6.4. Advancements in Flexible End Terminations for High-Reliability Passive Components in Electrified Vehicles

Dean Buzby, Victoria DeLissio, Ryan Persons, Zach Kelly,
Heraeus Electronics, West Conshohocken, Pennsylvania, USA, dean.buzby@heraeus.com

ABSTRACT

The automotive industry's shift toward electrification is driving a significant increase in demand for high-reliability passive components, particularly multilayer ceramic capacitors (MLCCs). Electric vehicles (EVs) require up to 10 times more MLCCs than internal combustion engine (ICE) vehicles, intensifying the need for robust, cost-effective solutions.

This paper introduces a novel flexible end termination ink developed by Heraeus Electronics, designed to address the mechanical and logistical limitations of traditional thermoset epoxy-based terminations. Utilizing high-temperature thermoplastic chemistry, the new formulation offers superior flexural performance (up to 10 mm), room temperature stability, and reduced silver content. These advancements enhance reliability, simplify processing, and lower total cost of ownership, making the solution well-suited for the evolving demands of EV and high-reliability automotive applications.

INTRODUCTION

The rapid transition toward electrification in the automotive industry is reshaping the landscape of electronic component demands. Electric vehicles (EVs) necessitate far higher quantities of multilayer ceramic capacitors (MLCCs) compared to internal combustion engine (ICE) vehicles—up to 15,000–20,000 units per EV, compared to around 2,000–3,000 in ICE models. This growth is driven by the increasing complexity of subsystems such as radar, heads-up displays (HUDs), power electronics, battery management systems (BMS), and high-voltage inverters.

With this surge comes heightened scrutiny of component reliability. Automotive original equipment manufacturers (OEMs) impose stringent requirements to mitigate risks linked to mechanical stress, thermal cycling, vibrations, and moisture exposure. Failures at the component level can propagate, leading to system malfunctions or even safety-critical failures.

UNDERSTANDING FAILURE MECHANISMS

Mechanical Cracking in Surface-Mount Passive Components

Mechanical cracking stands out as the most prevalent failure mode in surface-mount passive components, particularly in multilayer ceramic capacitors (MLCCs). This type of damage arises primarily due to board flexure, which can occur during various stages, including manufacturing, handling, or even throughout the regular operation of the electronic device. The stress induced by such flexure can propagate micro-cracks in the brittle ceramic structure of MLCCs, which over time, may evolve into critical failures.

The impact of these cracks can be multifaceted. Firstly, they significantly alter key electrical properties such as capacitance, resistance, and inductance. Variability in these parameters can compromise circuit performance, leading to erratic behavior. Secondly, cracks disrupt the dielectric integrity of the capacitor, paving the way for leakage currents, which can erode the efficiency of electronic components and cause energy loss. Lastly, in severe cases, these cracks create conductive pathways that may result in short circuits, posing safety hazards and risking complete system failures. These issues are particularly concerning in automotive applications, where the reliability of electronic systems is critical for both safety and performance.

Challenges with Conventional Flexible Terminations

To mitigate the risks posed by mechanical cracking, the industry has widely adopted flexible terminations, predominantly utilizing thermoset epoxy materials. While these materials provide a measure of mechanical cushioning to absorb the strains from board flexure, they are not without drawbacks, which span logistical, operational, and economic dimensions.

One significant challenge is storage. Thermoset epoxy materials demand cold-chain logistics to prevent premature curing, adding complexity to supply chain management. The shelf life of these materials is also constrained; once thawed, their usability window is limited, leading to potential material wastage if not used promptly. Economically, the high silver content in these terminations substantially increases raw material costs. Furthermore, the manufacturing process is intricate, involving time-consuming preparation steps that decrease overall process efficiency and throughput.

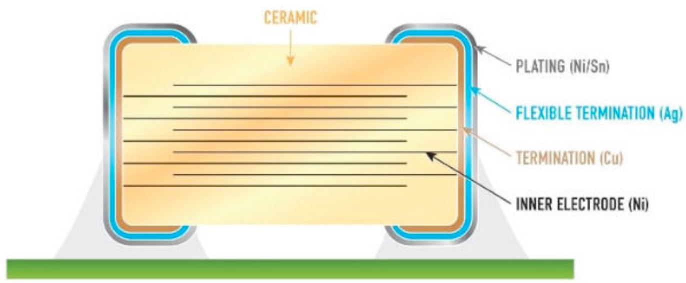

Fig.1. Cross section of MLCC with termination materials

FLEXIBLE TERMINATION MATERIALS ADVANCEMENTS

In response to these limitations, we have developed a production-friendly flexible termination ink formulated with high-temperature thermoplastic polymer chemistry. These next-generation materials aim to address the shortcomings of their epoxy-based predecessors while enhancing performance and simplifying processing.

Superior Mechanical and Electrical Characteristics
Thermoplastic-based inks offer remarkable mechanical resilience. They can endure board flexing up to 10 mm without exhibiting any cracks, effectively doubling the industry benchmark. This enhanced durability significantly reduces the risk of mechanical failure in demanding environments. Electrically, components utilizing these inks demonstrate exceptional stability. Even after experiencing mechanical stress, the capacitance deviation remains below 3%, a performance metric that surpasses traditional flexible terminations.

Optimized Storage and Handling
One of the standout advantages of thermoplastic inks is their stability at room temperature for up to six months. This eliminates the need for cold storage, thereby streamlining logistics and reducing storage costs. Manufacturers benefit from more flexible inventory management without the pressure of immediate material use to prevent spoilage.

Cost Efficiency and Sustainability
Economically, the reduction of silver content by approximately 5–10% directly lowers material costs. Additionally, the decreased material waste resulting from better shelf life and handling efficiency contributes to cost savings. The absence of specialized shipping requirements, often necessary for temperature-sensitive materials, further reduces operational expenses and environmental impact.

PERFORMANCE TESTING AND VALIDATION

To ensure these advanced materials meet the stringent demands of automotive and other high-reliability sectors, comprehensive testing protocols are employed.

Flex testing, following the AEC-Q200-005 standard, has demonstrated that components with thermoplastic-based terminations exhibit no signs of cracking or electrical degradation even under 10 mm of board flex.

Adhesion tests confirm robust bonding across diverse interfaces, with no occurrences of delamination, underscoring the reliability of the material under mechanical stress.

Furthermore, the surface finish quality remains smooth and free of defects, maintaining compatibility with nickel/tin (Ni/Sn) plating processes essential for ensuring high-quality production outputs.

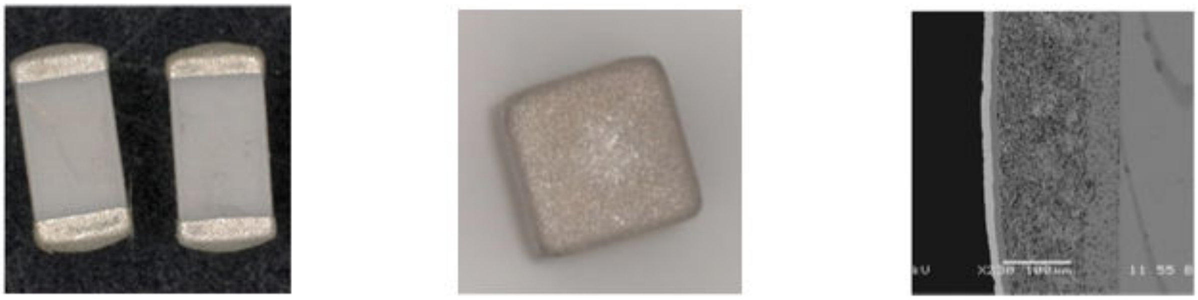

Fig.2. Cosmetics of end terminations including sidebands, apex, and Ni/Sn plating.

SEAMLESS PROCESS INTEGRATION

Integrating thermoplastic-based flexible terminations into existing manufacturing workflows is straightforward, minimizing the need for process modifications. The recommended drying conditions range between 90–140°C for 15–20 minutes, followed by a curing phase at 200°C for one hour.

These parameters are compatible with standard production equipment and protocols. Additionally, the materials operate effectively across a broad temperature spectrum, from –55°C to 125°C, ensuring their suitability for various environmental conditions encountered in automotive and industrial applications.

CONCLUSION

In conclusion, the evolution from traditional epoxy-based flexible terminations to thermoplastic-based alternatives represents a significant advancement in both performance and efficiency. By addressing the critical issues of mechanical reliability, storage logistics, cost, and ease of manufacturing, these innovations set a new benchmark for the electronic components industry, particularly in applications where reliability cannot be compromised.

The shift towards electrification not only amplifies the demand for high-reliability passive components but also calls for materials that can meet evolving performance and manufacturing needs. Innovations in flexible termination materials, particularly those leveraging thermoplastic chemistry, represent a significant advancement. They deliver enhanced mechanical durability, electrical stability, cost efficiency, and simplified logistics—key attributes for supporting the next generation of high-reliability automotive electronics.

These advancements ensure that as the automotive industry scales to meet the growing EV market, component reliability and manufacturing efficiency progress in tandem.

REFERENCES

1] Heraeus Electronics ET2010 high-temperature thermoplastic polymer flexible termination ink datasheet. https://www.heraeus.com/media/media/het/doc_het/tds/thick_film_2/end_terminations/TDS_End_Terminations_ET2010.pdf