SEMICONDUCTORS: ADVANCEMENTS IN COPPER WIRE BONDING TECHNOLOGY

Summary

With each new generation, electronic devices are expected to deliver higher performance in increasingly compact spaces. This ongoing trend necessitates the continual miniaturization of components and the refinement of structures. The advent of wire bonding has revolutionized the assembly and packaging of integrated circuits and other devices in the semiconductor industry. This paper offers a comprehensive exploration of the historical background of wire bonding, including its evolution, advancements, and the economic advantages and considerations associated with its implementation. In addition, the importance of the forming gas in the quality of the copper wire and the impact of the oxygen level during the process will be discussed. Gas mixers and gas analysers not only make the process particularly economical, but also make a significant contribution to improving the entire wire bonding process.

CONTENT:

1. INTRODUCTION

Wire bonding is a crucial technology in the microelectronics industry, facilitating the interconnection of integrated circuit (IC) devices and their packages. Following decades of using gold (Au) wires, advancements in wire bonding have facilitated the replacement of gold wires with copper (Cu) wires. However, this change has come with some challenges regarding the quality of the interconnection process. The modification in the connections and use of the forming gases are introduced to address the aforementioned challenges. The crucial role of the gas mixers and gas analysers in the achievement of the high-quality of this shielding gas is undeniable. In the paper, during part 2 to 6, various aspects of copper wire bonding have been investigated.

Part 2 provides a comprehensive overview of Cu wire bonding technology. It delves into its historical progression, tracing its origins from the early days of wire bonding to the present, where Cu has emerged as a popular alternative to traditional Au wire. Different bonding methods are elucidated, displaying the evolution of the process and the technical innovations that have shaped modern Cu wire bonding. Moreover, this section examines new methods recently developed, highlighting their potential advantages and their implications for the future of microelectronics packaging.

Part 3 focuses on the effectiveness of oxygen (O2) levels during the Cu wire bonding process. O2 levels can significantly influence the bonding process results and affect the properties of Cu wire bonds. This part of the research sheds light on the effect of the O2 level on the bond quality.

Part 4 explores the factors affecting the achievement of a robust and complete FAB to create a reliable bond. Using Shielding gas (forming gas), controlling the flow rate of forming gas, controlling the flow rate of EFO, and the gap length of EFO are considered as the mentioned affective factors.

Part 5 explores the practical application and value of a gas mixer, gas analyser, and some related equipment in the Cu wire bonding process. These devices are essential in controlling the composition and purity of the forming gases used during annealing. Understanding their usability and benefits can lead to more efficient and accurate bonding processes, contributing to higher yields and improved manufacturing reliability.

Finally, in part 6, the research culminates with a glimpse into future developments in Cu wire bonding technology by introducing potential areas of innovation and research in the improvement of gas mixers and related accessories. These new technologies pave the way for more reliable and efficient microelectronics packaging in the future.

2. HISTORY, TECHNOLOGY AND METHODS, ADVANTAGES AND DISADVANTAGES

2.1. HISTORY OF WIRE BONDING

Early days:

The early 1950s: Introduction of wire bonding for interconnecting IC chips.
Use of manual wire bonding techniques with Au wire.

Advancements:

1960s-1970s: Development of automatic wire bonding machines for mass production.
Widespread adoption of gold wire as the preferred bonding material.

The emergence of Cu wire bonding:

The late 1990s-2000s: Exploration of alternative materials due to rising Au prices.
Introduction of Cu wire as a potential alternative to Au wire.

Acceptance and adoption:

The early 2000s: Initial use of Cu wire bonding in specific applications.
The advantages of Cu wire, such as cost-effectiveness and superior properties, gain recognition.

Mainstream usage:

2010s: Growing acceptance and implementation of Cu wire bonding.
Widespread adoption across various semiconductor packages.

Ongoing research:

Current: Continuous research and development to enhance Cu wire bonding technology.
Exploration of new materials and advanced bonding techniques.

2.2. WIRE BONDING TECHNOLOGY

Wire bonding is a method to create electrical interconnection between two metallic materials, which include wire and pad surface or wire to lead surface. Wire bonding uses thin wire and a combination of heat, pressure and/or ultrasonic energy, and depending on the material of the wire and pad, alloys such as solid solution or intermetallic compound (IMC) can be formed at the bonding interface [1]. There are three technologies to the wire bonding process, namely, thermocompression bonding, ultrasonic bonding, and thermosonic bonding. A comparison of these three wire bonding technologies is shown in Table I [2].

2.2.1. Thermocompression bonding

Thermocompression bonding is a process using temperature and pressure. This process requires a temperature above 300 °C and a bonding force of about 0.147–0.245 N which are too high and can damage the under-pad structure [2].

2.2.2. Ultrasonic bonding

Ultrasonic bonding utilizes force and ultrasonic power and in contrast to thermocompression bonding, it does not require high temperature. This technology is performed at room temperature, because ultrasonic energy causes morphological changes equivalent to those caused by heat, thus causing less damage [2].

2.2.3. Thermosonic bonding

Thermosonic bonding technology consists of ultrasonic energy, pressure, and heat to form a metallurgical bond. The bonding force and time in ultrasonic and thermosonic bonding are lower than those in thermocompression bonding. In the thermosonic bonding process, heat is provided by placing the package on a heated stage or with a thermal bonding tool. The bonding force is applied to contact with the bond surface by pressing the bonding tool into the wire. The tool force controls the amount of required weight to connect the wire to the pad surface. Wire and pad metallization is softened by heat and ultrasonic energy, and it is caused to deform against the pad metallization thus forming a metallurgical bond [2].

TABLE 1. Wire bonding technology

	Thermocompression	Thermosonic	Ultrasonic
Ultrasonic power	No	Yes	Yes
Bonding force	High	Low	Low
Temperature	High (> 300℃)	Middle (120-220 ℃)	Low (room temperature)
Bonding time	Long	Short	Short
Wire material	Au	Au	Au, Al
Pad material	Au, Al	Au, Al	Au, Al
Contamination	Strongly affected	Middle	Middle

2.3. CLASSIFICATION OF WIRE BONDING

Wire bonds can be classified into two types: ball–wedge bonding and wedge–wedge bonding.

2.3.1. Ball-wedge bonding

In the ball-wedge bond process, three axes of movement (X-, Y- and Z-direction) are required. This method is used for forming most of the wires in electrical packaging and commonly for Au and Cu wires [2].

2.3.2. Wedge-wedge bonding

Wedge bonding is preferred in deep access, fine pitch, and low- and short-loop applications, including microwaves and optoelectronics. It requires four axes of movement (X-, Y-, and Z-direction, as well as θ). It is noticeable that, in this type of bonding, aluminum (Al) wires are used [2].

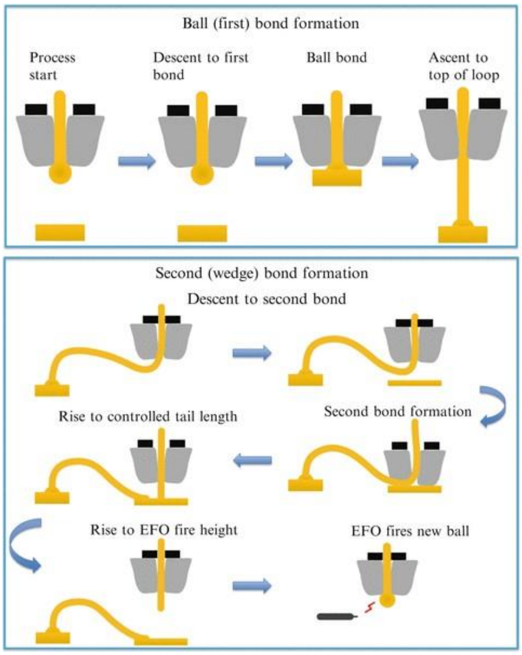
Among the wire bonding technologies, thermosonic bonding is the most common wire bonding technique used in semiconductor packages. Also, ball–wedge bonding is more commonly used than wedge–wedge wire bonds because it is so faster than wedge-wedge bonding [2]. A comparison of ball bonding and wedge bonding is shown in Table II [2].

TABLE 2. Comparison of different bonding applications

	Ball bonding	Wedge bonding
Bonding techniques	Thermocompression (T/C)	Thermosonic (T/S)
	Thermosonic (T/S)	Ultrasonic (U/S)
Temperature	T/C—> 300 °C	Al wire—U/S at room temperature
	T/S—120–220 °C	Au wire—T/S 120–220 °C
Wire size	Small (<75 μm)	Any size wire or ribbon
Pad size	Large (3–5 times of wire diameter)	Smaller pad size than a ball bond. Good for microwave applications. The pad size = 2–3 times of wire diameter (could be = 1.2 times of ribbon width)
Pad material	Au, Al	Au, Al
Wire material	Au	Au, Al
Speed	Fast (10 wires/s)	Relatively slow (4 wires/s)

During the ball-wedge bonding process, thermosonic bonding creates the first bond called the ball bond, usually on the chip pad, and then the second bond called the wedge bond, to another metal. First, the free end of the wire is divided into three parts: a free air ball (FAB), a heat-affected zone (HAZ), and an as-drawn wire because of electrical flame-off (EFO). The EFO process forms the FAB by ionization of the air gap. Figure 1 [2] shows a schematic of the ball-wedge bonding process. Based on Figure 1, the bonding tool called capillary goes down to the location of the first bond. In step 3, thermal and ultrasonic energy make the first bond by bonding a spherical ball to the pad. During steps 4,5 and 6, the loop moves to the other metal to form the second bond. The motion of the loop is programmed to achieve the desired loop height and shape. Step 7 is the level at which the second bond is created to bond the opposite end of the wire loop to the metal of the substrate. During steps 8,9 and 10 the bonding tool rises to break off the tail of the wire, and then the height of the bonding tool rises further to the formation of the ball to create the first bond again [2].

FIGURE 1. The ball-wedge wire bonding



2.4. ADVANTAGES AND DISADVANTAGES OF GOLD AND COPPER WIRE

Au wire has been the most common wire used to connect Al pads on IC chips to lead frames. Au wire has been used for more than 55 years because of some advantages, including mechanical and electrical properties, high reliability, and ease of assembly [3]. However, the high costs of this wire and the continuous increase in market prices cause the exploration of alternative metallurgies [2]. These reasons led to the exploration of alternative wires for Au. Lower cost, higher mechanical strength, lower electrical resistance, slower intermetallic growth on Al pads, and higher thermal conductivity are all the reasons that make Cu a considerable alternative. However, replacing Cu wire with Au wire has many challenges including high oxidation rate, corrosion, and high hardness [3]. Table 2 [4] shows a comparison of the properties of Au and Cu wires. Due to the high hardness of Cu wire compared to Au and the low oxidation resistance, a series of factors and parameters in the bonding process, including bonding force, must be controlled. The high hardness of Cu and high bonding force cause damage to the Al pads during the process. To reduce the risk of being damaged Al pads by Cu wires, the industry has used thicker Al pads than those used in the Au wire bonding as well as nickel (Ni)-based finishes. Also, to prevent oxidation, an inert gas must be used during the bonding process. In some cases, to increase resistance oxidation, wire manufacturers have used palladium-coated Cu wire (PdCu). However, the low cost of Cu has driven the transition from Au wire to Cu wire [2].

TABLE 3. Material properties of Au and Cu wires

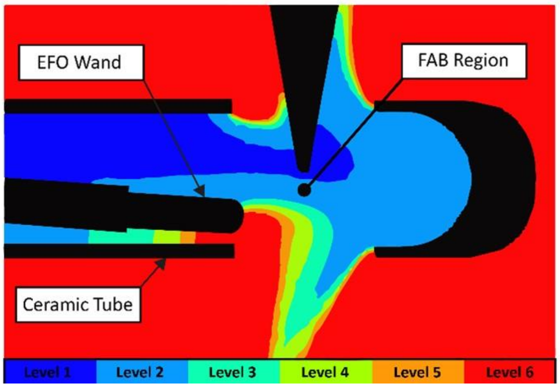
Property	AU	Cu
Thermal conductivity (W/mK)	320	400
Electrical resistivity (Ωm)	2.20	1.72
Young's modulus (GPa)	60	130
Poisson's ratio	0.44	0.34
Yield stress (MPa)	32.70	200
Coefficient of thermal expansion (ppm/℃)	14.40	16.50
Vicker's hardness (MPa)	216	369

Today, there is a global approach towards employing integrated circuits (ICs) with Cu wire bonding. The increasing price of Au and the expanding worldwide demand for electronic devices are the primary factors driving this current trend. The companies named Amkor, Texas Instruments (TI), Heraeus, Altera, Carsem, Freescale, Infineon, and several Japanese companies, have adopted this approach in their relative facilities. However, many companies are not yet ready to use Cu wire in their industries due to the cost, equipment, and expertise to develop the Cu wire bonding process [3].

3. THE EFFECTIVENESS OF O2 LEVEL

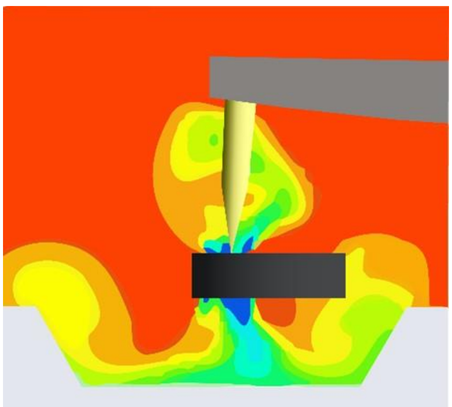
In the study by John Foley and others [5] the internal geometry and gas flow behavior are investigated using computation fluid dynamics (CFD). One of the parameters predicted from CFD is the oxygen levels within the FAB formation environment. The controlled environment is studied closely while monitoring oxygen levels with an oxygen sensor. The importance of O2 level in copper wire bonding is to ensure minimal oxidation occurs during the process, as oxidation will affect bondability, bond strength, and the quality of bonding. Fig. 2 [5] shows the CFD model of the internal geometry and behavior of gas flow are characterized.

FIGURE 2. CFD model analysis



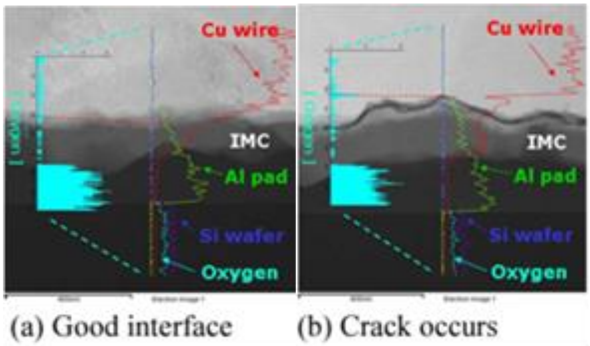
If the oxygen level is above a certain level, the FAB deforms and oxidizes. Oxygen level in the wire bonding process has become a quantifiable requirement for gas delivery system design. Fig. 3 [6] shows the CFD model of oxygen concentration. As the EFO current increases, the temperature caused by the melting of the copper wire elevates. It might induce a rapid expansion of the forming gas volume surrounding the FAB. If the gas flow rate is not sufficiently high to provide a completely inert gas cover during the melting of the copper FAB, oxidation may occur at the surface layer of the molten copper FAB due to the presence of oxygen in the surrounding air and eventually causing the formation of a pointed FAB [7].

FIGURE 3. Computational fluid dynamics model of oxygen (red = high, blue = low) concentration around the cover gas flow head



According to Ivy et al. [8], a lower oxygen level in an expanded area can be achieved by developing a finer-forming gas delivery system. After many years of innovation, advanced forming gas delivery systems nowadays can limit the oxygen content to less than 1% around the FAB. Fig. 4 [9] shows the comparison of oxygen content at the bonding interface. The presence of Cu in humid conditions makes it oxidize easily. Also, the performance of Cu-Al in high humidity reliability is low because the Cu-Al system is weak against corrosion which makes cracks between the Al pad and Cu wire. Generally, well-bonding cases detect very little oxygen at the Cu wire or Al pad part including the bond interface [9]. When high oxygen levels penetrate the external environment, it may cause corrosion, which can be controlled by lowering the moisture absorption material to prevent an inflow of oxygen which can increase the reliability of the process and avoid crack generation. In a humid environment to ensure copper wire bonding on the aluminum pad, a dry environment with less halogen and a large IMC is ideal [10].

FIGURE 4. Comparison of oxygen contents at the bonding interface



From the research of Z.W. Zhong [11] also, oxidation of Cu wire causes weak bondability for stitch bonds and thus leads to increasing the rates of non-sticking. When a spool of Cu wire is on the machine bonding for a long time, the thick oxide increases and prevents the creation of a good wedge bond. To address the poor stitch bondability due to surface oxidation, a new capillary has been developed with a new surface morphology. In short, FAB oxidation will result in inconsistent ball shape and size, posing challenges in controlling bonding parameters. The harder FAB which is created by the oxide layer, requires more force and ultrasonic energy to bond, and it will increase the risk of bond pad damage. Besides, the oxidation layer will affect the contact of pure metal between FAB and the bonding pad, and contribute to non-stick bonding, especially on second bonding, which is mostly wedge bonding.

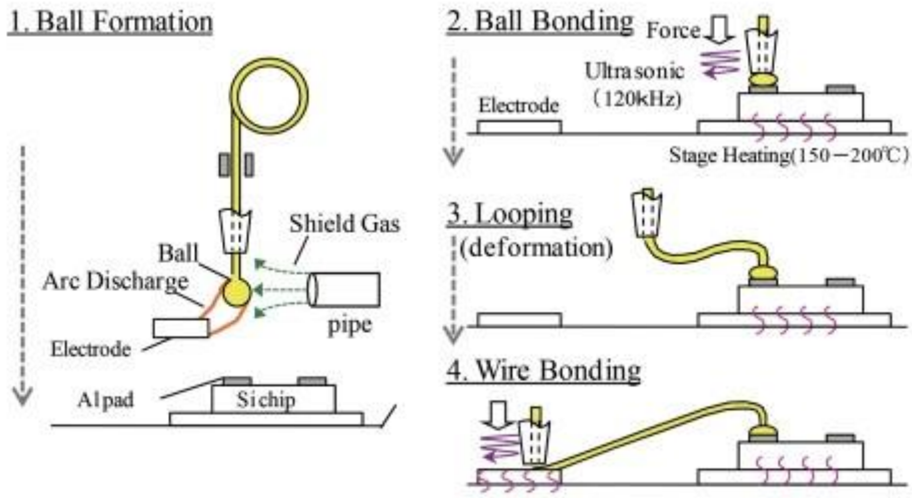
4. EFFECTIVE FACTORS ON THE QUALITY OF FREE-AIRE BALL

Although the mentioned specifications make the Cu wire bonding a suitable alternative, pure Cu wire is not recommended for use directly in the semiconductor industry because it could be easily oxidized. To create a symmetrical and spherical ball with precise dimensions throughout the EFO process, the FAB must not be oxidized during its formation. If the copper is oxidized, the oxide will form on the ball surfaces which will make the bonding process difficult and may even lead to pad damage and weak bonds. There are solutions to protect copper wires against oxidation, including the use of shielding gas (forming gas), the control of the flow rate of shielding gas, the control of the flow rate of EFO, and the gap length of EFO [2].

4.1. SHIELDING GAS (FORMING GAS)

To mitigate oxidation, the role of gases in achieving a reliable bond is significant. Forming gas composed of H2 and N2 with various ratios, typically 5% H2 and 95% N2 is a protective gas to inject during the bonding. Fig.5 [12] shows the process of wire bonding and injection forming gas during the FAB formation. The purity of nitrogen and hydrogen used in forming gas is usually grade 5, which contains about 3 ppm hydrogen and 3 ppm moisture. Based on the study from Chauhan et al. [2] initially, N2 was used to provide an inert atmosphere around the FAB, but after a while, it was found that a mixture of N2 and H2 can act more effectively than pure N2 to prevent oxidation. However, in Pd-Cu wire, N2 gas alone is sufficient to prevent oxidation [3]. The presence of H2 in the forming gas plays a great responsibility in forming the ball, the benefits of adding this gas include providing additional thermal conductivity during FAB formation, producing a larger FAB, tending to create a spherical FAB, and reducing oxidation [13].

FIGURE 5. Wire bonding process



According to the study by T. Uno [13] H2 gas effects are discussed in terms of two characteristics, heating power and arc constriction. Compared to other gas species, H2 has a higher arc voltage because of the lighter atomic weight of the gas. The higher the arc voltage and heat flux density, the greater the heating power of the H2-shielded arc. Eventually, H2 in the forming gas is expected to provide more heating energy to the Cu wire rather than pure N2, resulting in a larger FAB size for the N2+H2 mixture. On the other hand, as it was mentioned, H2 has a lighter atomic weight and lower H-H bond energy. Therefore, it tends to expand outward in the arc discharge compared to N2 gas which leads to a greater cooling action of H2. Heat transfer causes the temperature on the arc fringe to decrease and arc plasma would go off it. The net effect of the cooling of H2 is the consequent arc constriction. This effect is the 'thermal pinch effect' in welding technology which is significant with H2 in the forming gas. Table 4 [13] shows the FAB size of coated Cu wire (EX1) and bare wire in the pure N2 and N2+H2. However, an important issue during injection forming gas in the FAB process is increasing H2. In addition to the advantages that H2 brings to the FAB process, it can come with disadvantages including higher costs, and safety issues with hydrogen as a flammable gas [13]. H2 is a highly flammable gas and belongs to the group of gases of impact insulation class (IIC) and temperature class T1, which makes it one of the hottest and most dangerous gases [14]. The flammable range of Hydrogen (spanning from 4% to 77%), coupled with features like ignition properties and buoyancy requiring engineering control, mandates the establishment of a system to ensure its safe use [15].

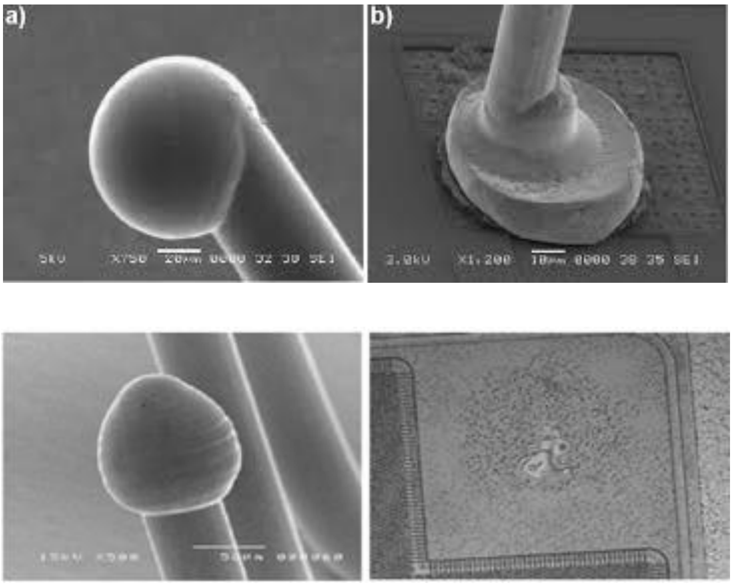
Table 4. Size of Cu wire

Forming gas	EX1	Bare Cu
N2	48.7	48.4
N2+5%H2	51.5	50.9

4.2. FLOW RATE OF FORMING GAS

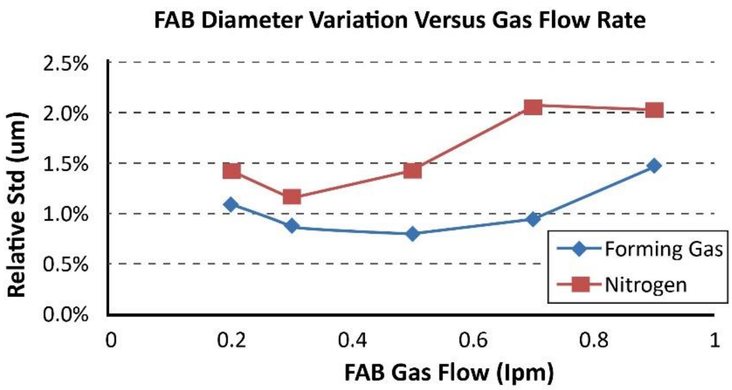
The quality of the FAB can be controlled by the forming gas flow rates. According to Pequegnat, Mayer, Persic & Zhou [16] high flow rates may cause defects in the shape of the FAB due to the flow change from laminar to turbulent and the change of the EFO process. Fig. 6 [17] shows Golf bonds are caused by tilting of the FAB caused by excessive input energy or too rapid flow of shielding gas.

FIGURE 6. Golf bond caused by tilted FAB formed with excessive input energy or too fast flow of shielding gas



Oppositely, if the forming gas supply is insufficient, the FAB will be oxidized because the oxygen surges into the glass tube through the hole where the capillary passes [2]. Therefore, the gas flow rate should be controlled in FAB formation to create a perfect FAB. Jiang et al. [7] conducted an experiment to optimize the forming gas flow rate and EFO settings for copper FAB with a certain diameter. They reported that a flow rate lower than the optimum level leads to partially oxidized and distorted FABs. However, a flow rate higher than the optimum level leads to a strong convection effect and the formation of pointed balls. Also, the effect of gas flow rate on FAB formation is proved by Chylak et al. [6], where consistency of the FAB diameter becomes worse for gas flow rates at both the high and the low end of the range. Fig. 7 [6] shows the variation of FAB diameter versus the rate of FAB cover gas flow rate for both forming gas and nitrogen. In conclusion, the flow rate of the forming gas influences the prevention of oxidation and the shape of the FAB, because a low forming gas flow rate cannot prevent the FAB from oxidizing, and a high flow rate may cause a pointed ball.

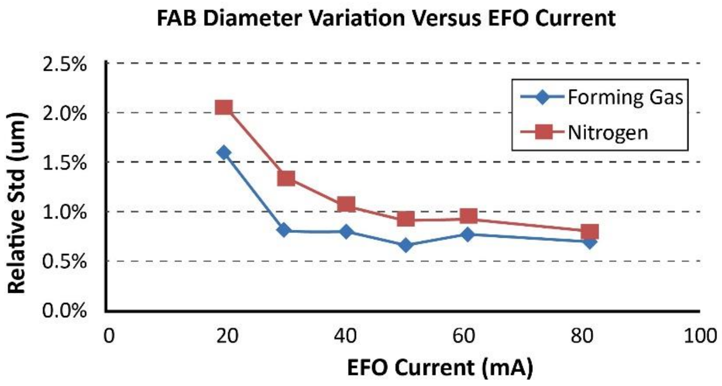
FIGURE 7. FAB Diameter variation versus FAB cover gas flow rate for both Forming Gas and Nitrogen for 15µm Pd-Cu wire



4.3. FLOW RATE OF EFO

EFO current, which can be different depending on the type of wire, has a significant effect on FAB formation. For example, Cu wire requires a higher EFO current than Au wire. EFO current and EFO firing time are ultimately associated. The lower the EFO current, the longer the EFO firing time to produce the same FAB diameter. If the EFO current is increased, there is a higher tendency to form the clubbed balls [6]. Fig. 8 [6] illustrates the variation of FAB diameter in different EFO currents for both forming gas and nitrogen. The variation in wire diameter impacts FAB diameter, yet it remains uncontrolled in Cu wire bonding. Depending on the wire diameter, EFO current, and firing time, the ratio of FAB diameter to wire diameter should fall within the range of 1.6 to 3. Therefore, based on the type and diameter of the wire, the EFO current and gas flow rate should be optimized [2].

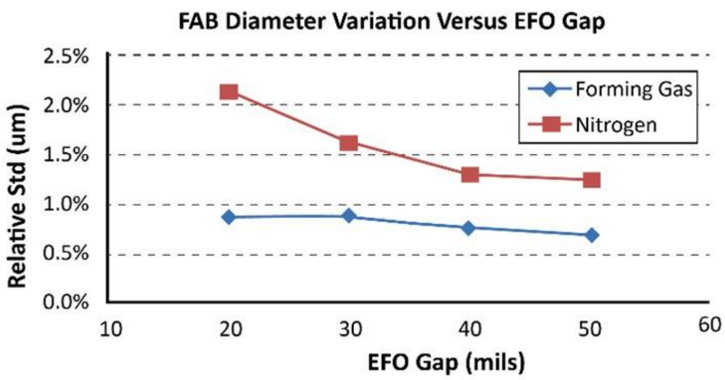
FIGURE 8. FAB Diameter variation versus EFO Current
for both Forming Gas and Nitrogen for 15μm Pd-Coated Cu wire



4.4. THE GAP LENGTH OF EFO

Additionally, the vertical distance between the tip of the EFO wand and the tail of the wire before FAB formation is an important consideration in copper wire bonding. Fig. 9 [6] illustrates the variation of FAB diameter in different EFO gap settings for both forming gas and N2. According to Chylak et al. [6], the shorter the EFO Gap, the higher the consistency of the FAB diameter.

FIGURE 9. FAB Diameter variation versus EFO Gap setting for both Forming Gas and Nitrogen for 15μm Pd-Cu wire



To conclude, there are two options for gas types to choose from as shielding gas: pure N2 gas and a mixture of 95% N2 and 5% H2 gas (forming gas). Pure N2 gas can be used for

Pd-Cu wire while for bare Cu wire, N2+H2 mixture forming gas is recommended. In addition to the shielding gas, several other parameters merit consideration in the FAB formation process, including gas flow rates, temperature, the vertical distance between the tip of the EFO wand and the tail of the wire before FAB formation, and the amplitude of the EFO current.

5. GAS MIXERS AND THEIR VALUABLE APPLICATION IN COPPER WIRE BONDING PROCESS

As discussed, in the FAB formation process, oxidation must be avoided to obtain a symmetrical FAB without deviation in size and result in a reliable bond. The oxidation of Cu can be prevented by using forming gas during bonding. It should be considered that oxidation also could occur if the flow rate of the forming gas is not controlled properly. The forming gas is a mixture of hydrogen and nitrogen; nitrogen is an inert gas that shields oxygen from the environment, and hydrogen promotes the soldering process [2]. Although pre-mixed standard gas combinations are commonly available, there is a notable advantage to on-site gas mixing, particularly in scenarios involving high consumption, the requirement for specialized gas compositions, or frequent adjustments to the gas mixture [18]. A high-quality and homogeneous mixture of two or more technical gases is best produced using gas mixers. They provide a customizable combination with adaptable capacity to suit specific project requirements with variable flow rates of up to 2180 Nm3/h. For an even higher flow rate, the simultaneous operation of multiple mixers is made possible through the integration of changeover devices. These devices not only enhance operational flexibility during peak production phases but also facilitate seamless transitions between mixers in the event of malfunctions or for calibration purposes.

5.1. TYPE OF GAS MIXER

Gas mixers are available in various types, including those equipped with mechanical mixing valves, electronic mixing valves, and flow rate controllers such as Mass Flow Controllers (MFCs) [19].

5.1.1. Gas mixer with mechanical mixing valve

This type is available in two versions, metering valve and proportional valve. For two gas mixtures, proportional valves are ideal which have two gas inlets and one gas outlet. With three or more gases, simpler mechanical metering valves, with one valve for each gas, can be used [19].

5.1.2. Gas mixer with flow rate controllers (mass flow controller or mfc)

Gas mixers with MFC technology have maximum precision in gas mixing. These systems regulate the production of gas mixtures by controlling the mass flow of each gas involved. The volumetric flow rate of the gases is logged in the relevant mass flow controller which utilizes thermal conductivity for regulation. Then the volumetric flow rates of the individual gases are combined to create the desired mixture [19].

FIGURE 10. Different types of gas mixers

5.2. THE ACCESSORIES OF THE GAS MIXER TO IMPROVE THE QUALITY

5.2.1 Analyser

Gas analysers are highly versatile and determine gas concentrations in gas mixtures quickly and precisely. By monitoring the mixture, they can send feedback to the mixer to keep the concentration within the set range. These devices are equipped with various and highly accurate sensors that make the analysers easy to operate and the entire process more reliable. By providing high quality and safety in the process, the analysers can be integrated with a gas mixer where continuous analysis (in-line) of the gas concentration is required. These devices can analyze the level of the H2 of the gas mixture, which can affect the quality of the FAB process. Among the options of analysers, the Ethernet interface, USB interface, remote settings, software for monitoring, fully automatic calibration, data logging, digital printer, and email service can be mentioned [19].

FIGURE 11. Integrated analyser (Inline)

5.2.2. Inlet Pressure Monitoring

Inlet pressure monitoring is one of the other accessories that help to improve the quality of gas mixers. By monitoring the pressure of up to five gases simultaneously, these devices guarantee the quality and productivity of the production process. Pressure monitoring devices have optical and acoustic alarms that are activated in case of gas failure. They also have an explosion-proof system for use in hazardous areas [19].

FIGURE 12. Inlet pressure monitoring

5.2.3. Automatic Switchover

Continuous supply of gas is one of the essential requirements of many industries, especially in the semiconductor industry. The switchover is a parallel installation of dual gas supplied which helps uninterrupted gas supply. This device is a suitable solution during periods of peak demand and facilitates the maintenance of gas mixers. The switch station monitors the performance of the gas supply by receiving data from integrated analysers and pressure transmitters. When a pressure drop occurs, the switchover device cuts off the flow of the first system and activates the second system. This process ensures uninterrupted gas supply and continuous production by transitioning between systems. Also, during maintenance or repair of one of the mixers, it can be switched over to another system without cutting off the production process. These operations are conveniently carried out via touch screen [19].

Figure 13. Automatic Switchover

6. POTENTIAL AREAS OF INNOVATION THAT CAN DRIVE ADVANCEMENTS IN THE GAS MIXERS AND GAS ANALYSERS

As previously mentioned, gas mixers have a crucial role in the semiconductor industry because they serve as a lifeline for copper wire bonding technology. However, to improve the bonding process it is necessary to equip gas mixers with the latest technologies. As already stated above, the percentage of oxygen around the FAB has a significant effect on the quality of the FAB and as a result the bond. Gas mixers equipped with a flow control system and an O_2 analyser can measure the level of oxygen continuously, and the flow rate of the forming gas can be controlled accordingly. This method can greatly help to increase the quality of the bonding process and optimize the consumption of forming gases. Another issue is the purity of gases, which affects the reliability of bonding. In the future, one of the elements that will be investigated will be the effect of the purity of gases on the quality of the FAB formation. An area for further improvement in this context is the enhancement of communication and device monitoring capabilities. In the realm of the Internet of Things (IoT), real-world events are detected and processed to generate relevant responses. It is worth noting that any IoT application that utilizes software to generate a response to a triggering event can be considered an initial form of artificial intelligence (AI). As a result, AI plays a vital role in enabling the IoT to function optimally. Chances are with the advancement of the IoT and the subsequent increase in the use of AI, communication, and control of gas mixers will happen without human intervention and bring about more efficiency.

7. CONCLUSION

Given the rapid evolution of technology and the crucial role of advancements in the semiconductor industry, this paper provided an overview of the historical development of the wire bonding process and its subsequent improvements. It was observed that the increasing gold costs resulted in the substitution of copper wire in this industry. The paper discussed the challenges encountered by using copper wires and the technologies implemented to improve the bonding process in semiconductor industries. In exploring copper wire bonding methods, ball-wedge bonding emerged as a preferred one. However, in this method, oxidation posed a significant challenge, resulting in pad damage and weak partial connections following the molding process. Forming gas, a mixture of nitrogen and hydrogen was examined as an effective solution to prevent oxidation during the FAB process. This protective gas can be produced using state-of-the-art gas mixers and analyzed and controlled continuously by high-tech gas analysers. Gas mixers can be improved by flow control systems and continuous O2 analysers to enhance the quality of the bonding process while optimizing the flow rate. Also, these devices will likely be equipped with artificial intelligence capabilities, enabling more integrated communication and monitoring features.

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ACRONYMS

- IC Integrated Circuit
- O2 Oxygen
- Cu Copper
- Au Gold
- IMC intermetallic compound
- FAB Free Air Ball
- HAZ Heat-affected zone
- EFO Electric Flame-Off
- Al Aluminum
- Ag Silver
- Pd Palladium
- Pd-Cu Palladium-Copper
- EX1 Coated Cu wire
- Ni Nickel
- TI Texas Instruments
- N2 Nitrogen
- H2 Hydrogen
- FG Forming Gas
- IIC Impact Insulation Class
- CFD Computation Fluid Dynamics
- MFC Mass Flow Controller
- IoT Internet of Things
- AI Artificial Intelligence