LOW TEMPERATURE ASSEMBLY OF LED PACKAGES ON PET & POLYIMIDE FLEXIBLE SUBSTRATES

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ABSTRACT

This paper presents a structured study covering the assembly of mid power LED packages on thermally conductive polyethylene terephthalate (PET/Polyester) and polyimide flexible substrates. The study evaluates the feasibility of using PET as a low cost, low temperature alternative with SnBi Alloy to traditional polyimide with SAC based alloy assemblies. Initially, an assembly method was developed for both polyimide and PET based substrates respectively. The results of this assembly such as light output, voiding and basic solder joint reliability are discussed in this paper.

Keywords: SSL, LED, Low Temperature Assembly, Flexible Circuits, Polyimide and PET Substrates, Sn-Bi Solder Paste.

INTRODUCTION

LEDs are now becoming more prevalent and are being widely used in a variety of applications such as Automotive Lighting, Commercial and Indoor Lighting. The two key enabling technologies are:

- LEDs - which have surpassed many conventional lighting technologies (CFL & Incandescent) in terms of lifetime, energy efficiency, versatility, and color quality. Furthermore, the up-front costs of LEDs are decreasing.
- Flexible Circuits – which are facilitating reductions in material stack / footprint and improvement in process flexibility Furthermore, flexible circuits allow reduction in material and process costs.

Typically, polyimide (PI) is the most commonly used flexible substrate in conjunction with SAC-based Solder Pastes (a melting point of around 218°C). With recent advancements in Polyethylene Terephthalate or more commonly known as Polyester (PET), these substrates were used along with polyimide substrates for this study. A new low temperature Tin-Bismuth based solder paste was also developed.

Thus, this study assessed the feasibility of utilizing flexible substrates with low temperature solders for Solid State Lighting.

ASSEMBLY MATERIALS & COMPONENTS

Materials and components were chosen based on commercially available LED packages, solder pastes and flexible substrates.

Mid Power LED package

The Solid State Lighting Industry (SSL) industry continues to develop packages and materials that improve LED performance.

For this study the Luxeon® 3535L package was selected. It consists of a 3535 lead-frame design (3.5mm x 3.5mm). A small notch on the corner of the package marks the cathode side of the emitter package. The anode and cathode both serve as thermal pads for the emitter, with the majority of the heat being conducted through the larger pad, corresponding to the cathode.

Figure 1. Image of Mid Power LED Package (Refer 1)

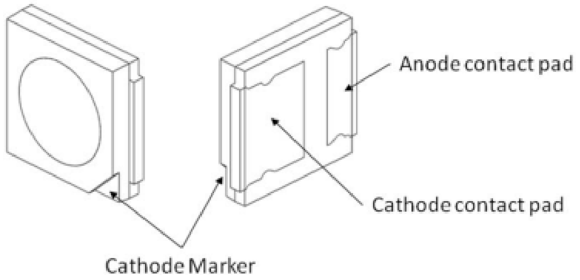


Figure 2. LED Package Rendering Including Solder Footprint (Refer 1)

Polyimide (PI) and Polyethylene Terephthalate (PET) Substrates

Flexible circuits allow for a reduced board material stack over rigid boards and are able to provide designers with a higher freedom on design in the SSL industry. Thus, lighting manufacturers utilize flexible circuits as a solution. The increased demand for flex circuits is most noticeable in applications for indoor linear lighting, cabin lighting for automobiles, backlights mobile displays, digital cameras and flat panel displays.

There are a number of different materials used as base films for flexible circuits including: polyester (PET), polyimide (PI), polyethylene napthalate (PEN), Polyetherimide (PEI), etc. Each substrate has its unique electrical, mechanical, chemical and thermal properties. For this study the LED packages were assembled on two extensively utilized base materials in the flexible circuits industry. Polyimide (PI) and Polyethylene Terephthalate (PET): Both substrates have a similar thickness and construction comprised of a copper-aluminum composite.

The test vehicle with both substrates was designed in a 9x7 LED matrix. A total of sixty-three (63) LED packages were assembled in this configuration as shown in Table 1. The image of the test vehicle used is shown in Figure 3.

Table 1. Details of the Test Vehicle Substrates

Test Vehicle Details:	
Polyethylene Terephthalate (PET)	Dimensions: 18”x12” Solder Pad Sites: 63 (9x7)
Polyimide (PI)	Dimensions: 18”x12” Solder Pad Sites: 63 (9x7)

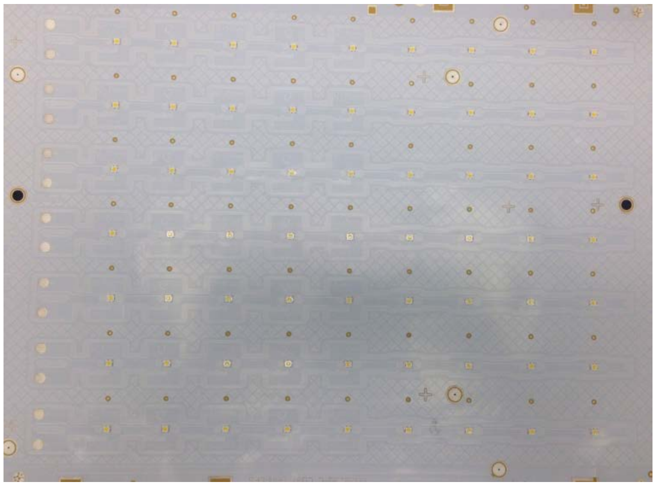


Figure 3. Substrate Design

A cross sectional view of the PI substrate is shown in Figure 4.

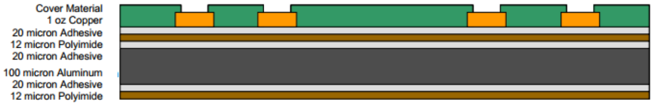


Figure 4. Cross Sectional View of Q-Prime® Substrate (Polyimide) (Refer 2)

Solder Paste

Lead-free Sn-Ag-Cu pastes are typically used in assemblies utilizing polyimide flexible substrates. Solder Pastes using Sn-Ag-Cu alloys have melting ranges between 217°C and 228°C, requiring reflow temperatures in the range of 245°C to 265°C. Although manufacturers who utilize flexible circuits have adapted to these higher reflow temperatures, a set of very strong drivers is pushing forward the use of lower reflow temperatures in application of LEDs assembled on flexible substrates. The major benefits of using low temperature alloys are: (Refer 3, 4, 5)

- Assembly of heat sensitive packages and components.
- Long-term reliability, as low temperature solders reduce exposure to thermal excursion, warpage and other defects caused by excessive heat. .
- Reduced material costs by using low temperature alloy and solder paste, low Tg PCBs and low temperature compatible components.
- Reduced energy costs through lowering temperature processing.
- Higher throughputs by reducing reflow / processing cycle time.

In general, assemblies involving LED components are considered to be a temperature-sensitive. So heat induced defects such as browning and softening of the silicone lens, and discoloration of the white solder mask typically utilized in LED assembles, affects the light output. Furthermore, in case of flexible circuits/assemblies, higher temperatures can cause delamination and warpage of substrates. Low-temperature solders are preferred for these applications. Simultaneously, Sn-Ag-Cu alloys will also be used for other applications. In this study a novel low-temperature Sn-Bi alloy (SBX02) solder paste is used allowing the assembly of the LED packages to be reflowed under 175°C, Further, a solder paste with a SAC305 alloy was also used as the baseline.

PROCESS AND ASSEMBLY DETAILS

Test Matrix

Based on the package, substrate and materials selected the process involved three key assembly permutations, Figure 5 shows these combinations. First combination involved using a polyimide substrate with a SAC305 solder paste representing the current industry practice. The second combination involved again, a polyimide substrate in conjunction with a low-temperature SBX02 alloy based solder paste. This combination represents the traditional substrate with the low-temperature solder paste. The final combination used a Polyester (PET) substrate with the low-temperature solder paste.

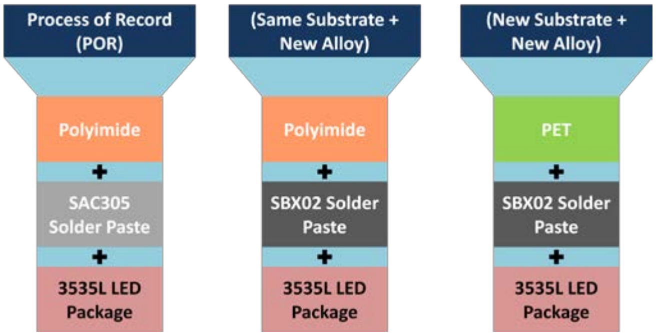


Figure 5. Three Tier Combination of LED assemblies on Flexible Substrates.

Process Details

Table 2 summarizes the SMT equipment that was used for assembling the LED packages onto the substrate combinations.

Table 2. SMT Equipment Summary

SMT Equipment	Equipment Details
Stencil Printer	Standard Stencil Printer
Pick and Place	Standard Pick and Place Machine
Placement Nozzle	Flex Jet nozzle
Reflow Oven	Seven Zone Reflow Oven

Solder Paste Printing

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

Table 3. Print Parameters

SMT Parameters	SMT Process Details (SI Standard)	SMT Process Details (Metric System)
Print Speed	1 inch/sec.	25 mm/s
Print Pressure	1.25 lbs/inch	0.22 kg/cm
Stencil Release	0.02 inches/sec	0.508 mm/sec
Snap off	0 inches (on contact printing)	
Wipe Frequency	Dry wipe after each print	

Component Placement

A pick and place machine with flex jet head was used for the picking and placing the LED package. Care was taken to avoid any contact of the nozzle exterior with the LED domed silicone lens.

Reflow Soldering

A reflow oven, with seven heating and two cooling zones was used for the reflow assembly. All boards were assembled in an air atmosphere with the following Temperature/Humidity conditions: 20.4-25.2C / 16-47% RH. All of the substrates used in the study were pre-baked before going under their respective reflow conditions. The table below summarizes the reflow conditions for each combination.

Table 4. Reflow Parameters

Substrate + Solder Paste	Reflow Conditions
Polyimide + SAC305	High Soak 150-200C/105s 245C Peak 68-75s TAL
Polyimide + SBX02	Low Soak 100-120C/104s 175C Peak 65s TAL
PET + P53 SBX02	Low Soak 100-120C/104s 175C Peak 65s TAL

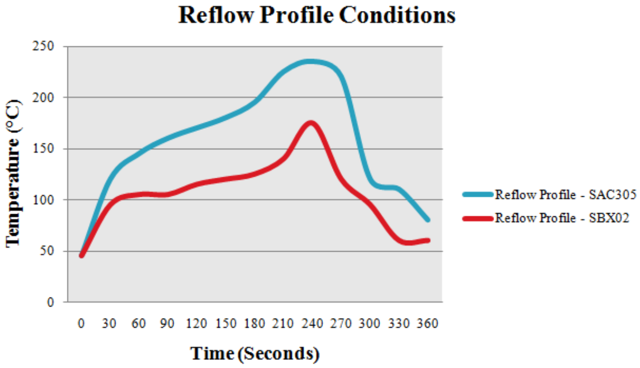


Figure 6. Reflow Profile of SAC305 vs. SBX02

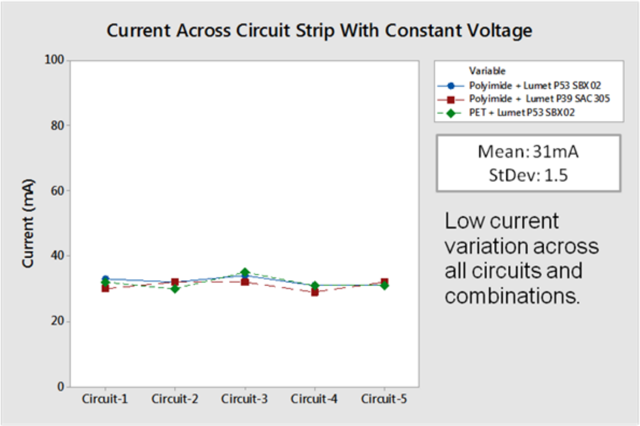
RESULTS AND DISCUSSIONS

After the final assembly, multiple tests were undertaken:

- The first test was to check the light output of the assembly by measuring the current across each assembly. This ensured a proper assembly and functionality of the circuit.
- Secondly, a voiding study was conducted by X-Ray analysis. Thermal management is a key requirement in SSL assemblies. Voiding can play a vital role in the efficiency of thermal transfer from package to board.
- In order to evaluate the solder layer , a cross section analysis of all the combinations of substrate and solder paste were undertaken.
- Further thermal cycling of all the combinations are underway and will be presented in Phase II of this paper.

Light Output Measurements and Results

A light up test was conducted to ensure the LED packages both on PET and Polyimide was operational. Using a commercially available power supply with a constant input voltage of 25V, the current across each circuit was recorded as shown in Figure 7. Each substrate was tested visually to ensure the LED lit for a minimum of 3 seconds as seen in Figure 8.



Mean: 31mA
StDev: 1.5

Low current variation across all circuits and combinations.

Figure 7. Current Across Substrate & Paste Combination.

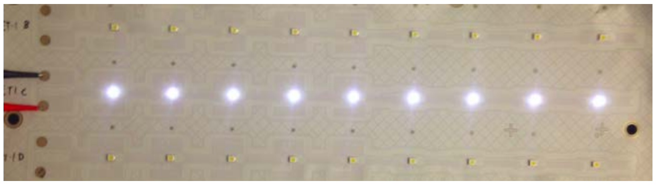


Figure 8. Typical LED Circuit Under Operation.

The current measured across each circuit produces a low variation from the mean. A significant decrease in current would indicate an increase in resistance. The light output test confirmed that all combinations of the LED circuits passed the reflow processing conditions. Furthermore, the LED circuit shown in Figure 8 lit up confirming there are no failures within the assembled LED package, solder layer or board circuitry.

Voids Measurement and Results

Voids can reduce the overall rate of heat transfer between the LED package and board. This reduction of heat transfer efficiency can cause the LED to degrade much quicker. This can lead to:

- Reduced solder joint integrity which lowers overall life expectancy / reliability of the LED.
- Inefficient manufacturing process with a reduced first pass yields.
- Higher costs due to scrapped materials i.e. boards, LED packages, and solder.

An X-ray machine was used to measure the voids percentages (by area) of the reflowed solder joints. A total of 40 randomly selected solder sites for each solder paste and board combination were evaluated.

A typical example of an individual site on PET with SBX02 under X-Ray inspection can be seen below in Figure 9. Void % by pad and total void % were analyzed.

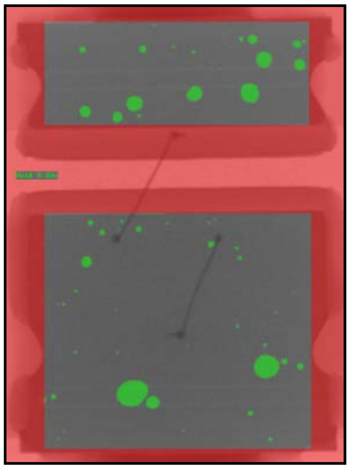


Figure 9. Void % by Total Area

Figure 10 shows a box plot for % voids per total pad area for the 3 combinations of paste and substrate type. It shows that overall, the % of voids are under 10%. PET in conjunction with the use of SBX02 solder paste produces the least amount of voids as seen in Table 5.

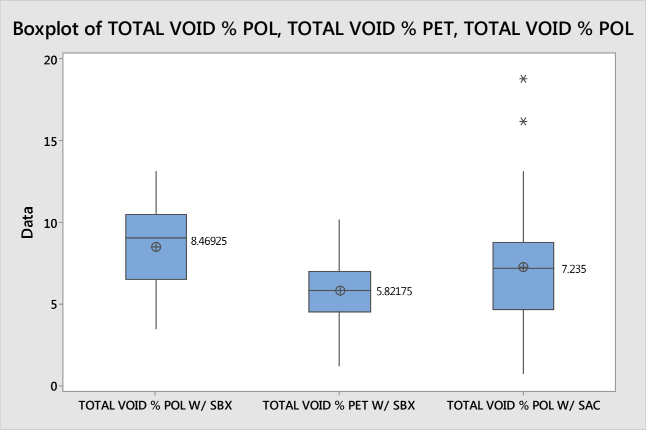


Figure 10. Box Plot of Total Area Void %.

Table 5. Void % and Standard Deviation.

Combination	Mean Void %	Standard Deviation
PET + SBX02	5.82	1.97
Polyimide + SAC305	7.23	3.64
Polyimide + SBX02	8.46	2.43

The average percentage of voiding in all 3 combinations falls below 10%. The maximum size of a single void including their respective sum of standard deviation for any combination falls below 10.89%.

Solder Layer Measurements and Results

Cross sections were undertaken for PET and polyimide substrates the solder layer for the joints are characterized below. Examples of PET and polyimide using low-temperature SBX02 are shown in Figures 11A, B and 12A, B below. polyimide using SAC305 are shown in Figures 13A, B. Figures 11A, 12A and 13A corresponds to a general cross sectional profile of the LED package, while 11B 12B and 13B shows the edge view (fillet) of the solder joint structure.

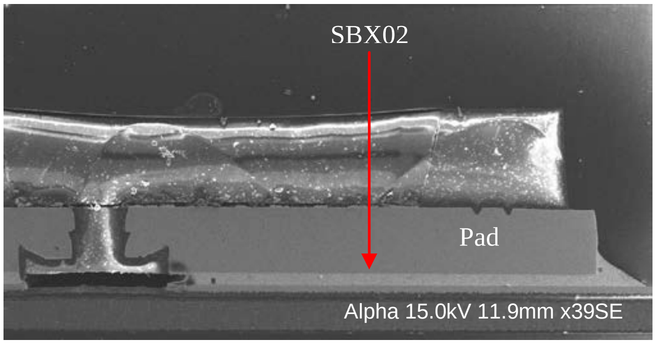


Figure 11A. Overall View of an LED Package on PET with SBX02

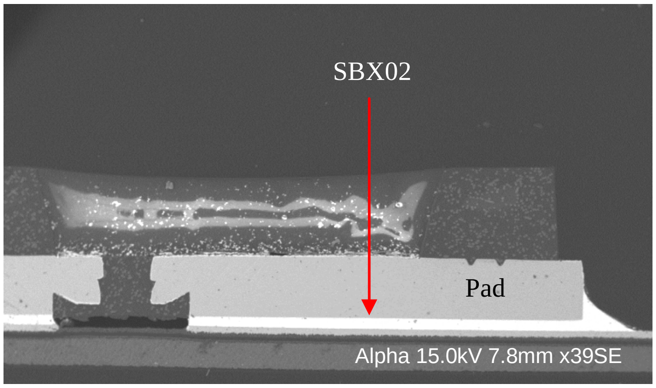


Figure 12A. Overall View of an LED Package on Polyimide with SBX02

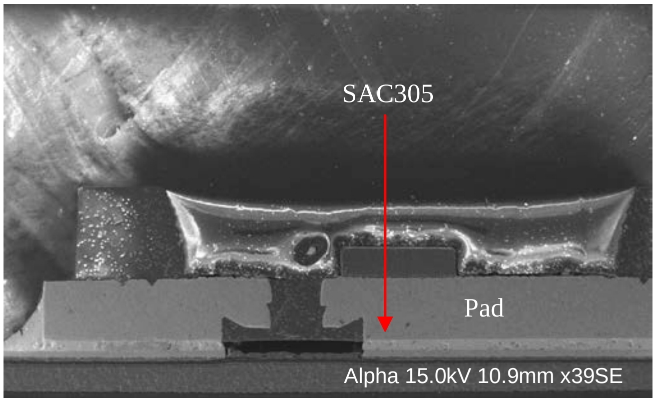


Figure 13A. Overall View of an LED Package on Polyimide with SAC305

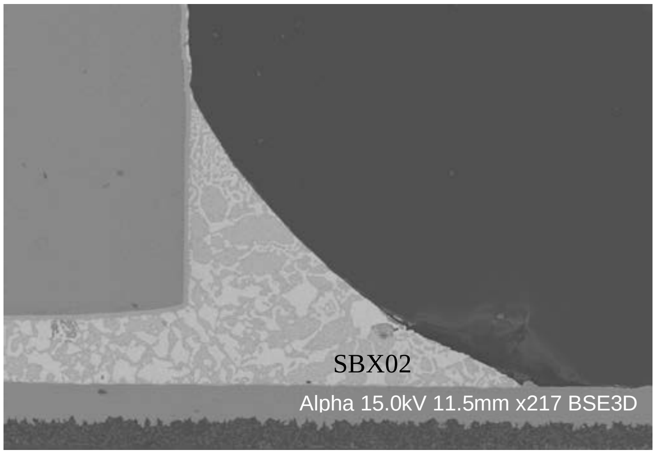


Figure 11B. Solder Edge View of LED Package on PET with SBX02

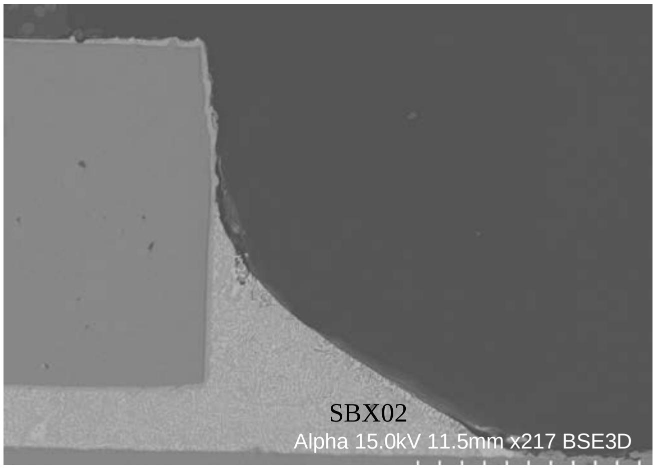


Figure 12B. Solder Edge View of LED Package on Polyimide with SBX02

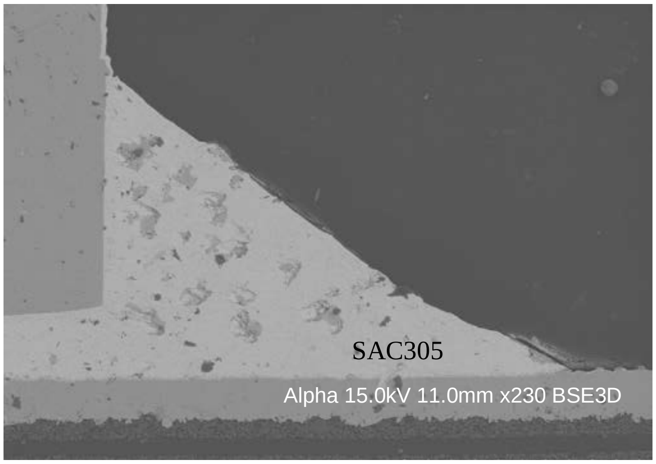


Figure 13B. Solder Edge View of LED Package on Polyimide with SAC305

The solder joints exhibited excellent fillet. No visual cracking was observed across all 3 combinations.

SUMMARY AND CONCLUSIONS

In this study Polyimide and PET were evaluated with low-temperature solders with the SAC305 assembly considered as a process of record. Solder joints assembled with these new materials (substrates and paste) mentioned in this paper were robust.

All of the assembled packages passed the light output test. Concluding there are no failures within the solder joint, LED package itself or board circuitry. The X-Ray inspection showed minimal voiding percentages that meet or exceed typical SSL industry requirements. Furthermore, cross sectional analysis showed excellent fillet and robust solder joints.

Currently, the substrates assembled for this study are under going thermal cycling tests. After the completion of 2000 cycles, light output, lumen output over lifetime and IMC will be discussed in Phase II.

In conclusion, this work demonstrated that new thermally conductive PET substrates can be used with low temperature solders. This option enables a multiple advantages such as:

- Using PET as a low cost, low-temperature alternative to polyimide substrates.
- Utilizing low-temperature solders, enabling a cascading assembly option. (Using SAC based solders for the first assemblies followed by a low-temperature assembly).

Thus, thermally conductive PET substrates with low-temperature solders can be used to replace polyimide with SAC based solders for applications such as interior lighting for automotive, commercial lighting and indoor lighting.

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