LOW VOIDING RELIABLE SOLDER INTERCONNECTS FOR LED PACKAGES ON METAL CORE PCBS

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ABSTRACT
SSL Assemblies need to meet high reliability requirements such as Energy Star Category A which dictates a B50/L70 lifetime of 35,000 hours for commercial and outdoor residential lighting. Solder joints with low void content are critical for long term performance and reliability. Two types of MCPCB substrates, 4 different solder pastes and one type of LED ceramic package were evaluated in this study to develop a low voiding assembly process. Results of the study and recommendations for achieving low voiding are presented.

Key words: LED package, MCPCB; solder joint % voids

INTRODUCTION
Applications for light emitting diodes (LEDs) are increasing dramatically in the lighting sector. The 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 luminaires (Solid State Lighting) are very high due to the relatively high cost of such luminaires. For commercial and outdoor residential lighting, 70% lumen maintenance after 35,000 hours and a (3) year warranty is required for LED packages, modules and arrays to meet Energy Star Category A criteria. For high reliability, long lifetime and color maintenance of LED lights, it is critical to have excellent assembly interconnect reliability; i.e., package to insulated metal-core substrate solder joints with low voiding for low thermal resistance and hence good heat dissipation.

ASSEMBLY MATERIALS & COMPONENTS:
Materials and components were chosen based on commercially available LED packages, solder pastes and MCPCB substrates.

High power LED package:
A high power InGaN-based LED package (Ref.1) was used in this study. It is a compact package that can be surface mounted and can provide high lumen output and superior thermal performance. An image and cross-section of the LED package are shown in Figures 1 and 2, respectively (Ref 1).

Figure 1. Image of InGaN LED package

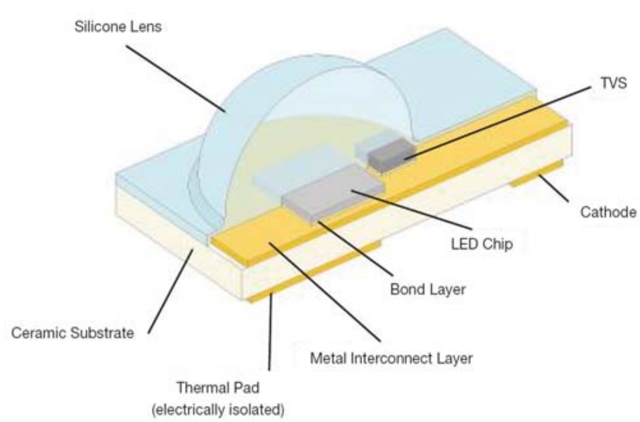


Figure 2. Cross section of LED package

MCPCBs and Dielectric:
The LED package is a surface mount component and can be assembled on a typical FR4 board or on an MCPCB (Metal

Core Printed Circuit Board). MCPCBs are also referred as Metal Clad PCBs. An MCPCB has a thin, thermally conductive dielectric layer bonded to an aluminum or copper substrate for good heat dissipation.

Each of the board materials 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 typical FR4 boards along with improved thermal performance, enabling heat conduction from LED packages into the metal core board material. A partial image of the MCPCB used in this study is shown in Figure 3; a 6x6 array of 36 parts per substrate was used here. A cross-section of a MCPCB is shown in Figure 4 (Ref 2).

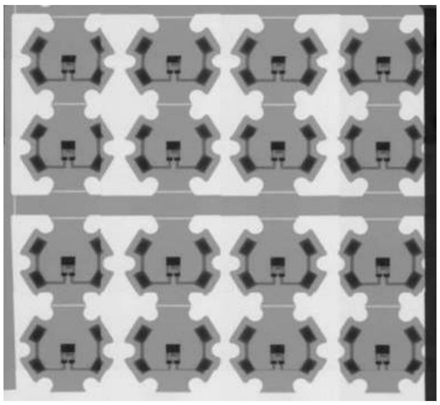


Figure 3. Image of MCPCB Test Board

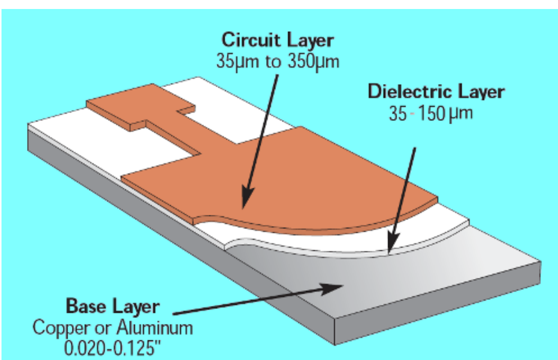


Figure 4. Cross Section of MCPCB substrate

For this study MCPCB boards with two dielectric materials were used, as described below:

MCPCB with Dielectric A: An MCPCB with dielectric A minimizes thermal impedance and conducts heat more effectively and efficiently than standard printed wiring boards (PWBs), an attribute important for LED packages.

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 MCPCB substrate. This dielectric is also preferred when the application requires reliable operation over a large temperature range and number of thermal cycles, while still providing very good thermal performance.

The relationship between the modulus of the MCPCB dielectric and the solder over the range of application temperatures to which the assembly will be subjected 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 that of 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.

Table 1 summarizes the materials and dimensional details of the MCPCB substrates used in this study, which have ENIG surface finish.

Table 1. MCPCB Materials and Thicknesses

Layer ID	Material and Thickness
Metal Core	Aluminum: 1.57 mm
Dielectric	A: 76 µm; B: 102 µm
Circuit Layer	Copper: 35 µm

Solder paste materials:
Four different solder pastes (with four different metal alloys) were selected for this study. These pastes used Type 3 solder powder and have 88-90 wt% metal contents. Details of these solder pastes are as follows:

Solder Paste A: This is a no-clean, zero halogen, and lead-free SAC305 alloy solder paste designed for a broad range of applications. This solder paste has a broad processing window thereby providing excellent print capability performance and high production yields.

Solder Paste B: This is a no-clean, zero halogen, and lead-free Maxrel^{TM} alloy solder paste that is suitable for fine feature printing applications. The Maxrel^{TM} alloy is known for its superior thermal cycling/shock performance relative to other high temperature solder alloys.

Solder Paste C: This is a no-clean, zero halogen, and lead-free SACX Plus^{TM}0807 alloy solder paste that is suitable for fine feature printing applications and has reduced Ag level for lower cost.

Solder Paste D: This is a no-clean, zero halogen, and lead-free solder paste that enables low temperature surface mount assembly due to the low melting point (<140°C) of the SnBiAg alloy.

LED ASSEMBLY PROCESS

Table 2 summarizes the SMT equipment that was used for the LED assembly.

Table 2. Assembly Process Equipment

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

Solder Paste Printing:
Solder paste printing was done using the MPM UP3000 stencil printer with a 5 mil thick laser cut stainless steel stencil with a 1 to 1 ratio of aperture size to pad size. Stencil printing parameters used for all solder pastes are shown in Table 3.

Table 3. Stencil printing parameters

Print Parameters	Print Parameter Details
Print Speed	2.54 cm/sec
Print Pressure	268 grams/cm of blade
Stencil Release	0.051 cm/sec
Snap off	0 cm (on contact printing)

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 LED package pick-up and placement. Care was taken to avoid any contact of the nozzle exterior with the LED domed silicone lens.

Reflow Soldering:
An Electrovert OmniFlo 7 reflow oven, with seven heating and two cooling zones was used for the reflow assembly. All boards were assembled in an air atmosphere.

Voids Measurement:
A Nikon Model XTV160 Xray machine was used to measure the voids percentages (by area) of the reflowed solder joints. For each solder paste and board dielectric type, (5) boards were assembled and at least 50% of the solder joints on each board were measured for %voids.

Reflow Profile Pre-Screening Test:
A pre-screening test was performed using two types of reflow profiles (high soak and straight ramp), the SAC305 solder paste and MCPCB board with type B dielectric, to determine the best type of profile for the LED assembly based on percent voids in the reflowed joints. The pre-screening test results (shown in Figure 5) show that a high soak profile results in slightly fewer voids and also a narrower % voids distribution. Therefore, high soak profiles were used for this study. The high soak profiles used for the high temperature alloy solder pastes (SAC305, Maxrel™ and SACX Plus™0807 pastes) and the low temperature SnBiAg paste are shown in Figures 6 and 7, respectively.

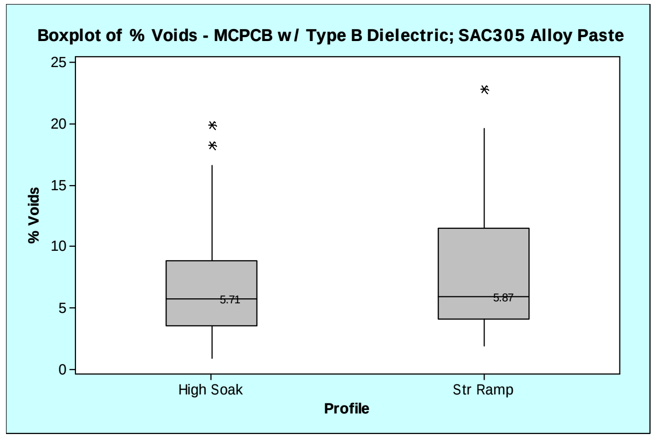


Figure 5. Box plot of %Voids vs Reflow Profile

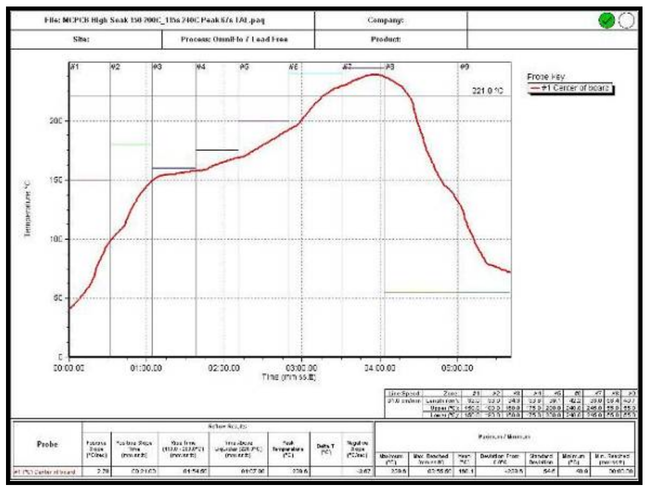


Figure 6. High Soak Profile for SAC305, SACX Plus™0807 & Maxrel™ Alloy Pastes; 150-200°C/115 sec Soak/ 240°C Peak/ 67sec TAL

VOIDING TEST RESULTS
The % voids data for the test boards was analyzed using Minitab and Microsoft Excel.

A main effects plot for the (2) variables in this study (MCPCB board dielectric and solder paste) is shown in Figure 8. This plot shows that the board dielectric has a relatively minor effect on the overall % voids for the LED package assembled with the various solder pastes on the MCPCB boards. However, the solder paste has a significant effect on % voids. The Maxrel™ alloy paste results in average void percentages of ~15%, while the SAC305 paste results in <9% voids overall.

In Figure 9 is shown a box plot for % voids verses the MCPCB board dielectric type. It shows that overall, the board dielectric had very little effect on the % voids with almost the same medians (10.5, 10.9 % voids) and ranges for both types.

Figure 7. High Soak Profile for SnBiAg Alloy Paste; 100-110°C/75 sec Soak/ 175°C Peak/ 60sec TAL

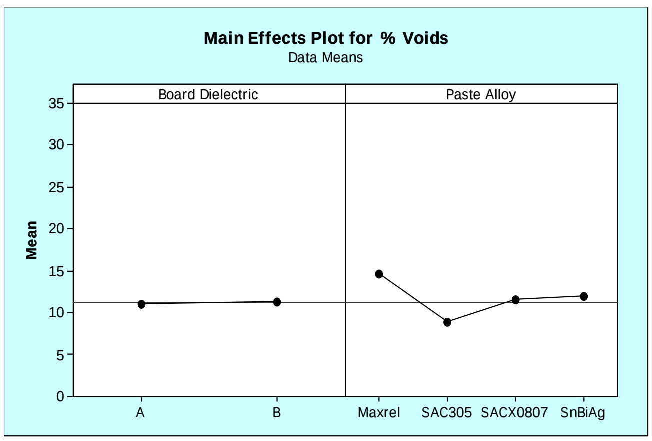


Figure 8. Main Effects Plot for Board Dielectric and Solder Paste

In Figure 10 is shown a box plot for % voids by MCPCB board dielectric type and solder paste alloy. Apparent here is a slight effect of board dielectric type for the different solder pastes, but the trend varies depending on paste alloy. For the Maxrel™ and SAC305 alloy pastes, the type B dielectric results in lower voids percentages, while for the SACX Plus™0807 and SnBiAg alloy pastes the type A board dielectric results in lower voids percentages. The SAC305 solder paste results in the lowest void percentage of the four pastes; this particular solder paste is known for its' low voiding attribute. Note that all of the solder pastes resulted in <20% voids, meeting the IPC Class 2 voids specification.

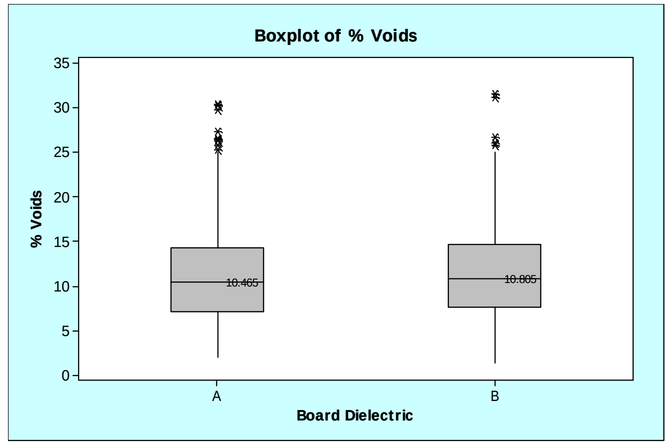


Figure 9. Box Plot of %Voids Verses MCPCB Board Dielectric

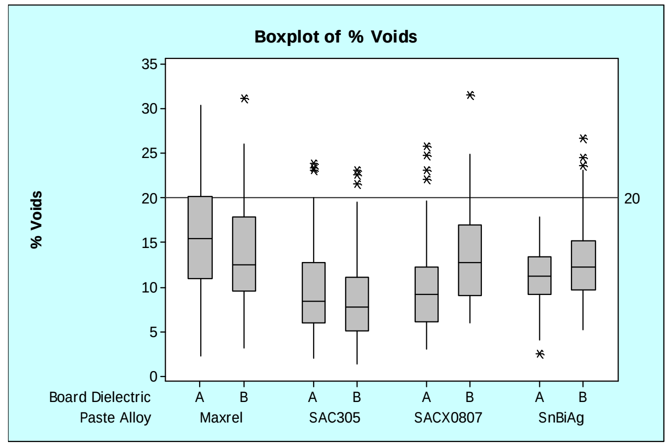


Figure 10. Box Plot of % Voids verses Board Dielectric Type and Paste Alloy

Figure 11 is a bar chart of void size verses the % of solder joints. Overall, >90% of the solder joints have void sizes that are 0-4% of the solder joint area. The "Zero" value on the x-axis refers to void sizes that are <0.005%.

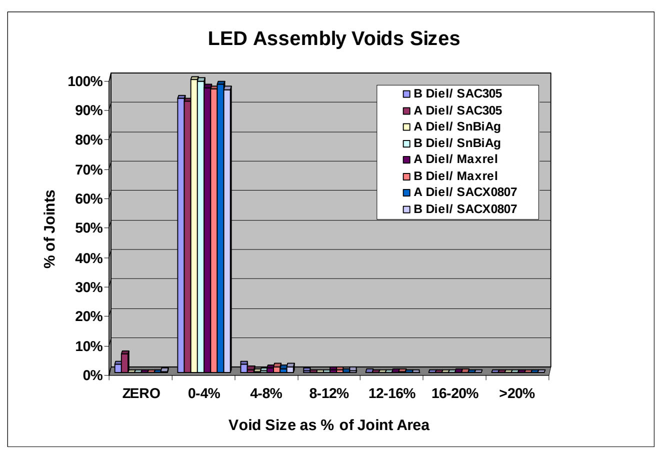


Figure 11. LED Assembly Void Sizes

Figures 12 and 13 are bar charts of the average and maximum void sizes, respectively, as a function of solder paste alloy and MCPCB dielectric type. For all (4) solder pastes, the type A MCPCB dielectric results in smaller average and maximum void sizes than does the type B dielectric. The low melting point SnBiAg paste results in the smallest average void size, probably because it is reflowed at a lower temperature than the SAC and Maxrel™ alloy pastes. In terms of maximum void size, the SAC305 and SnBiAg alloy pastes are comparable, with maximum void sizes of 10~13% of the joint area.

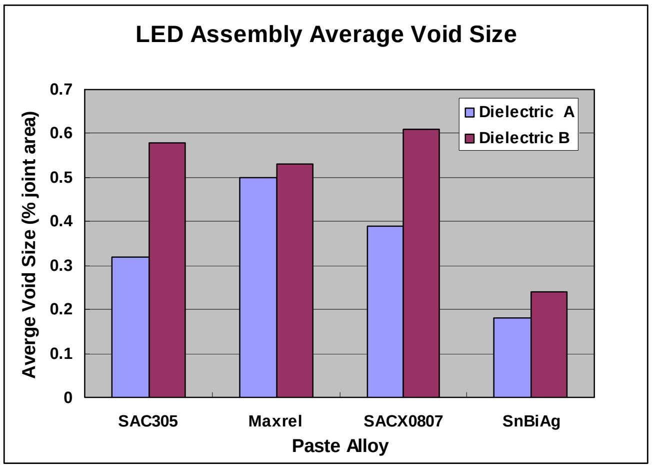


Figure 12. LED Assembly Average Void Sizes

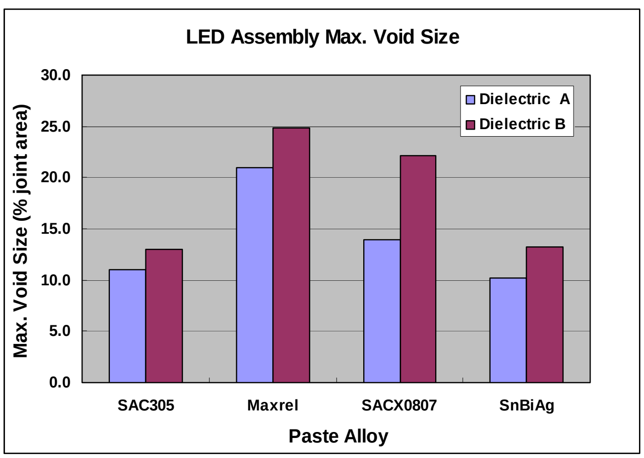


Figure 13. LED Assembly Maximum Void Sizes

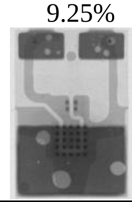
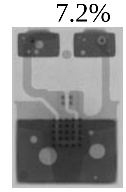
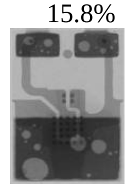
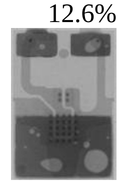
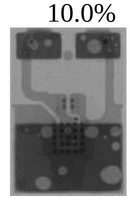
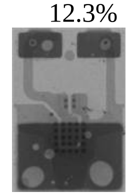
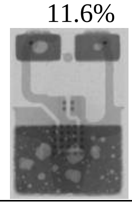
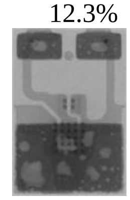
Table 4 shows typical Xray voids images and corresponding voids percentages for each solder paste and board dielectric combination.

SUMMARY AND CONCLUSIONS

Commercially available solder pastes with (4) different metal alloys were evaluated for % voids in the reflowed joints when used to attach a commercially available LED package on MCPCB substrates having (2) different dielectric types. The SAC305 alloy paste results in the lowest void percentages in the reflowed joints for both MCPCB dielectrics. This particular paste is known for its good voiding performance. Not discussed herein, but key, is the effect of paste flux on voiding.

The effect of board dielectric type on voiding performance is solder paste specific with (2) of the pastes resulting in lower % voids when reflowed on boards with the type A dielectric (SACX Plus™0807 and SnBiAg pastes) and (2) pastes showing better voids performance on boards with the type B dielectric (SAC305, Maxrel™). In terms of average and maximum void sizes, the reflowed joints for the type A dielectric boards are superior for all pastes, and the SnBiAg paste results in the smallest void sizes.

Table 4. X-ray Voids Images

Solder Paste	MCPCB Dielectric A	MCPCB Dielectric B
A (SAC305)	9.25% 	7.2% 
B (Maxrel™)	15.8% 	12.6% 
C (SACX0807)	10.0% 	12.3% 
D (SnBiAg)	11.6% 	12.3% 

Overall, for all pastes and board dielectric types, >90% of the solder joints had void sizes of 0-4% of the solder joint area and less than 20% voids on average. The SAC305 alloy paste combined with the type B board dielectric results in the lowest % voids (<8.5%).

The boards assembled for this study will be subjected to further tests including electrical measurements, die shear, thermal cycling, thermal shock and solder joint characterization by cross-sectioning (Ref.3).

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