Delivering on the Reliability Requirement for Advanced Automotive Electronics:

Filler Technology Improves Thermal Performance of Non-Conductive Die Attach Paste

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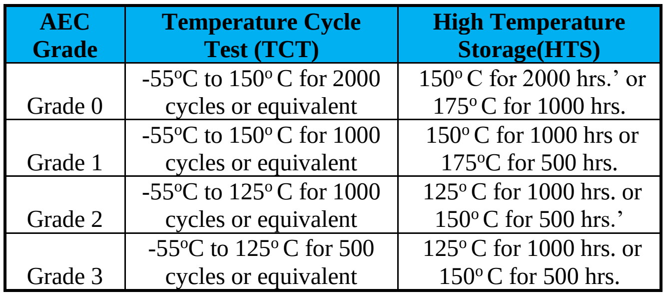
Semiconductor device miniaturization and expanded function remain the prevailing dual ambitions across applications – from data centers to mobile phones to automobiles. Marrying these objectives while also prioritizing reliability – especially for safety-critical sectors such as automotive – is becoming increasingly complex. Electronics-enabled features are dominating automotive innovation (according to Deloitte, electronic vehicle content accounted for almost 40% of the cost of a car in 2017, and projects that figure to reach 45% by 2030(1)) and ensuring exceptional performance within the framework of cost-conscious manufacturing and strict safety guidelines demands new approaches to material formulation and selection.

Underpinning state-of-the-art automotive electronics design is advanced semiconductor technology. In fact, the vehicle of today has been described as ‘a computer on wheels’, controlled by semiconductors and sensors. Appreciating this reality makes the focus on improving electronic systems reliability all the more important. The integrity and performance of semiconductor packages are dependent on many factors, not the least of which is the capability of the die attach materials which are used to bond electrically active die to substrates. Engineering die attach adhesives for compliance with increasingly harsh environmental testing that pushes the limits of temperature cycling and duration is disrupting traditional formulation approaches, particularly for high thermal non-electrically conductive die attach pastes.

Reexamining Die Attach Material Capability

Die attach adhesives within certain automotive electronics applications are required to pass stringent thermal cycling and high temperature storage testing. (**Figure 1**) Unsurprisingly, there are varying automotive grade objectives depending on where the device will be integrated, with the most demanding standard being that of automotive grade 0. In addition to meeting automotive reliability specifications, some packages also require high thermal conductivity materials that enable efficient heat dissipation to help lower the junction temperature of the semiconductor die, allowing for better package performance, higher applied voltage and a longer device lifetime.



AEC Grade	Temperature Cycle Test (TCT)	High Temperature Storage(HTS)
Grade 0	-55°C to 150° C for 2000 cycles or equivalent	150° C for 2000 hrs.’ or 175° C for 1000 hrs.
Grade 1	-55°C to 150° C for 1000 cycles or equivalent	150° C for 1000 hrs or 175°C for 500 hrs.
Grade 2	-55°C to 125° C for 1000 cycles or equivalent	125° C for 1000 hrs. or 150° C for 500 hrs.’
Grade 3	-55°C to 125° C for 500 cycles or equivalent	125° C for 1000 hrs. or 150° C for 500 hrs.

Figure 1: Automotive reliability standards by grade as defined by Automotive Electronic Council, AEC-Q006 (Cu Wire).

Traditionally, ensuring high thermal conductivity within die attach systems involves using metal fillers – silver, for example – that are integrated into a polymer matrix. While this is effective, many filler materials are not only thermally conductive, but also electrically conductive. Providing high thermal capability in a non-electrically conductive die attach adhesive formula is increasingly important, as new package configurations now dictate their use. For example, multi-chip modules (MCMs) and/or integrated packages often include a controller die adjacent to a field effect transistor (FET) die. In this situation, it is necessary to use a non-electrically conductive die attach adhesive for the controller die in order to maintain isolation so as to mitigate current leakage and crosstalk with the FET die (**Figure 2**). Non-conductive die attach materials employed for the controller die should provide an efficient thermal path to the lead frame for heat dissipation. Because of the higher voltage in newer device designs, as well as the tighter die-to-die placement, an electrically-insulating die attach material with high thermal capabilities is required. Historically, however, non-electrically conductive die attach adhesives haven't been able to deliver high thermal conductivity and the low viscosity necessary for high UPH. Until now, this has been an either-or proposition.

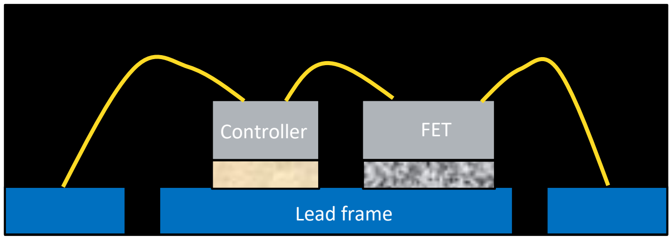


Figure 2: The controller die requires electrical isolation from the FET die but still demands high thermal control.

Filler Formulation: Understanding Limitations

In general, non-electrically conductive die attach adhesives have leveraged inorganic fillers such as silica to provide insulation, rheology characteristics and CTE control, but the thermal conductivity range is typically very limited at < 1.0 W/m-K and not suitable for many newer-generation, high reliability package designs. Improving thermal conductivity, therefore, requires more thermally-capable fillers such as alumina (Al_20_3), boron nitride (BN) or alumina nitride (AlN) in combination with high filler loading. Unfortunately, non-optimized filler loading – while addressing thermal conductivity – can have drawbacks, including:

- Increased material hardness and brittleness that cannot withstand stress induced by curing shrinkage and CTE mismatch during temperature cycling.
- Reduced adhesion to the interface.
- High viscosity that is not compatible with thinner bond lines/dispense patterns and high UPH manufacturing.

Because of these factors, filler selection, particle distribution and resin chemistry of non-electrically conductive die attach adhesives must be balanced to meet the demands of automotive grade reliability applications.

The Right Combination: Balancing Performance and Productivity

A recent die attach material development project set out to analyze filler and resin behavior in an effort to increase thermal conductivity while complying with manufacturing demands and automotive grade 0 reliability expectations. Four different types of high thermal conductivity fillers – all containing aluminum – were tested, and ultimately an aluminum oxide (Al_2O_3) filler that was able to achieve high thermal conductivity and relatively low viscosity was selected. While the filler material met the thermal and viscosity requirements, additional modification was required to achieve the very demanding production and performance necessary for automotive grade 0 compliance, manufacturing conditions and package dimensional challenges. Considerations included:

- Filler maximum particle size to control for very thin bond lines that are typically 25 µm (though somewhere in the range of 12 µm to 50 µm is possible) and small needle dispensing.
- Particle sizes that are too large can become positioned between the upper surface and lower substrate and may provide an electrical pathway, resulting in lower breakthrough voltage and reduced reliability, so particle size optimization is important.
- Large particles can also cause die tilt during bonding, so dimension optimization is considered.
- Balancing particle size distribution and maintaining a similar average particle size.
- Integrating a filler surface treatment to improve dispersion, wetting and surface adhesion.

Taking all of these factors into consideration, a newly-developed, high thermal conductivity, electrically-insulating die attach paste with innovative alumina filler technology has been developed. (**Figure 3**) Achieving 3.0 W/m-K thermal conductivity -- significantly higher than that of most non-electrically conductive die attach adhesives -- good dispensability, thin bond line capability and meeting automotive grade 0 standards, this new non-electrically conductive die attach paste is a market breakthrough, with broad application for any device where exceptionally high reliability is required.

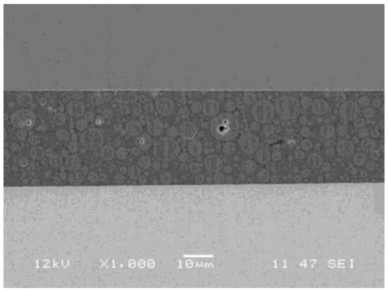


Figure 3: Bond line of new high thermal non-electrically conductive die attach paste shows no defects.

This development and the understanding gained about filler manipulation and resin interaction to secure reliable, process-friendly, high thermal conductivity performance within a non-electrically conductive die attach platform will inform future formulations for advanced material innovation.

For more information, contact the authors.

Sources:

1. https://www.caranddriver.com/features/a32034437/computer-chips-in-cars/

This article is a summary of study results originally presented in an in-depth paper at ECTC 2021.