact} + R_{Chip} \\ \therefore R_{contact} &= \frac{1}{2} \cdot (R_{measured} - 2 \cdot R_{electrode} - R_{Chip}) \end{aligned} \tag{4.1}$$

Where $R_{measured}$, $R_{electrode}$ and R_{Chip} are known.

SECTION 5

CONCLUSION

The objective of this study was to attach the MEMS resonator die on the paper substrate of the IoT4Ag soil moisture sensor. Wire bonding on aluminium pads was successful whereas on the silver metallization it was unsuccessful. But the wires could be connected to the silver metallization using Silver epoxy, which is a promising workaround for the problem. Flipchip bonding techniques for flexible electronics were reviewed. Anisotropically Conductive Adhesive Paste seems promising since it needs no bumps formation on the chip and fewer process steps as compared to Anisotropically Conductive Films (ACF) and greater reliability as Compared to Non Conductive Adhesives (NCA) which also needs bumps on the chip. But ACF allows for wafer level processing since the entire wafer can be covered with the adhesive film and cured to reduce process time.

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