HARMONIZATION OF DC THERMAL RESISTANCE SETTINGS AND LIMITS OF RF POWER TRANSISTORS IN SILVER SINTER ON ACP PACKAGES

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ABSTRACT

As a key player in the RF Power industry, Ampleon continuously improves its processes to adapt to changing technologies and to provide its customers products with top-notch quality while maintaining cost-effectiveness. One of these cost-down improvements is converting the die attach method of existing air cavity plastic (ACP) packages from thermocompression to silver (Ag) sinter.

The relatively thicker die attach material of the Ag sinter process affects the thermal characteristics of the products. In final test (FT), increase in the thermal resistance (Rth) is expected due the thicker interface between the die and flange. With this change, it is highly likely that Rth will be measured outside the current specification limits. Therefore, new limits must be set.

To define the correct Rth limits for products that will adopt the new diebonding method, a design of experiment (DOE) on different bond line thicknesses (BLT) will be needed. Low, medium, and high BLT information combined with Rth data are subjected to regression analysis to define the Rth limits based on acceptable BLT range.

Setting the Rth limits is originally done per device for products that transitions from one die attach method to another, but since there are more than 30 ACP devices to be converted to Ag sinter, it will be both costly and tedious if each device will have its own DOE. To minimize the need for DOE, products were grouped according to structural similarity – a carrier device was selected for every group from which the DOE will be performed and Rth limits will be determined.

This paper will discuss in detail how the team managed to trim down the number of devices by a structural similarity analysis and alignment of the Rth settings, and how it helped not only to lessen the efforts for limits recalculation but also created a system for a harmonized Rth limits shared among different groups of devices.

1. 0 INTRODUCTION

To keep up with the emerging technologies in various semiconductor assembly processes, Ampleon decided to change the die attach process from thermocompression to silver sinter for 32 products in its current portfolio of air cavity plastic (ACP) packages.

1.1 Thermocompression vs Ag Sinter Die Attach

Thermocompression uses no adhesives to mount the die onto the flange. Instead, it uses large amounts of heat and force to form a metallic bond between the die and the flange. For this die attach method, dice are plated with a backside metallization (BSM) layer of gold (Au) and tin (Sn) that forms the bond.

Silver sinter die attach, on the other hand, does not require BSM as a silver sintered paste is used to join the die and flange. During the sintering process, the silver particles in the paste diffuse throughout the bonding area to create a strong thermal and electrical connection. One significant advantage of silver sinter over thermocompression is that it poses less concern about voiding. However, the bond line thickness (BLT) of the silver sintered paste should be properly controlled to avoid electrical and reliability issues.

1.2 Thermal Resistance (Rth) at Final Test

Though several controls are already in place in the diebond process to maintain the BLT at the desired levels, there must be an effective screening at final test (FT) to capture potential escapees from assembly.

The change in the diebond process does not directly affect the electrical performance of the product but more on its thermal characteristics. This is mainly due to the difference in the die attach material thickness – typically 5um for thermocompression and >20um bond line thickness for silver sinter.

Thermal resistance (Rth) is measured in DC test. It is a method of screening the die attach quality by detecting temperature variations which indicate the presence of voids or delamination. Voids and delamination can cause hotspots on the active die due to the uneven distribution of heat from the die to the header. In other words, Rth indicates how effectively the products dissipate heat from the die to the flange.

1.3 Defining Optimum BLT

Technically, a low die attach thickness should result to better thermal conductivity. However, applying too little silver sinter paste makes the die attach more susceptible to delamination which is also not ideal for heat dissipation. Therefore, a reliability assessment was performed on various wet BLT conditions on pre-selected types that cover different die sizes.

Table 1. BLT Conditions for Reliability Assessment

Variant	Bond Line Thickness
A	Low (20-30um)
B	Medium (40-50um)
C	High (60-70um)

Based on the reliability test results, all passed the criteria for delamination. Corner delamination manifested on Variant A during the extended temperature cycling test (TMCL) but based on the criteria it is still acceptable and it did not affect the Rth so it should not be too big of an issue. Variants B and C, on the other hand, showed a large shift in Rth after extended readpoints in High Temperature Storage Life (HTSL) test, which is more pronounced on the high BLT leg.

As per the reliability risk assessment, the safe BLT target is from the low to medium thickness and the process control limits will be somewhere between this range to ensure optimum bond line thickness with minimal risk for corner delamination and high Rth shift.

1.4 Problem Statement

If normal procedure is followed, Rth limits will be defined per individual product level for devices that will undergo change in die attach method. This requires building DOE lots with at least 3 legs from the lowest to the highest acceptable BLT range for all concerned devices.

However, it will be costly (since evaluation lots are not deliverable to the customers) and tedious to complete the re-assessment of the Rth limits for all the 32 devices that will transition to Ag sinter. Trimming down the list is necessary so that the company can save on both resources and time in implementing the change.

2. 0 REVIEW OF RELATED WORK

The air cavity plastic packages are not the first devices to transition to silver sinter diebonding. A smaller, molded plastic package was initially converted to the said die attach process. However, instead of being converted from thermocompression, this came from soft solder and the transition was focused on going lead-free as part of the Restriction on Hazardous Substances (RoHS) compliance. The approach done for this smaller package is structural similarity on die area and aspect ratio that resulted to around 80% reduction in DOE requirement.

Rth did not change dramatically for the molded type as the soft solder method has relatively the same die attach thickness as silver sinter but redefining the Rth limits was necessary to adapt to the acceptable bond line thickness range of the silver sinter process. Regression analysis was applied to determine the new Rth limits using 1:1 Rth vs BLT data. The said technique will also be employed to set the new Rth limits for the ACP types.

3.0 METHODOLOGY

3.1 Structural Similarity

To narrow down the list of devices for qualification, structural similarity assessment was performed. It is a tool that allows the re-use of generic data for different products with the same structures. In the case of the air cavity devices, the checking for structural similarity was done on the subpackage type, die technology and die size. Current Rth settings were also scrutinized.

3.1.1 Subpackage

The air cavity plastic product line of Ampleon is composed of several subpackages. The subpackages can further be broken down depending on the dimension, number of sections, and number of leads. But based on the 32 devices alone, subpackage can be classified into two major groups according to dimension, all are in dual-section configuration. In this paper, these will be called small and big packages in reference to the length of the package.

Table 2. Subpackage Classification

Package Dimension	No. of Devices
Big package	24
Small package	8

3.1.2 Die Technology and Application

Another ground for classification is the die technology and product application. The devices were further grouped into four – Gen10 high efficiency (HE), Gen10 high power (HP), Gen9 high voltage (HV) and Gen9/10 products.

Table 3. Subpackage and Die Technology Classification

Package Dimension	Die Technology	No. of Devices
Big package	Gen10 HE	7
	Gen10 HP	10
	Gen9 HV	2
	Gen9/10	5
Small package	Gen10 HE	4
	Gen9 HV	4

3.1.3 Die Size

The size of the active area of the die is a factor for classification as well. The larger the active area of the die is, the higher the power that is needed to heat up the die and properly measure the Rth. Since the affected devices are using different dice, it is also important to categorize them per die dimension.

Table 4. Subpackage, Die Technology and Die Size Classification

Package Dimension	Die Technology	Die Size	No. of Devices	Cluster
Big package	Gen10 HE	large	7	A
	Gen10 HP	large	10	B
	Gen9 HV	largest	2	C
	Gen9/10	medium	3	D
		small	2	E
Small package	Gen 10 HE	large	4	F
	Gen9 HV	largest	3	G
		smallest	1	H

The 32 devices were narrowed down to just 8 groups upon assessment of their structural similarities. Clusters were defined to easily identify each group. Then, a carrier device from each cluster was selected on which the design of experiment will be performed.

3.2 Design of Experiment

Since the change in die attach method is expected to impact the thermal resistance, it is imperative that new limits are defined. This will be determined through a DOE with at least 3 legs with different dry bond line thickness specifications labeled as low, medium, and high. The low, medium and high BLT for the DOE is not to be mixed up with the information from Table 1, but all legs are within the allowable thickness.

Twenty pieces from each BLT leg are identified, serialized, and subjected to 100% measurement of bond line thickness. The same serialization is used in DC test to record the Rth response.

The recorded data are processed to obtain a 1:1 BLT vs Rth information and through regression analysis, Rth limits will be set according to the lowest and highest acceptable BLT.

The resulting limits from the DOE of a carrier product will be adopted by the devices falling under the same group.

3.3 Rth Settings

For the limits to be applicable on structurally similar devices, the settings should also be aligned among devices in the same group.

There are multiple factors that are being set for the Rth test, but the alignment will focus on the supplied current (Id) and dissipation or pulse time (Tp) as variables, other factors will remain unchanged unless really necessary.

Fig. 1 shows that in Cluster A, all devices have the same Id and Tp settings which is ideal for structurally similar devices.

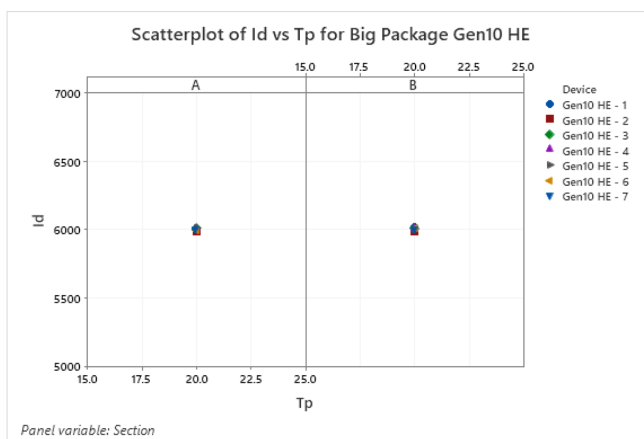

Fig. 1. Id and Tp settings for Cluster A. Uniform Id and Tp are used by all devices on both sections.

This is also the case for Clusters C and H (see Appendix A).

On the other hand, the figure below shows that structurally similar devices from Cluster B have varying Id and Tp settings for Rth test.

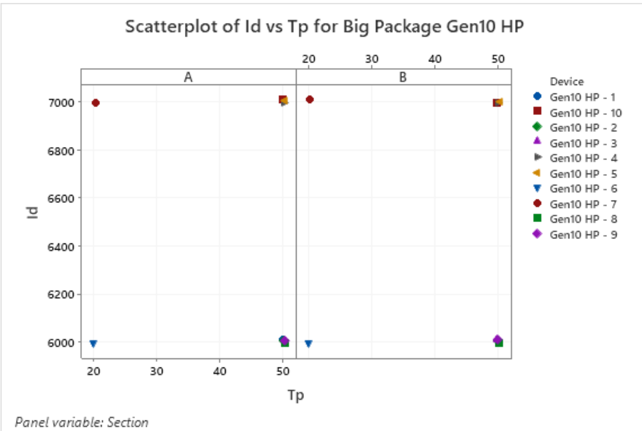

Fig. 2. Id and Tp settings for Cluster B. Non-uniform Id and Tp are used by each device on either sections.

Similar cases are observed on Clusters, D, E, F and G (see Appendix B). For these clusters, the optimum settings must be selected and fanned out to other types within the group.

As a guide on which setting to implement for the group, the Dvm of the device must be around 100mV or higher to ensure that the dice are heated up enough to properly differentiate the response of devices with good die attach quality against those with poor die attach. Dvm is basically the delta between 2 voltages measured, one measured when the device is in cold state and the other after heating up the device by supplying it with a higher power. This parameter is the primary input for calculating the Rth response.

Another item to look for is the product's stability under the selected Rth test condition. Take Fig. 3 as an example, Dvm is plotted against the dissipation time which is swept from 5ms up to 50ms using two different Id settings. Both curves are stable because they appear to be smooth with no sudden spikes nor drops. At 50ms, Dvm values for both Ids are >100mV but if Tp will be at 20ms, only Id=7A will be able to reach the Dvm requirement.

From the example, Id=7A and Tp=20ms is chosen for the carrier device of Cluster B since it has the least dissipation time that meets the Dvm requirement without presence of oscillations in the graph. Shorter dissipation time is preferred as it translates to shorter test time as well but of course, the criteria for Dvm and stability should always be leading.

Similar practice was done on other clusters with varying Id and Tp settings.

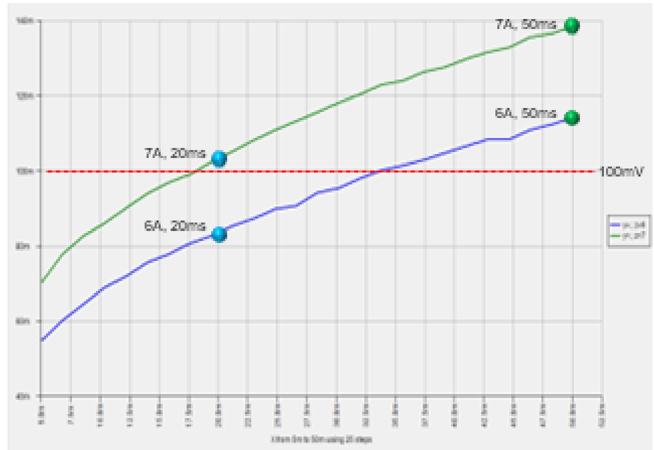

Fig. 3. Dvm Trace at Id=6A and Id=7A for Cluster B Carrier Device

With the settings finalized, Rth limits can then be determined from the BLT DOE legs and harmonized per cluster.

4.0 RESULTS AND DISCUSSION

Based on the assessment, structural similarity helped to trim down the 32 ACP devices into 8 groups only, translating to 75% less devices with DOE requirement. However, this alone is not enough to set optimal Rth limits.

Thorough scrutiny and alignment of the current Rth settings is equally important so that the devices per cluster can effectively apply the structural similarity concept for the Rth settings and limits.

Summarized in Figs. 4-5 are the final Id and Tp settings per cluster where it can be seen that devices from each cluster now share the same setting per section, except the Id of Cluster C since its number of dice per section is not equal. Tp, on the other hand is uniform at 20ms for all devices from different clusters.

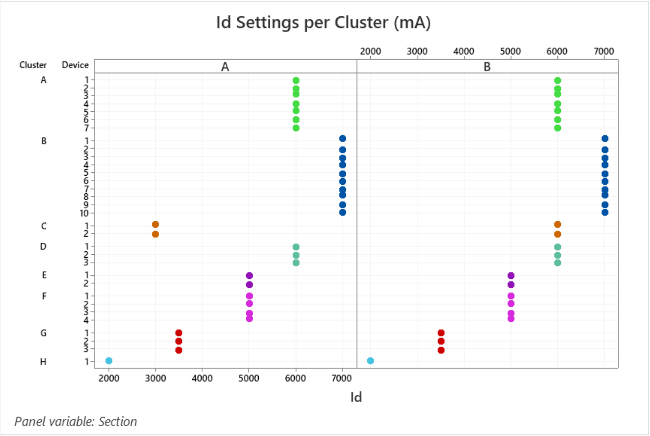

Fig. 4. Id Settings per ACP Cluster

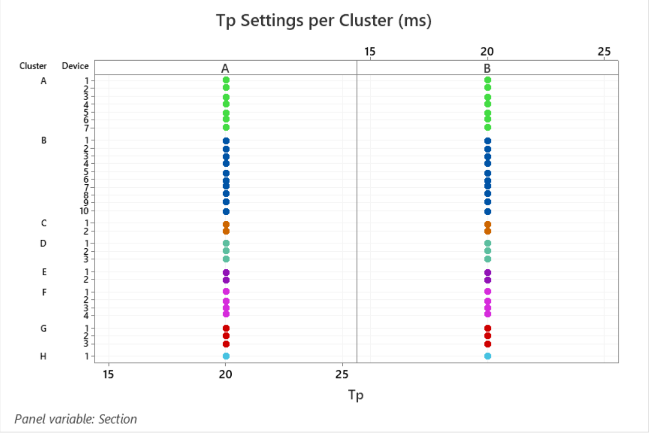

Fig. 5. Tp Settings per ACP Cluster

To calculate the Rth limits, the 1:1 bond line thickness and Rth data are used. These data are plugged into a statistical tool and processed through regression analysis.

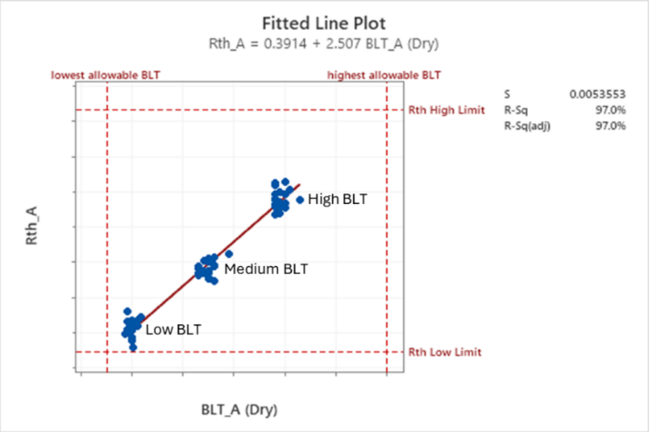

Fig. 6. Regression Analysis for BLT DOE of Cluster C Section A

From Fig. 6, it can be seen that Rth has a good correlation with the bond line thickness – the higher the bond line thickness, the higher the Rth response. This is also justified by the R-sq value of 97%. The resulting regression equation, in which the Rth is a function of the BLT, will then be used to determine the limits. The lowest and highest allowable BLT are plugged in to the equation to compute for the low and high Rth limits, respectively.

The calculated limits will then be applied also for structurally similar devices with the same Rth settings. As of April 2024, Rth limits were already defined for 6 clusters. To ensure that the Rth test conditions and new limits have no violation with respect to the products' form, fit and function, the changes are being scrutinized by the company's change review board before production implementation.

5.0 CONCLUSION

With this project, the team was able to harmonize the Rth settings and limits of different air cavity plastic packages through structural similarity and understanding of the products' thermal behavior under different conditions. The learnings were used to simplify the qualification approach, managing a 75% reduction for DOE requirement.

6.0 RECOMMENDATIONS

The team recommends completing the Rth limits assessment of the remaining clusters. Should there be more ACP types to be converted from thermocompression to silver sinter or if there are new products for release, it is advised to check if those devices fall under an existing cluster and employ the corresponding Rth settings and limits.

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- Johan de Jonge
- Bernd Kratteit
- Huub Keultjes

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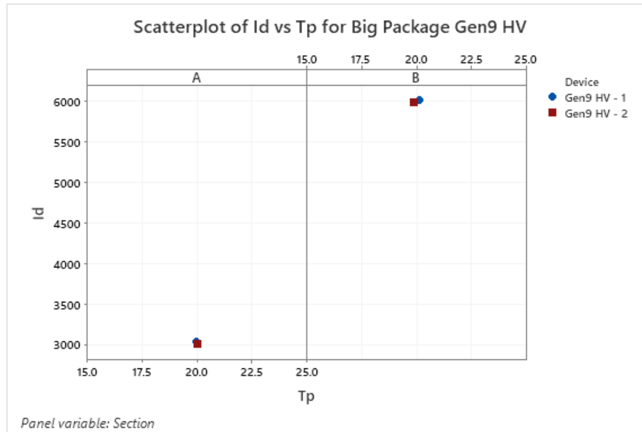
10.0 APPENDIX

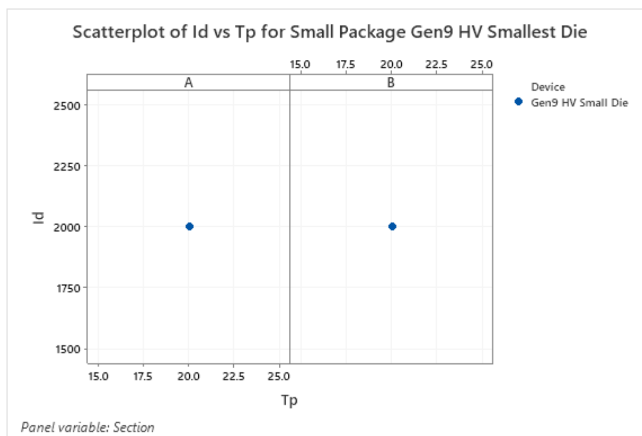
Appendix A – Clusters with Uniform Id and Tp

Cluster C:



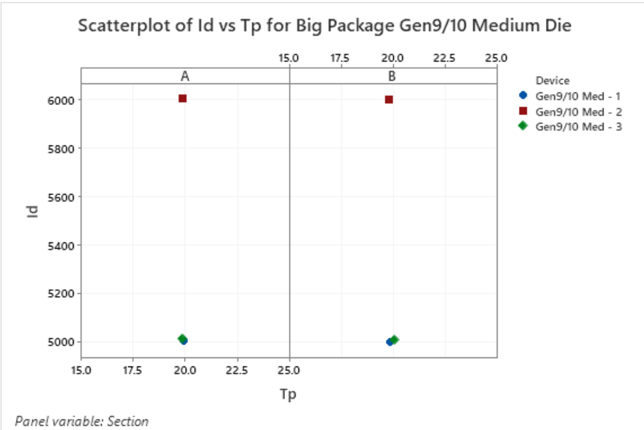
Cluster C has different settings for either section since section A consists of only 1 active di whereas section B has 2 of the same die.

Cluster H:

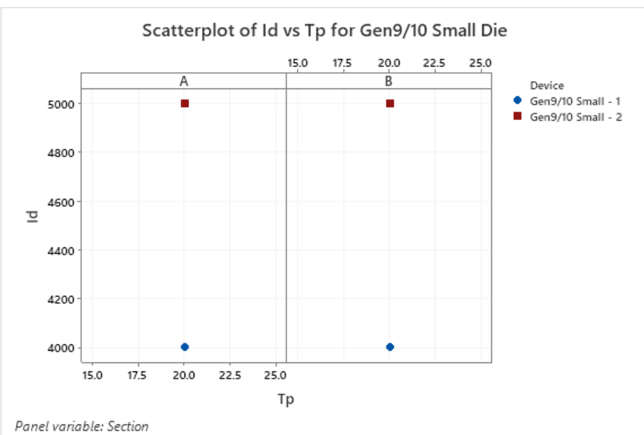


Appendix B – Clusters with Non-uniform Id and Tp

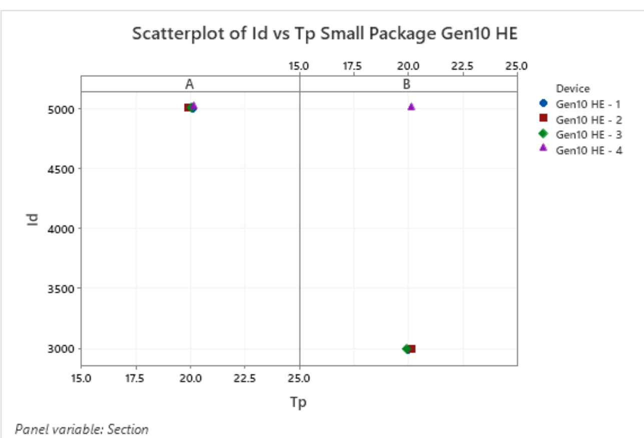
Cluster D:



Cluster E:



Cluster F:



Cluster G: