Design Considerations That Influence LED Solder Joint Reliability on IMS Printed Circuit Boards

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ABSTRACT

LEDs are the dominant lighting solution for many automotive applications. Their efficiency and increased design flexibility make them ideal for electrical vehicles over traditional incandescent lights. Designers can select a variety of substrates when designing an LED printed circuit board and many times designers only consider thermal performance. An insulated metal substrate or IMS board is commonly chosen as they are the highest thermally conductive type of circuit board.

For maximum thermal conductivity more copper, thinner dielectric and maximum pad attachment is commonly chosen. Solder fatigue is often not considered when selecting the IMS dielectric material. The design parameters such as copper thickness, dielectric thickness, and pad routing can all influence solder fatigue. In this paper we examine the influence of three factors on thermal-mechanical solder joint reliability of LEDs mounted on an IMS PCB using FEA.

Key words: IMS, Solder Fatigue, LED

Acronyms

FEA	Finite Element Analysis
IMS	Insulated Metal Substrate
LED	Light Emitting Diode
SAC305	Sn/Ag3%/Cu0.5% Solder
Tg	Glass Transition Temperature
CTE	Coefficient of Thermal Expansion
PCB	Printed Circuit Board
TTF	Time or Cycles to 63.2% Failure

INTRODUCTION

IMS circuit boards are used in many high-power applications. An IMS board consists of a metal substrate (usually aluminum or copper) and a dielectric layer to which copper traces are attached. Figure 1 shows the typical construction of an IMS PCB.

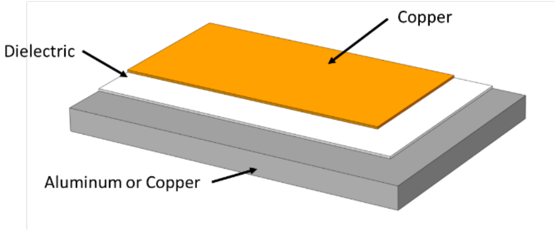

Figure 1. IMS Construction

The dielectrics used in IMS boards are formulated to have good thermal conduction, which makes them ideal for use with heat generating parts like LEDs. Widespread usage of LEDs mounted on IMS PCBs can be found in the automotive industry.

Many designers primarily focus on the thermal conduction aspect of the PCB design without considering other factors. Automotive standards specify some harsh thermal cycling tests and solder fatigue must be considered. Routing, copper thickness, and dielectric mechanical properties are some important factors that all contribute to the robustness of the solder joint when subjected to thermal-mechanical strain.

The purpose of this paper is to study the predicted cycles to failure impact on an LED mounted on an IMS PCB. The parameters studied are copper weight, pad routing, and dielectric material. Figure 2 shows the pad routing options that were compared. The copper weights compared were 1oz, 2oz, and 3oz. The influence of two dielectrics was also studied.

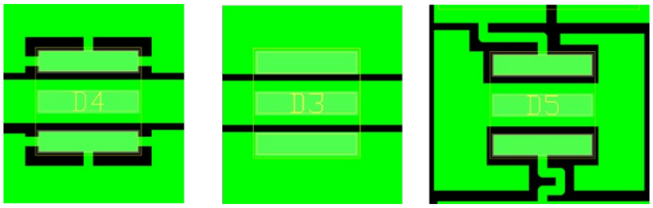

Figure 2. Pad Connection Types

VALIDATION OF APPROACH

Prior to any comparison study the validity of the approach must be considered. Failure data from various sources was gathered and FEA models created for each. Table 1 shows the failure data that was used for validation.

Table 1. Available Failure Data

Source	LED	Dielectric	TTF	Cycle (°C)
DFR2	Nichia 219C	Bergquist MP	3960	20 to 85
Cree [1]	XB-D	Bergquist HT	3044	-40 to 125
Cree [1]	XP-G	Bergquist HT	2628	-40 to 125
Cree [1]	MT-G	Bergquist HT	476	-40 to 125
DFR3	Luxon Rebel	Opulent	440	-40 to 150
DFR1	-	TCB-8	201	-40 to 150

Quarter symmetric models of each LED were generated. Figure 3 shows an example of a quarter symmetric model.

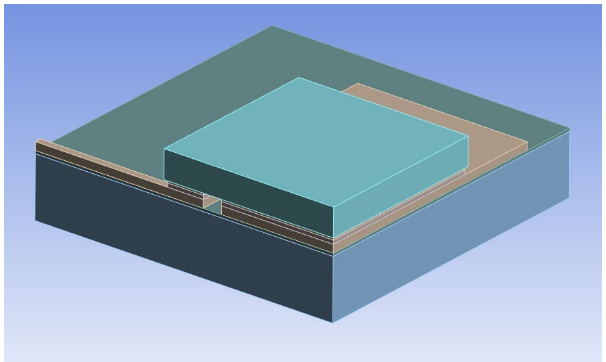

Figure 3. Quarter symmetric LED model

Syed's creep energy density equation was used to predict the cycles to failure [2]:

$$N_f = (0.0019 \times w_{acc})^{-1}$$

Schubert's SAC305 properties were used for the Garofalo. Constitutive creep model [3]. The comparison of the FEA predictions and the data is shown in Figure 4. The predictions slightly underpredict the available failure data. However, the correlations are good, and the approach is valid for the trade-off study.

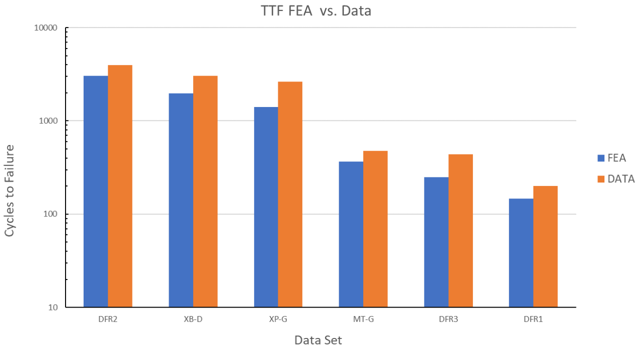

Figure 4. FEA Life Prediction vs. Life Data

CONFIGURATION PARAMETERS

Two different dielectrics were considered. Bergquist HT with a glass transition temperature of 150°C and Bergquist HR T30.20 with a glass transition temperature of 90°C. Figure 5 shows the variation of elastic modulus with temperature. Three routing schemes were modeled, see Figure 2. These are typical methods of pad escape routing on many surface mount devices. D4 routing is what is typically referred to as thermal relief connection to the surrounding copper, D3 is a direct pad attached to the copper where the pad would be defined by the surrounding solder mask, and D5 is a routed pad attachment.

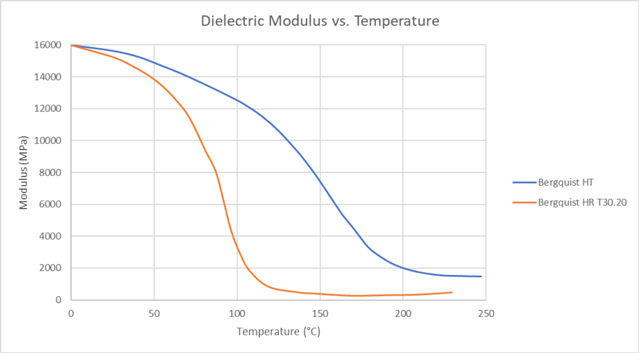

Figure 5. Temperature Dependent Modulus

FEA MODEL

A 3D model of the PCBA was created from the available ECAD date from which quarter symmetric models of the LEDs were then generated. Figure 6 shows the model of the LED and Figure 7 the complete PCBA model.

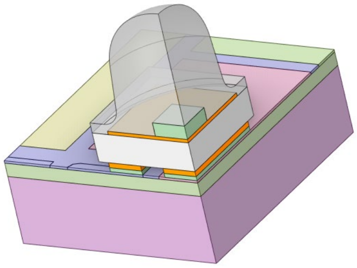

Figure 6. LED Model

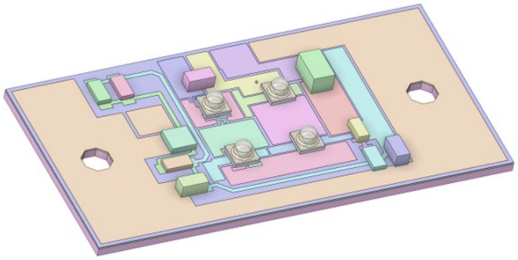

Figure 7. PCBA Model

A thermal cycle between -40 and 125°C was used for this analysis as shown in Figure 8. The creep work energy difference between the time at 8400 and 4020 was used to calculate the cycles to failure.

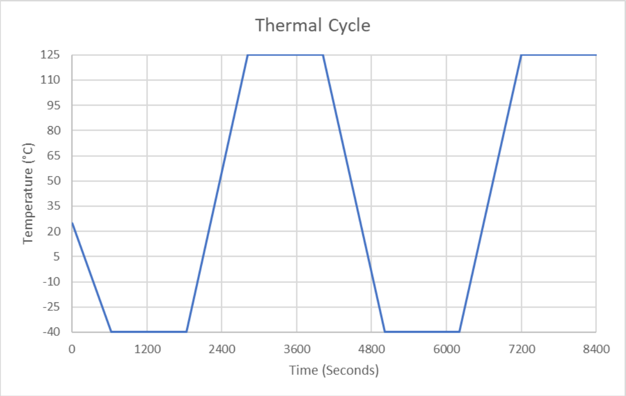

Figure 8. Thermal Cycle

Figure 9 shows an example of the creep work used to calculate the cycles to failure.

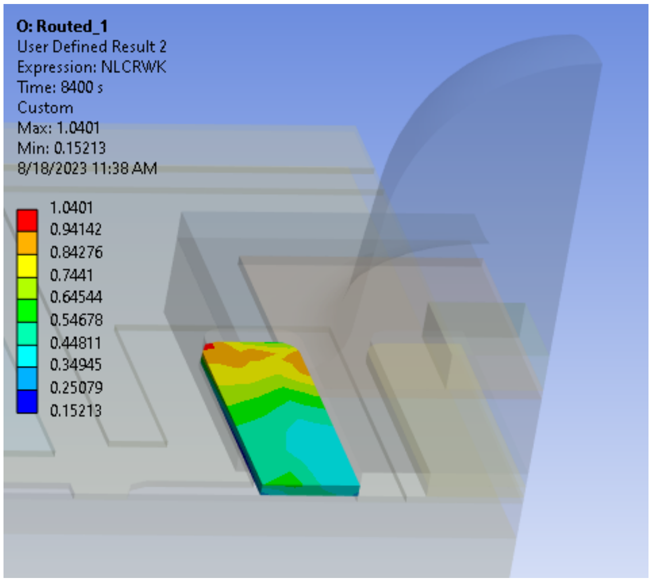

Figure 9. Solder Joint Creep Work

RESULTS

Tables 2, 3, 4, and 5 list the prediction results for the various configurations on an aluminum substrate board. Table 2 shows that Berquist HR T30.20 performs better than Berquist HT with the best configuration being 1oz copper and a routed pad.

Table 2: Attachment Method TTF (1 oz Copper)

Attachment Method	Berquist HT	Berquist HR T30.20
Plane	735	884
Thermal Relief	1386	2815
Routed	1710	3671

The lower glass transition temperature of the HR T30.20 reduces the stress on the solder joints during high temperature dwells. More attachment area between the pads on the board and the dielectric decreases the predicted fatigue life. Increasing the attachment area between the pad and the surrounding copper increases the coupling between the pad and the substrate, increasing the strain imparted into the LED solder joints during thermal cycling.

Table 3: Copper Thickness TTF – Routed

Dielectric	1oz Cu	2oz Cu	3oz Cu
Berquist HT	1710	1547	1463
Berquist HR T30.20	3671	3285	2547

Increasing copper thickness also reduces solder fatigue performance as shown in Tables 3, 4 and, 5.

Table 4: Copper Thickness TTF – Thermal Relief

Dielectric	1oz Cu	2oz Cu	3oz Cu
Berquist HT	1386	1163	1038
Berquist HR T30.20	2851	1740	1375

Table 5: Copper Thickness TTF – Plane Attach

Dielectric	1oz Cu	2oz Cu	3oz Cu
Berquist HT	735	600	549
Berquist HR T30.20	884	688	622

LEDs that have routed pads are predicted to be more reliable than LEDs that have pads directly connected to the surrounding copper flood. Reliability decreases slightly as the copper thickness increases. Figures 10 and 11 illustrate the reliability differences between LEDs mounted on IMS boards using Berquist HT and Bergquist HR T30.20.

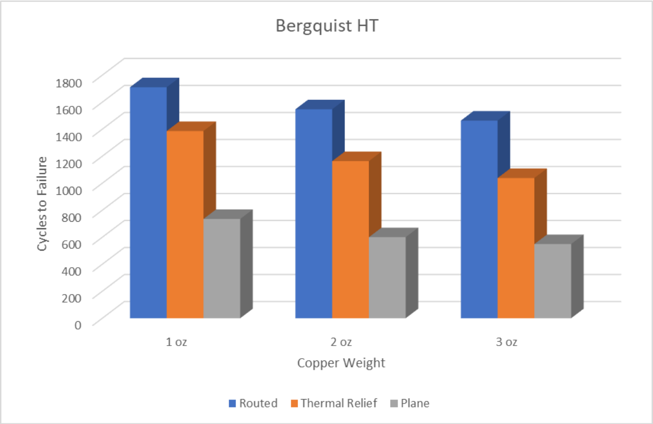

Figure 10. Bergquist HT Results

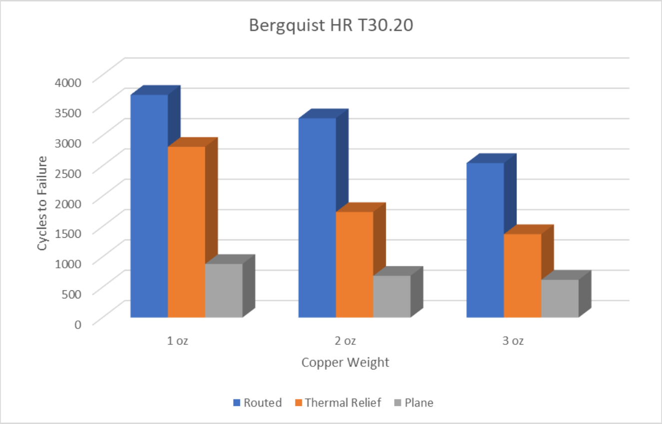

Figure 11. Bergquist HR T30.20 Results

CONCLUSION

The results show that using soft dielectric, thinner copper, and routed pads increase solder fatigue reliability. However, these parameters could influence the thermal performance of the board resulting in the LEDs operating at a higher temperature. A FEA conduction analysis was done to predict the potential temperature rise between the various pad routing options with the results shown in Figure 12.

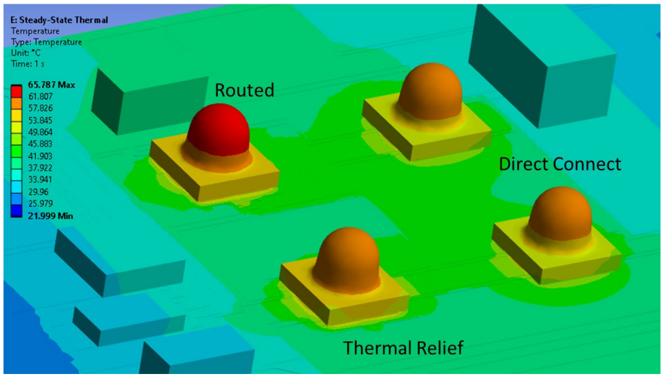

Figure 12. Thermal Conduction Study

Figure 12 illustrates that a 4°C temperature rise can be expected between a routed attachment versus a direct pad attachment. Designers need to consider this small temperature increase and the impact it could have on LED life. However, for solder joint fatigue, a temperature increase of 4°C changes the predicted life of the joint for the routed pad layout from 1710 cycles to 1555 cycles which is still 2X greater than the predicted cycles to failure for the plane configuration of 735 cycles.

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