THERMAL IMPEDANCE EVOLUTION OF NON-PFAS THERMAL INTERFACE MATERIALS UNDER HIGH TEMPERATURE AND HUMIDITY EXPOSURE

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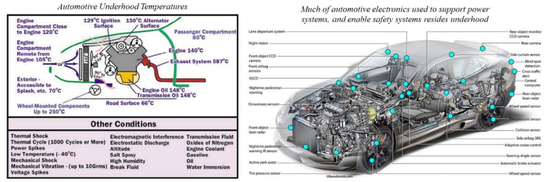
Motivation



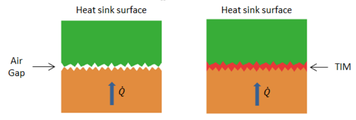
- Electronics may be located on-engine, on-transmission, on-wheel-well, or on-firewall an be exposed to temperatures of -40C to +200C, high-humidity, in addition to road-shock and vibration.
- There are technical gaps related to Non-PFAS materials using in high-temperature packaging for automotive electronics.

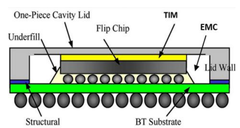
Objectives

- PFAS (per- and polyfluoroalkyl substances) are widely used in electronic packaging materials due to their unique properties, such as chemical and thermal stability, electrical insulation, and moisture resistance. These characteristics can significantly enhance the performance and durability of electronics, particularly in environments that demand robust heat and chemical resistance.
- This paper focuses on evaluating the reliability and stability of non-PFAS electronic packaging materials, specifically TIM and Underfill.
- In this study, we are following the JESD22-A113, which requires samples to be exposed to both 60C60%RH and 85C85%RH for 168 hours duration, and JESD22-A101, which specifies that samples should survive 85°C/85%RH conditions for over 1000 hours. In our investigation, samples were exposed to 85°C/85%RH for over 2000 hours to evaluate their reliability performance.

Investigation Approach

Development of relationships between the semiconductor package-structure-material-processing-performance and their impact on reliability and use-life in automotive environments of wide temperature extremes





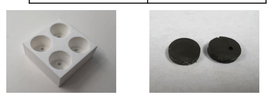
$$RA = R \times A = \frac{T_h - T_c}{Q_{ave}} \times A = (2R_{cont} + \frac{L}{k}) \times A$$

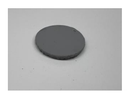
Material and Sample Preparation

Thickness(mm)	3.5
Diameter(mm)	16

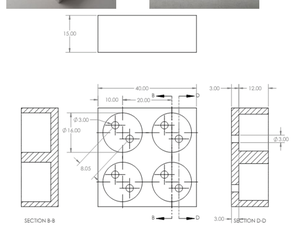
Thickness(inch)	0.11
Diameter(mm)	30

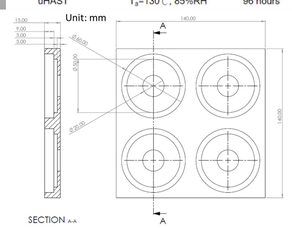
JESD22-A101





HTST	T_S=150℃	1000 hours
THT	T_S=85℃, 85%RH	1000 hours
TCT	T_S=-65℃ ~ 150℃	500 cycles
PCT	T_S=121℃,100%RH,2ATM	168 hours
uHAST	T_S=130℃, 85%RH	96 hours



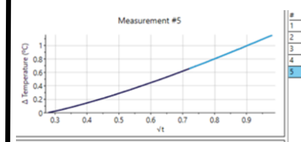


Test Vehicle

Materials Properties

Material System	Viscosity	Thermal Conductivity (W/m-K)	Cure Profile
NP_TIM1	130000	5.2	125°C/ 30 mins +150°C/ 60 mins.
NP_TIM2	78000	3.5	125°C/ 30 mins +150°C/ 60 mins
P_TIM 3	66000	1.92	150°C/ 30 mins

MTPS Result of uncured UF

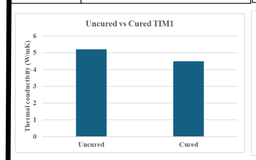


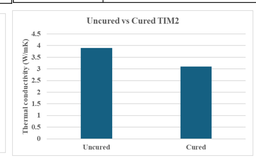
#	Valid k (W/mK)	Effusivity (Ws½/m²K)
1	0.5160	874.4
2	0.5212	879.5
3	0.5303	888.4
4	0.5285	886.6
5	0.5294	887.5

Test Summary:	Average	% RSD
Thermal Conductivity (W/mK)	0.5251	1.0594
Effusivity (Ws½/m²K)	883.3	0.6159

Cured and Uncured Non-PFAS TIMs

TIM1	Thermal Conductivity(W/mK)	TIM2	Thermal Conductivity(W/mK)
Uncured	5.2	Uncured	3.9
Cured	4.5	Cured	3.1





Curing Condition: 125°C/ 30 mins +150°C/ 60 mins.

125°C/ 30 mins +150°C/ 60 mins

Mathematical Principle

Effusivity is defined as the square root of the product of thermal conductivity k, density ρ and specific heat capacity C_p, and has the units of $\frac{W\sqrt{s}}{m^2K}$. The TCi system used for the material characterization measures effusivity directly and determines conductivity from this measurement.

The voltage change of the sensor is represented by:

$$\Delta V(t) = \frac{1.1284.I.A.G\sqrt{t}}{e_1 + e_2}$$

Where I is the sensor current, and A is the specimen cross-sectional area. The voltage output of the sensor is measured. The temperature change on the sensor surface (x=0) is given by:

$$\Delta T(x=0,t) = \frac{1.1284G\sqrt{t}}{e_1 + e_2}$$

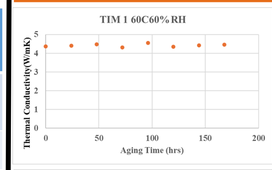
Where ΔT = change in sensor surface temperature (°C), G = power flux supplied to sensor (W/m^2), t = time measured from start of process (sec), e_1 = equivalent effusivity of sensor ($\frac{W\sqrt{s}}{m^2K}$), e_2 = effusivity of measured material ($\frac{W\sqrt{s}}{m^2K}$).

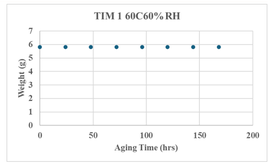
The heat equation in one dimension with a constant supply of heat per time per volume, G', is given below:

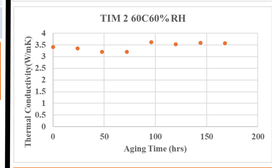
$$\rho C_p \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} + G'$$

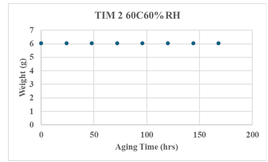
Where λ is the thermal conductivity, T is the temperature, t is time, x is the dimension measured along the specimen thickness with x=0 located at the sensor-specimen interface, G is the power flux supplied to the sensor (W/m²). For one-dimensional heat flow and no thermal contact resistance at the interface between the sensor and sample under test.

60C60%RH for Non-PFAS

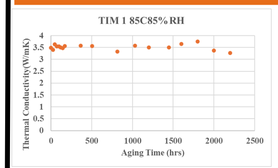


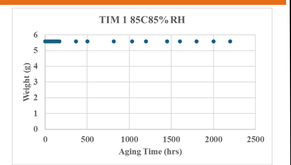


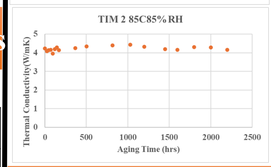


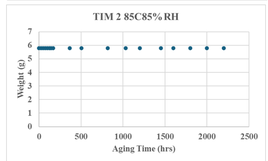


85C85%RH for Non-PFAS









Arrhenius Equation

$$\ln(\frac{K_T}{K_0}) = -\frac{K_a}{kT} + \ln(t)$$

Vertical axis: $\ln(\frac{K_T}{K_0})$

Horizontal axis: 1/T (inverse of temperature)

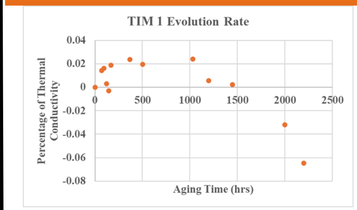
Slope: $-\frac{E_a}{k}$, which can be used to estimate the activation energy E_a

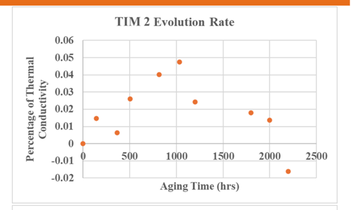
t: aging time

k=8.617×10−5eV/K

$T(K) = T(℃) + 273.15$

Temperature and Humidity

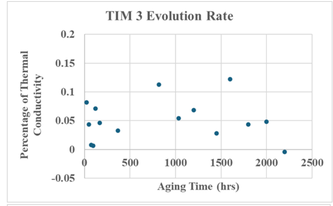


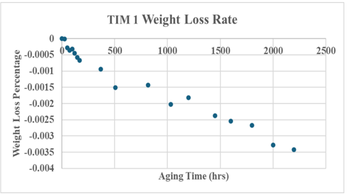


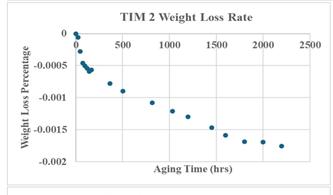
TIM1: Activation energy Ea = 0.1091 eV

TIM2:Activation energy Ea = 0.1580 eV

TIM3: Activation energy Ea = 0.0004 eV





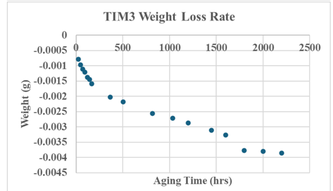


TIM1: Time exponent n for 85C= -0.0022

TIM1: Time exponent n for 60C= 0.0513

TIM2: Time exponent n for 85C= 0.0089

TIM2: Time exponent n for 60C= 0.0513



TIM3: Time exponent n for 85C = 0.0030

TIM3: Time exponent n for 60C = 0.0122

Summary and Conclusions

- Characterization of Thermal conductivity and weight loss at different aging temperatures & high humidity exposure has been done to evaluate the material degradation.
- The transient plane source method is employed to measure the thermal conductivity of non-PFAs UFs and TIMs. For uncured samples, a modified transient plane source method is used, while the Flex Transient Plane Source method is applied to cured samples. The research investigates the evolution of thermal conductivity in TIMs exposed to high temperature and humidity environments over a period of 2000 hours.
- At 85ºC & 85%RH and 60ºC & 60%RH, the degradation rate is not significant for 3 TIMs till 168 hours.
- At 85ºC & 85%RH, the degradation rate is not significant for 3 TIMs up to 2200 hours.
- Curing effect decrease the thermal conductivity for TIMs. Thermal conductivity for uncured samples (liquid) are higher than cured samples(solid).
- Sample weight continuously decrease from pristine to long term aging.
- Time Exponent Evolution for Arrhenius Equation is reported.

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