# Thermosonic Bonding: Analyzing the Effects of Ultrasound, Heat, and Metallurgical Processes on Gold and Copper Wire Bonds

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## THE SOURCE OF THIS SUMMARY IS THE FOLLOWING SCIENTIFIC PUBLICATION

Title: A brief review of selected aspects of the materials science of ball bonding

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**Equipment Used:**

Ultrasonic bonding machines with variable frequency (120–140 kHz).

**Samples Used**

Substrates: Aluminum-alloy metallization (Al-0.5%Cu, Al-0.5%Cu-1.0%Si)

Wire types: 4N Gold (Au), Copper (Cu), and Pd-coated Cu wires.

**Number of samples:**

Varied depending on experiment; references suggest numerous samples to evaluate variance in bond strength and microstructure under different parameters .

**Tests Performed**

Tensile stress-strain testing of Au and Cu wiresPressure Cooker Tests (PCT)

Thermal Humidity Bias (THB)

Temperature Cycling (TCL).

**Analyzing methods**

SEM for microstructure visualization.

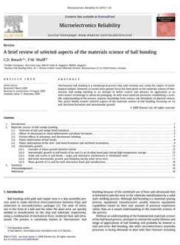
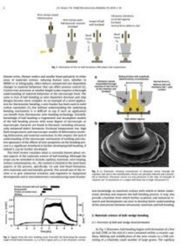
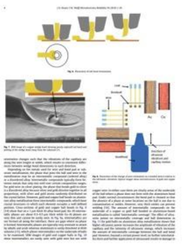
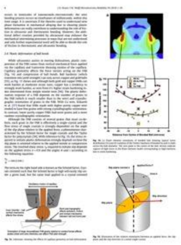
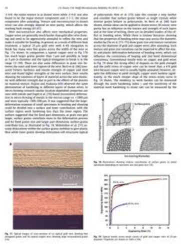
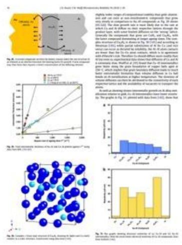
Finite Element Modeling (FEM) for stress-strain simulations.

Statistical analysis of bond strength and failure modes.

**Number of diagrams**

12 figures (diagrams, graphs)

5 SEM images showing bond structures and intermetallic coverage

## Executive Summary

In the field of microelectronics, wire bonding represents a pivotal process, utilized for the interconnection of minute wires between a chip and a substrate. The research project is concerned with the comprehension and enhancement of the ball bonding process, which entails the utilization of gold or copper wires. The wires are affixed to metal pads on the chip through a combination of mechanical pressure, heat, and ultrasound, in a process known as thermosonic bonding.

The objective of this study is to address the challenges posed by the use of smaller wires and more complex chip designs, which make it difficult to ensure strong and reliable bonds. The study examines the microscopic interactions between materials during the bonding process, with a particular focus on the formation of bonds between metals such as gold, copper, and aluminum.

The findings indicate that controlling the ultrasonic energy and heat applied during bonding is crucial for improving bond quality and reducing defects such as voids and cracks. Additionally, the research elucidates the influence of wire materials and bond pad compositions on bond strength, offering insights into optimizing the process for modern electronic devices.

## Main Focus

This paper presents a detailed examination of the materials science underlying thermosonic ball bonding, with a particular emphasis on the mechanical and metallurgical interactions observed in gold (Au) and copper (Cu) wire bonding with aluminum (Al) alloy bond pads. The objective is to enhance comprehension of the phase formation and plastic deformation that occur during bond formation and their implications for bond reliability, particularly in the context of high-temperature conditions and stress tests.

## Background and Motivation

The process of wire bonding, particularly when utilizing gold and copper wires, represents a pivotal step in the field of microelectronics packaging. As devices continue to become increasingly miniaturized, it is imperative to gain a deeper understanding of the effects of materials and bonding parameters to ensure the reliability of these interconnects. The research is driven by the challenges posed by fine-pitch bonding, smaller bond pad sizes, and the increased use of Cu wire. Despite its cost benefits and mechanical strength,

Cu wire. Despite its cost benefits and mechanical strength, Cu wire presents reliability challenges due to its tendency to oxidize and form brittle intermetallics with Al bond pads. The objective of this study is to address these issues by investigating the factors that influence the quality and longevity of Au and Cu ball bonds on Al alloy pads. These factors include ultrasonic energy, bond force, and wire metallization.

## Methodology

The research employs a combination of experimental and theoretical approaches to analyze the ball bonding process, employing a methodology that is both empirical and theoretical in nature. The principal methodologies employed are as follows:

- Tensile Stress-Strain Analysis: An evaluation of the mechanical properties of Au and Cu wires was conducted, including an assessment of work hardening and strain rate sensitivity.
- High-temperature storage (HTS) is a process whereby materials are stored at elevated temperatures. Ball bonds are subjected to elevated temperatures (up to 175°C) to facilitate the study of intermetallic growth and bond degradation over time.
- (PCT), Temperature Cycling (TCL), and Thermal Humidity Bias (THB) tests were conducted.
- Ultrasonic Power Modulation: Bonding experiments were conducted at varying levels of ultrasonic power to study the effect of this variable on bond quality, deformation, and intermetallic phase growth.
- Scanning electron microscopy (SEM) is employed for: This method is employed to evaluate the microstructure, intermetallic phase formation, and void/crack propagation at the bond interface.
- Finite Element Modeling (FEM): The simulation of stress-strain distributions and deformation patterns in ball bonds under varying ultrasonic power and bonding forces is a key application of this technique.
- Environmental stress tests were conducted. To assess the reliability of the bond in harsh environmental conditions, Pressure Cooker Tests (PCT), Temperature Cycling (TCL), and Thermal Humidity Bias (THB) tests were conducted.
- Ultrasonic Power Modulation: Bonding experiments were conducted at varying levels of ultrasonic power to study the effect of this variable on bond quality, deformation, and intermetallic phase growth.



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## Key Findings

- **Intermetallic growth in Au and Cu bonds**: At elevated temperatures, intermetallics such as Au8Al3 form rapidly, increasing in thickness over time. While this can enhance bond reliability, it can also result in void formation. In comparison to Au–Al phases, Cu–Al intermetallics, such as $CuAl_2$ are thinner and more brittle, which results in a higher susceptibility to crack formation and reliability issues during stress tests.
- **Impact of Ultrasonic Power:** The application of elevated ultrasonic power has been observed to enhance the extent of plastic deformation and intermetallic coverage. However, the utilization of excessive power has been shown to result in the over-deformation of the material, the formation of voids, and a reduction in bond strength. This is attributed to the damage caused to the neck region of both Au and Cu bonds. The deformation patterns observed in Cu bonds were less uniform than those in Au bonds, likely due to the coarser grain structure of the Cu wire. This resulted in inconsistent bond dimensions and lower pull strength in reliability tests.
- **Mechanical Properties and Plastic Deformation:** The deformation of Au wires was observed to be more uniform, which was attributed to their finer grain structure and higher strain rate sensitivity. This resulted in more consistent bond dimensions and a reduction in the variance in pull strength. In contrast, Cu wires, with their larger grain sizes, demonstrated greater variability in deformation behavior, which led to higher inconsistencies in bond quality, particularly in the formation of the second bond.
- **Phase Formation and Void Formation:** The presence of voids and cracks was more prevalent in Cu bonds, attributable to the thin intermetallic layers and the necessity for higher ultrasonic power during the bonding process. This, in conjunction with the inherent rigidity of copper, gives rise to more pronounced complications during stress tests such as thermal cycling.

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## Implications for Future Research and Industry

**Optimization of Process Parameters for Cu Bonding:** The research findings suggest the necessity for precise adjustment of ultrasonic power and bonding force, particularly in Cu bonding, to prevent excessive deformation and void formation. One potential avenue for future research is the development of novel capillary designs that reduce stress concentration at the bond interface and minimize void formation during Cu bonding.

**Exploration of Alternative Wire Materials:** Palladium-coated Cu wires (PdCu) and other metal alloys may be considered as potential alternatives to pure Cu wires due to their enhanced resistance to oxidation and superior performance in environmental stress tests.

**Intermetallic Growth Management:** Further research is necessary to ascertain the long-term stability of Cu–Al intermetallic phases and their role in bond reliability. A more comprehensive examination of the manner in which these phases evolve over time at varying temperature ranges could prove instrumental in the development of more robust bonding processes.

**Improved Understanding of Grain Structure and Deformation Behavior:** Further research should concentrate on the influence of wire grain size and texture on deformation behavior and bond consistency. A systematic investigation into the effects of grain orientation and recrystallization during the bonding process could provide new insights into the means of improving bond strength and reliability.


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## Limitations

One of the principal constraints of the study is the considerable variability observed in Cu wire bonding, which can be attributed to the inconsistent plastic deformation of its larger grains. This renders the implementation of a uniform bonding process across disparate devices a challenging endeavor. Although the study employed a variety of stress tests, additional long-term reliability tests under extreme environmental conditions (e.g., extended temperature cycling or humidity exposure) could provide a more comprehensive understanding of the failure mechanisms in Cu bonds.

Further research is required to elucidate the precise mechanisms underlying void formation in Cu–Al bonds, particularly to distinguish the influence of ultrasonic power from other process variables such as bond force and temperature. The present study concentrated predominantly on Au and Cu bonding with Al alloy bond pads. Future research could investigate alternative metallizations, including nickel or silver, which may exhibit disparate intermetallic growth behaviors and bonding characteristics.

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