Reducing Wire Bond Failure: How Adjusting Bond Foot Angles Improves Power Module Reliability

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Title: Testing and simulation of lifetime for wire bond interconnections with varying bond foot angle

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Equipment Used:

ANSYS Workbench for simulations

Combined pull and shear test machine for bond wire testing

Samples Used

Al_2O_3 DBC substrates soldered to copper baseplates

Diodes and IGBT chips with aluminum wire bonds (500 µm diameter)

Number of samples:

Over 50 devices under test (DUT) across various configurations

Tests Performed

Active power cycling tests

Shear testing

Analyzing methods

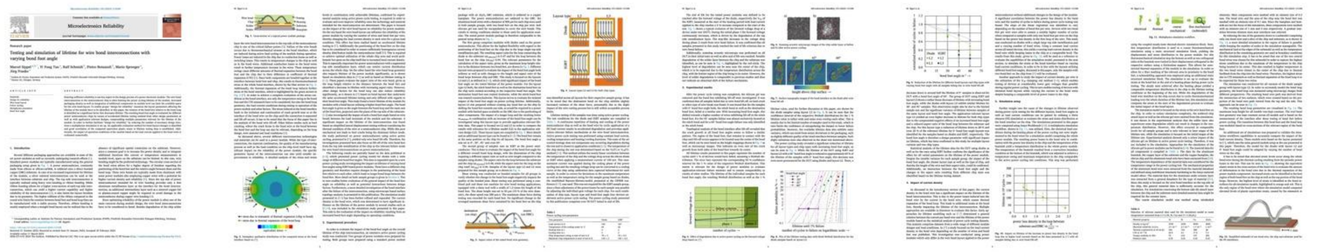
Scanning acoustic microscopy

Surface topography analysis

Figures & Facts

Pages: 11

Several figures with detailed stress distribution, lifetime testing, and simulation results. At least 6 detailed images, including scanning microscopy and strain distribution diagrams.



Executive Summary

The study focuses on wire bonding, a critical process for connecting electronic components within power modules. Wire bonding creates connections between a semiconductor chip and its supporting structure (substrate). In this research, scientists are examining how different angles at which the wire touches the chip, known as the bond foot angle, affect the longevity of these bonds. A larger bond foot angle tends to reduce the life of the wire bond because it introduces additional stress during operation. The team used both experiments and simulations to test the effects of varying bond foot angles on wire bond reliability.

They performed power cycling tests in which the wire bonds were repeatedly heated and cooled to simulate real-world conditions. They found that as the bond foot angle increases, the wire bond life decreases due to increased stress and strain. Using a multiphysics simulation model, they validated these results and showed that higher bond foot angles lead to more stress on the wire, which accelerates failure. This research helps improve wire bond design, making power electronics more reliable and durable by reducing bond foot angles during the design process.

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Main Focus

This research project examines the impact of varying bond foot angles on the reliability and lifetime of wire bond interconnections in power electronic modules. In particular, it elucidates how the bond foot angle affects thermomechanical stress and strain during power cycling, which can lead to wire bond lift-off. To this end, the study employs both experimental power cycling tests and advanced multiphysics simulations, with the objective of identifying and quantifying the influence of bond foot angles on bond durability, thereby facilitating the optimization of power module design.

Background and Motivation

In the context of power electronic modules, wire bonding represents the predominant methodology for establishing electrical connections. These modules are pervasively utilized in a multitude of applications, including those pertaining to automotive systems and renewable energy. The reliability of these wire bonds represents a critical limiting factor in the lifespan of the modules, particularly in high-stress environments such as power cycling.

As power density increases and the available space on the substrate becomes more constrained, it becomes essential to optimize the bond layout. Previous studies have identified geometric factors such as bond loop height and length as contributors to bond failure. However, the specific impact of bond foot angle has not been extensively quantified in practical applications. This study builds on previous research that demonstrated a correlation between higher bond foot angles and reduced lifetimes. The aim is to expand the understanding of this effect through both experimental validation and simulation.

Methodology

Two sets of wire-bonded power modules, comprising one with diodes and the other with IGBTs, were prepared for active power cycling tests. Both utilized an Al_2O_3 DBC substrate, soldered to copper baseplates, and the wire bonds were constructed with 500 µm diameter aluminum wires. The bond foot angles that were tested included 0°, 30°, 45°, and 60°, and these were conducted across two different layout configurations (L2 and L3). The power cycling tests involved the application of direct current (DC) to the chip, which was then heated and subsequently cooled. This process was conducted in order to simulate the conditions that would be encountered during normal operation.

The lifetime was defined as the point at which the forward voltage of the diode or the voltage across the capacitive element (VCE) of the IGBT increased by 5%. The experimental data was supplemented by a multiphysics simulation model constructed using ANSYS Workbench. The model was used to simulate the thermal, electrical, and mechanical behaviour of the wire bonds under power cycling conditions, with a particular focus on the equivalent plastic strain at the bond foot. The key parameters under investigation included temperature fluctuations, stress distribution, and strain at the bond interface. Additionally, shear testing was performed to validate the bond strength.

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Key Findings

- **Simulation Results**: The finite element simulations demonstrated an accurate replication of the experimental results, indicating that an increase in bond foot angles results in a notable rise in thermomechanical strain, particularly at the stitch bond. For bond foot angles exceeding 30°, failure was predominantly observed at the stitch bond, whereas at 0°, both the stitch and destination bonds exhibited comparable failure rates. The simulation indicated that the equivalent plastic strain increased in a nearly linear fashion with increasing bond foot angle. At a current density of 21 A per bond wire, the strain was observed to be approximately 20% higher at 60° compared to 0°.
- **Experimental Results**: The power cycling tests yielded clear evidence of an inverse relationship between bond foot angle and wire bond lifetime. An increase in bond foot angle from 0° to 60° resulted in a notable decrease in the observed lifetime, with the 60° samples exhibiting a lifetime that was 20-28% of that observed for the 0° samples. The L3 layout, which featured longer bond loops and lower aspect ratios, exhibited a more pronounced reduction in lifetime due to the combined effects of larger bond foot angles and higher current density.
- **Microscopic Analysis**: The surface topography of the bond following the bond lift-off procedure exhibited a consistent pattern of crack growth, with the cracks originating at the edges of the bond foot and propagating towards the center. This observation was in alignment with the simulation predictions.

Implications for Future Research and Industry

The findings of this research offer crucial insights that can inform the design of more reliable power modules. By identifying the bond foot angle as a critical factor influencing wire bond reliability, this research provides a practical approach to extend the operational lifespan of power electronics, particularly in space-constrained modules where layout flexibility is limited. The findings also indicate that a design strategy aimed at enhancing reliability should prioritize the minimization of bond foot angles in order to mitigate thermomechanical stress, particularly in applications involving high currents.

For future research, it is recommended that additional wire bond layout parameters be explored, including the number of bond wires per chip and the effects of varying metallization layers. Further refinement of the multiphysics simulation model, especially its ability to predict lifetime based on current density and bond geometry, could reduce the necessity for extensive lifetime testing during the design phase.

Limitations

The experimental results demonstrated notable variability, particularly between the samples with bond foot angles of 30° and 45°. The overlap of some confidence intervals restricts the precision of lifetime predictions. A larger sample size would facilitate the attainment of more statistically robust conclusions.

The simulation model did not account for variations in bond process parameters, which have the potential to affect the amount of plastic strain that the bond interface can tolerate before failure.

It should be noted that the model's predictions are specific to the tested bond process and may not be generalized to different manufacturing conditions. Furthermore, the simulation focused on the initial strain conditions at the beginning of the power cycling test. However, it did not model the evolution of strain as cracks propagate through the bond interface, which would provide a more comprehensive understanding of how bond degradation progresses over time.

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