Evolution of Semiconductor Bonding Wires: From Gold to Copper and Silver Over 25 Years

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Title: Evolutions of bonding wires used in semiconductor electronics: perspective over 25 years

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Equipment Used:

Not explicitly detailed; may involve wire bonders and reliability testing machines (e.g., temperature cycling and pressure cooker tests)

Samples Used

Substrate Type: Not explicitly listed

Substrate Material: Al (Aluminum) for bond pads

Types of Wires: Gold (Au), Copper (Cu), Silver (Ag)

Number of samples:

Not explicitly mentioned.

Tests Performed

High-Temperature Storage Test (HTST), Pressure Cooker Test (PCT), Humidity Stress Test (HAST), Temperature Cycling (TC)

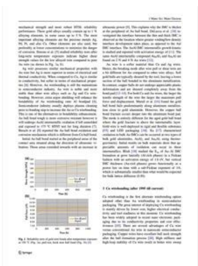
Analyzing methods

Reliability testing, intermetallic compound growth analysis, shear and pull tests, oxidation studies.

Number of diagrams

1 figure (diagrams, graphs)

5 SEM images showing bond structures and intermetallic coverage



Executive Summary

This study examines the evolution of bonding wires utilized in semiconductor electronics over the past 25 years, with a particular emphasis on gold (Au), copper (Cu), and the emerging utilization of silver (Ag) wires. Bonding wires are of paramount importance for the interconnection of semiconductor chips with other components in electronic devices, such as mobile phones and computers.

The researchers elucidate how gold was initially the material of choice due to its excellent conductivity and reliability. However, as its price increased, copper emerged as a lower-cost alternative. However, copper presents certain challenges, including susceptibility to corrosion, which necessitates careful handling during production.

In recent years, silver has been introduced as another alternative. It offers similar properties to gold but is softer than copper, making it less prone to cracking. The paper also covers various techniques used to improve the reliability of these materials, such as adding protective coatings like palladium. Overall, the study highlights how different materials and methods are being developed to meet the increasing demands for faster, cheaper, and more reliable semiconductor devices.

Main Focus

This review presents a critical examination of the evolution of bonding wires in semiconductor packaging, with a particular focus on gold (Au), copper (Cu), and silver (Ag) over the past 25 years. The study examines the reliability, corrosion mechanisms, and intermetallic compound (IMC) formation associated with each wire material, providing insights into their performance in harsh environments. Particular attention is devoted to the challenges of Cu wire, including its susceptibility to corrosion and the introduction of Ag as a promising alternative for high-reliability applications. The review offers a comprehensive analysis of the trade-offs between cost, performance, and reliability across different bonding wire materials.

Background and Motivation

Wire bonding represents a pivotal step in the process of semiconductor packaging, functioning as the principal method of establishing interconnectivity between the semiconductor die and the external circuitry. For decades, gold has been the industry standard due to its excellent electrical conductivity and resistance to oxidation. However, the increasing cost of gold has prompted a shift toward alternative materials, particularly copper, which offers a lower cost and higher mechanical strength. Despite the advantages of Cu, there are considerable technical obstacles to its use, including its high propensity to corrosion, which necessitates the development of protective coatings and enhanced bonding techniques.

In recent times, silver has emerged as a potential contender, offering a balance of cost-efficiency, mechanical properties, and electrical performance.

The objective of this study is to examine the historical development and current trends of these materials, while also identifying future research and industrial application directions. The objective of this paper is to provide a comprehensive analysis of the reliability, performance, and challenges associated with these bonding wires, with a particular focus on their suitability for demanding environments such as high-humidity and high-temperature applications.

Methodology

The review draws on a substantial body of literature and empirical research, with a particular focus on the performance of Au, Cu, and Ag wires under a range of environmental stressors. The review encompasses a range of reliability tests, including the High-Temperature Storage Test (HTST), Pressure Cooker Test (PCT), Humidity Stress Test (HAST), and Temperature Cycling (TC) test.

Furthermore, the study examines the mechanical properties of wires, the analysis of intermetallic compound growth, and the corrosion mechanisms affecting Cu/Al and Ag/Al intermetallic compounds. Techniques such as palladium coating and surface treatments to enhance bond integrity are also examined. Furthermore, the review examines the electrochemical reactions that result in intermetallic compound (IMC) degradation and failure in high-humidity environments.

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Key Findings

- **Gold wire**: The Au wire remains a highly reliable option due to its noble properties, which make it particularly well-suited to environments with high temperatures and moisture. Nevertheless, the increasing expense of the material has prompted industry stakeholders to investigate alternative solutions.
- **Copper Wire**: Copper wire offers superior mechanical strength and a lower cost, but presents significant challenges, especially in terms of corrosion and oxidation. The study identifies corrosion of the Cu/Al intermetallic compound (IMC) as a primary reliability issue under high-temperature, high-humidity (HAST) and prolonged creep testing (PCT) conditions. Copper forms intermetallic compounds (IMCs), such as Cu_9Al_4 and $CuAl_2$, which are susceptible to accelerated deterioration in high-humidity environments. The utilisation of palladium-coated Cu wires has been demonstrated to enhance moisture resistance and bonding reliability.
- **Silver wire**: Ag wire introduced more recently, provides a balance between cost and performance, offering high conductivity similar to that of gold and less stiffness than that of copper. Silver also shows better performance in pressure casting and hot continuous casting compared to copper wires, especially when alloyed with palladium. However, silver-aluminum intermetallics are softer, which can improve reliability in some applications, such as light-emitting diode packaging, by reducing pad damage.

The review presents data supporting the use of Pd-coated Cu and Ag wires for specific applications. It notes that Ag wires demonstrate superior bonding performance in LED packaging due to better intermetallic growth control and resistance to oxidation.

Implications for Future Research and Industry

The study indicates that although copper wire has become increasingly prevalent in high-input/output (I/O) packaging, its long-term reliability under stress remains a concern, particularly in environments with high humidity and temperature. Palladium-coated Cu wires demonstrate potential for enhancing moisture resistance; however, further development is necessary to address issues related to cracking and intermetallic compound (IMC) formation.

Silver wires, particularly those comprising an Ag-Pd alloy, represent a promising avenue for future research, particularly in regard to applications that necessitate the use of softer materials, such as those pertaining to LED and MEMS packaging. Future research should concentrate on the optimization of silver wire compositions with a view to enhancing their wear-out reliability and resistance to IMC degradation in harsh environments. Furthermore, the study suggests that the long-term performance of Ag wires in low-power and flexible substrate applications should be subjected to continued evaluation.

Limitations

A significant drawback of the study is the dearth of comprehensive real-world deployment data for Ag wires, particularly in the context of large-scale manufacturing. The study is based primarily on laboratory data, which may not fully reflect the operational challenges encountered in mass production. Furthermore, although the review encompasses the mechanical and reliability performance of bonding wires in general, it does not sufficiently examine the particular impact of disparate substrate materials and encapsulation techniques, which could additionally influence the long-term reliability of wire bonds. Furthermore, the environmental impact and recyclability of alternative wire materials are not sufficiently addressed, which could warrant greater attention in future research.

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