ASSEMBLY INTERCONNECT RELIABILITY IN SOLID STATE LIGHTING APPLICATIONS – PART 1

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ABSTRACT
Customer expectations for light emitting diode (LED) based luminaries (Solid State Lighting) are very high due to the relatively high cost of such luminaries. For commercial and outdoor residential applications, a B50, L70 of 35,000 hours and a 3 year warranty is needed to meet EnergyStar Category A requirements. For such high reliability and lifetime requirements, it is critical to have excellent assembly interconnect reliability (i.e. Package to Insulated Metal Substrate attach). This study presents the results of initial work related to understanding the reliability of Solid State Lighting assembly interconnects in a LED Package-Insulated Metal Substrate system.

INTRODUCTION
Applications for light emitting diodes (LEDs) are increasing dramatically in the lighting sector. Their benefits of LEDs over competing technologies include versatility and long-term reliability. Package and luminaire design are critical considerations in ensuring that performance and reliability targets are met for commercial applications.

Customer expectations for LED based luminaries (Solid State Lighting) are very high due to the relatively high cost of such luminaries. For commercial and outdoor residential applications, a B50, L70 of 35,000 hours and a 3 year warranty is needed to meet EnergyStar Category A requirements. For such high reliability and lifetime requirements, it is critical to have excellent assembly interconnect reliability (i.e. Package to Insulated Metal Substrate attach). This study covers the selection of various materials and development of assembly process. The results of initial work related to understanding the reliability of Solid State Lighting assembly interconnect in a LED Package-Insulated Metal Substrate system are discussed along with the process recommendations.

SELECTION OF ASSEMBLY MATERIALS & LED PACKAGE:
Materials were chosen based on commercially available LED package, solder paste and MCPCB substrates and compared to potential improvements in solder pastes and MCPCB substrate for the same LED package.

Selection of high power LED package:
In this study, LUXEON® Rebel a high power LED package manufactured by Philips Lumileds Lighting Company was used. It is a compact package that can be surface mounted and can provide high lumen output and superior thermal performance. From the InGaN and AlInGaP metallization patterns, we selected an InGaN LED package. Image of an InGaN Rebel package with isolated fiducials is shown in Figure 1. A cross section of the Rebel package is shown in Figure 2 (Ref 1).

Figure 1. Image of InGaN LUXEON Rebel package

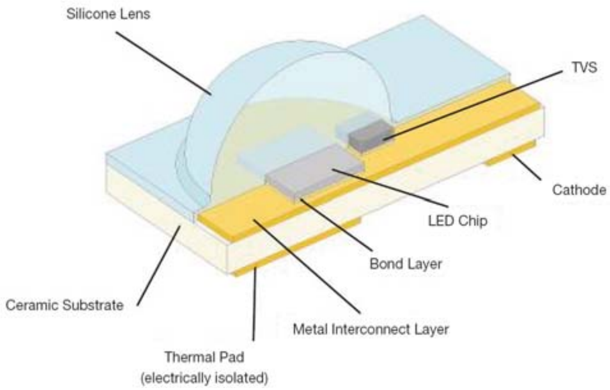

Figure 2. Cross section of LUXEON Rebel package

Selection of MCPCBs and Dielectric:
The LUXEON Rebel is a surface mount component and can be assembled on a typical FR4 board or on an MCPCB (Metal Core PCB). MCPCBs are also referred as Metal Clad PCBs. An MCPCB has a thin thermally conductive layer bonded to aluminum or copper substrate for heat dissipation.

Each of the board material has its own benefits and limitations. For example a FR4 board with open or filled and capped vias is a low cost solution for a regular LED assembly. MCPCBs offer more rigidity than a typical FR4 board along with improved thermal performance as all of the SSL packages conduct heat into the board material. An image of the MCPCB is shown in Figure 3. A cross-section of a MCPCB is shown in Figure 4 (Ref 2). Table 1 shows basic details of a typical MCPCB.

In this study we selected an MCPCB with two dielectric materials as described below:

MCPCB with Dielectric A: MCPCB with dielectric A minimizes thermal impedance and conducts heat more effectively and efficiently than standard printed wiring boards (PWBs).The low thermal impedance of MCPCB's outperform other PCB materials and offers a cost effective solution, eliminating additional LEDs for simplified designs and an overall less complicated production process.

MCPCB with Dielectric B: Dielectric B is a low modulus dielectric designed to reduce the strain on solder joints in applications where there is a large CTE mismatch between the surface mount component and the substrate of the MCPCB and a significant combination of temperature range and number of cycles in the application as well as high reliability requirements, while still providing very good thermal performance.

Base Layer	0.020"-0.125" / 0.5 –3.2 mm	Aluminum, Copper, Steel, or exotic
Dielectric	0.003"-0.006" / 75 -150 micron	Usually includes thermally conductive electrical insulator
Circuit Layer	1 oz –10 oz / 35 –350 micron	One or two-layer copper is common. More layers can be used

Table 1. Basic details of MCPCB

The relationship between the modulus of the dielectric in the MCPCB and the solder over the range of application temperatures that the assembly will be subjected to is a major factor in determining where the strain resulting from CTE mismatch between the surface mount component and substrate will be distributed. The modulus of dielectric A is of the same order of magnitude as most common MCPCB dielectrics available on the market, and as such can be referred to as a 'standard' MCPCB material in terms of solder joint reliability

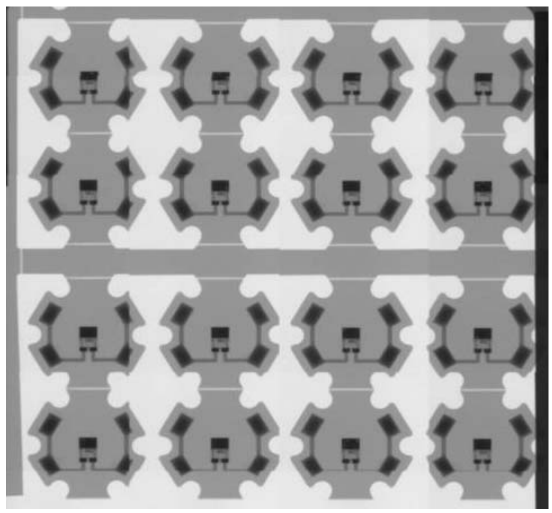

Figure 3. MCPCB Test Vehicle used for the study

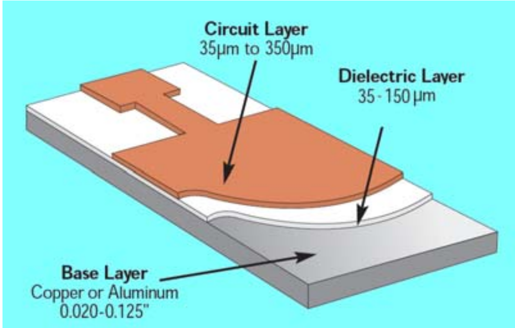

Figure 4. Cross section of a typical MCPCB

Selection of solder paste materials:
Two different solder pastes were selected for this study. Details of these solder pastes are:

Solder Paste A: A no-clean, lead-free SAC305 alloy solder paste with Type 3 grade solder powder, designed for a broad range of applications was selected for this study. This solder paste has a broad processing window therby providing excellent print capability performance and high production yields.

Solder Paste B: A no-clean, lead-free Maxrel™ based alloy solder paste with Type 3 grade solder powder, that is suitable for fine feature printing application was used in this experiment.

ASSEMBLY PROCESS DEVELOPMENT:

After selection of LED package, soldering and dielectric materials, a robust assembly process was developed. Assembly was performed on the same day for all the test boards and pastes. Table 2 summarizes the SMT equipment that was used for this LED assembly.

SMT Equipment	SMT Equipment Details
Stencil Printer	Speedline MPM UP3000 Ultraflex
Pick and Place	Universal Advantis with FlexJet head
Reflow Oven	Electrovert OmniFlo 7

Table 2. Assembly process equipment

Detailed assembly process parameters are discussed in the following three sections:

Solder Paste Printing:
MPM UP3000 stencil printer was used for solder paste printing. A 5mil thick Ni electroform stencil with 1:1 aperture was selected. Though stencil design can be optimized further, a 1:1 aperture stencil data has initially been generated for setting a baseline data. Stencil print parameters used for both solder pastes are shown in Table 3.

Print Parameters	Print Parameter Details
Print Speed	1 inch / sec
Print Pressure	1.5 lbs / inch of blade
Stencil Release	0.02 inches / sec
Snap off	0 inches (on contact printing)

Table 3. Stencil print parameters

Component Placement:
Universal Instrument's Advantis pick and place machine with FlexJet head was used for the LED assembly. An off-center pick-up was programmed for the LUXEON Rebel package pick-up and placement. Care was taken to avoid any contact / touching of the nozzle exterior to the silicone lens (LED dome).

Reflow Soldering:
An Electrovert OmniFlo 7 reflow oven, with seven heating zones and two cooling zones was used for the reflow assembly. All boards were assembled in an air atmosphere. A straight ramp reflow profile with a peak temperature of 240°C was used for both solder pastes. Please refer to Figure 5 for the reflow profile details.

FUNCTIONAL AND RELIABILITY TESTING

A comprehensive evaluation of the assembled LEDs has been undertaken. This evaluation includes both functional, mechanical and reliability testing of the assembled LED packages. The comprehensive test matrix being investigated is shown in Table 5. This paper presents results from the air to air thermal cycling tests.

1. Electrical Measurements:

Test description: Electrical measurements were performed on the as assembled (as soldered) LED packages. Measurements were performed after boards went through air to air thermal cycling test.

Test method: A power supply with the output set at 3V and the current limited over 1 Amp was used to perform the testing. Measurements were done on as soldered boards and on the boards that went through thermal cycling every 100 cycles.

Line Speed:	Zone:	#1	#2	#3	#4	#5	#6	#7	#8	#9
31.89 in/min	Length (in):	12.60	12.99	13.50	13.31	15.39	16.61	12.99	22.99	16.02
	Upper (°C):	130.0	150.0	180.0	210.0	240.0	250.0	240.0	55.0	55.0
	Lower (°C):	130.0	150.0	180.0	210.0	240.0	250.0	240.0	55.0	55.0

Probe	Reflow Results						Maximum / Minimum						
	Positive Slope (°C/sec)	Positive Slope Time (mm:ss.tt)	Rise Time (150.0 - 175.0°C) (mm:ss.tt)	Time Above Liquidus (221.0°C) (mm:ss.tt)	Peak Temperature (°C)	Delta T (°C)	Maximum (°C)	Max. Reached (mm:ss.tt)	Mean (°C)	Deviation From 0.0°C	Standard Deviation	Minimum (°C)	Min. Reached (mm:ss.tt)
#1 (°C) LED Mid...	2.87	00:19.50	00:17.50	00:55.50	239.6	0.8	239.6	02:40.50	156.3	+239.6	63.6	34.8	00:00.00
#2 (°C) LED Edge	2.72	00:24.50	00:19.00	00:54.00	238.8		238.8	02:57.00	155.3	+238.8	63.8	35.6	00:00.00

Probe	Time at Temperature			
	Time Above 221.0°C (mm:ss.tt)	Time To Reach 221.0°C (mm:ss.tt)	Time Above 240.0°C (mm:ss.tt)	Time To Reach 240.0°C (mm:ss.tt)
#1 (°C) LED Mid...	00:55.50	02:18.50	00:00.00	***
#2 (°C) LED Edge	00:54.00	02:24.50	00:00.00	***

Figure 5. MCPCB Straight Ramp Profile - 1.2C/s 240°C Peak 55s TAL

	TEST NAME	TEST DESCRIPTION
1	Electrical measurements	'Initial Amperes' measurement Initial LEDs (as assembled) After thermal cycling& After thermal shock
2	Voiding analysis	Voiding performance for each solder paste on two dielectric materials
3	Thermal cycling analysis	Thermal cycling air to air analysis -40°C to 125°C, 1000 cycles with dwell time of 30 minutes
4	Thermal shock analysis	Thermal shock liquid to liquid analysis -40°C to 105°C, 1000 cycles with dwell time of 30 minutes
5	Solder joint characterization	Cross sections of LEDs and IMC measurements: Initial LEDs (as assembled) After thermal cycling & After thermal shock
6	Mechanical testing (Package shear)	Package shear: Initial LEDs (as assembled) After thermal cycling

Table 5. Test matrix for functional, mechanical and reliability testing

Test results on as assembled boards:

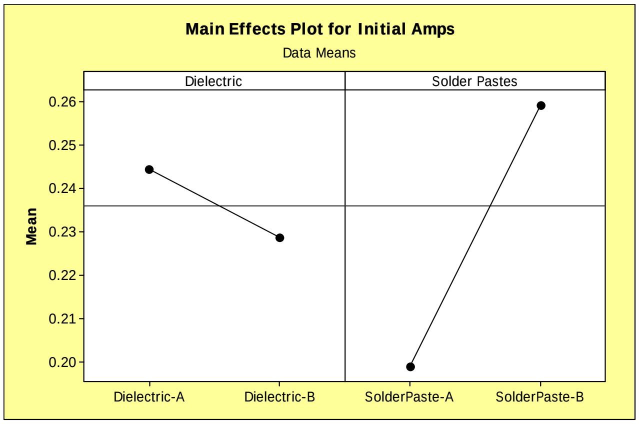

Figure 6. Initial Amperage for different solder pastes and board dielectrics

Figure 6 shows the main effects plot with electrical measurements on as assembled boards. The solder pastes appear to have a greater effect on amperage than the dielectric material.

2. Thermal Cycling Analysis:

Test description: For reliability study, air to air thermal cycling was performed on the assembled boards.

Test details: Assembled boards were placed in a Thermotron thermal cycling chamber for reliability studies at -40°C to 125°C, with 30 minute dwell time. Electrical measurements were undertaken with a power supply with a voltage limit of 3.0 volts and a current limit of 2 amps at 0 cycles and then every 100 cycles. Working LEDs were considered as passing, and non-working or dark LEDs were considered failing.

Test results and observations:

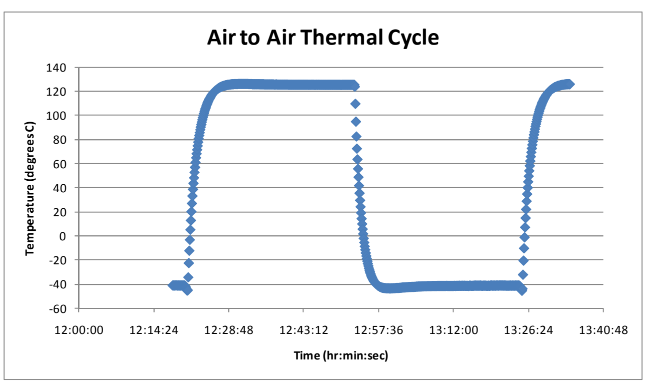

Figure 7: Thermal cycles as measured in the Thermotron environmental chamber

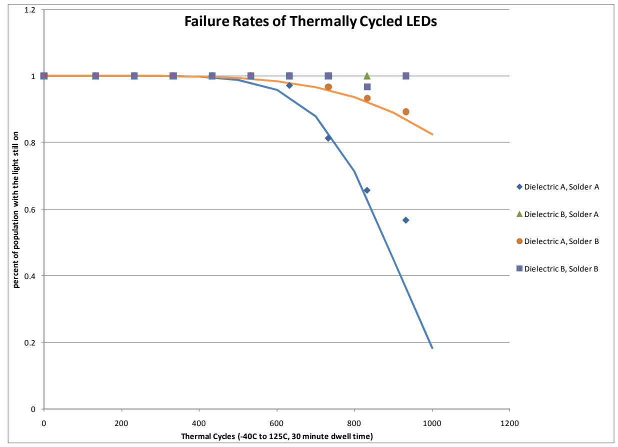

Figure 8: Failure rate vs. number of thermal cycles of combinations of MCPCB dielectrics and solders

Figure 8 shows the failure rate as a function of the number of thermal cycles of combinations of MCPCB dielectrics and solders. It is clear that with the lower modulus dielectric, joints with both solder paste A and solder paste B show almost no failures over 1000 cycles. With the higher, modulus dielectric, joints with solder paste B with Maxrel™ alloy show much lower failure rates than those with solder paste A with SAC305 alloy.

3. Solder Joint Characterization:

Test description: For solder joint characterization, as assembled boards were cross sectioned for microstructure and IMC measurement analysis.

Test details: IMC measurements on the MCPCB A and MCPCB B were performed on as assembled boards for both solder pastes used. SEM images of the cross-sections for both solder pastes were taken and are shown in Figure 9. All IMC measurements are in microns.

Test results and observations:

SEM images and IMC measurements show:

- Presence of a continuous Ni layer was noted at the interface of the MCPCB and solder pastes.
- Both Solder paste A and Solder paste B had similar IMC thickness on MCPCB A (around 1.65 micron). For MCPCB B material, Solder paste A had IMC thickness of 1.3 microns while Solder paste B had IMC thickness of 1.08 microns.

4. Voiding Analysis, Thermal Shock and Component Shear:

Voiding analysis, Thermal shock and Component shear tests are currently underway and will be published in Phase II of this work.

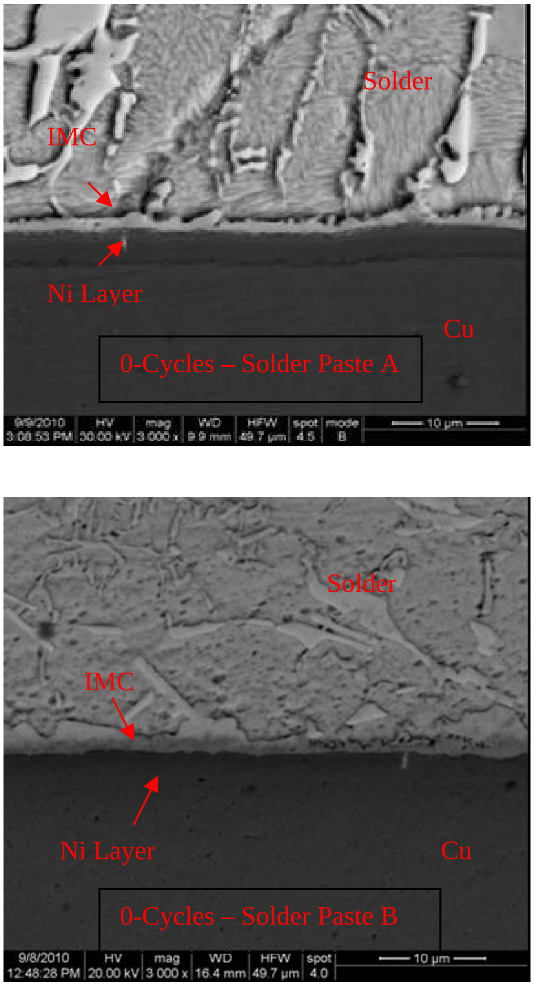

Figure 9. SEM micrographs of solder joints on MCPCB A for Solder Paste A and Solder Paste B

CONCLUSIONS AND SUMMARY

From the test results, one can conclude that:

1. The creep resistance of the solder is a significant factor in minimizing failures in solder joints due to strains incurred in thermal cycling.
2. The relationship between the modulus of the dielectric to the modulus of the solder over the temperature range in the thermal cycle can be an effective way to manipulate the strain away from the solder joint in thermal cycling, hence reducing failures due to solder joint fatigue.

Further, it is well understood in the literature that the magnitude of the thermal cycle, the geometry of the assembly under test, the CTE mismatch of the materials, and the duration of the dwell time in the thermal cycle (up to the time it takes for creep in the solder joint to be complete) will also have an impact on the device reliability as a function of solder joint fatigue and cracking in thermal cycling. With that understanding, we would expect that:

1. An MCPCB with a copper substrate would put less strain on the solder joint resulting in less damage to solder joints.
2. A smaller magnitude thermal cycle (such as one for indoor lighting applications) should also cause less strain on the solder joint.
3. A shorter dwell time at the extreme temperatures would allow the solder joint less time to creep, resulting in less damage to the joint per cycle.
4. Using a more creep resistant solder material would increase reliability of the solder joints subjected to such cycling.
5. The combination of solder and dielectric materials can be optimized in order to provide the required reliability for a given application.

ACKNOWLEDGEMENTS

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