Light Emitting Diode

Solder Crack Explanation and Evaluation

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Light Emitting Diode

1. Overview

Many products using LEDs have the LEDs mounted on printed circuit boards (PCBs) using solder (i.e. surface mount device [SMD] LEDs). The most common issues in the assemblies with SMD LEDs are cracks in the solder joints. This may occur depending on the combination of the SMD LED and the PCB, especially when the PCB is repeatedly exposed to environments with large differences in temperature. If there is a large difference in the linear expansion coefficient between them, it will increase the likelihood of solder cracks, and in some cases, it may lead to failures (i.e. the LEDs not emitting). Since the applications and environments using SMD LEDs are becoming more diverse, solder cracks are issues that require special attention and expertise.

This application note will cover the main cause of solder cracks, how to reduce the occurrence of solder cracks, and show evaluation results for temperature cycle tests for specific SMD LED and PCB combinations that may cause solder cracks.

2. Main Cause of Solder Cracks

To understand the main mechanism that causes solder cracks, the difference in the linear expansion coefficient between the PCB and the soldered component is one important factor. This section will explain how solder cracks are created and how the difference in liner expansion coefficient helps to cause solder cracks.

2.1. Linear Expansion Coefficient

Linear expansion coefficient or coefficient of linear thermal expansion (CTE) is the rate at which the length of an object changes as the temperature rises. Solder cracks are most likely to occur when the difference between the linear expansion coefficients of the SMD LED and PCB is large.

Table 1 shows the linear expansion coefficients[1] of common LED package materials and PCB materials.

Table 1. Linear expansion coefficients of common LED and PCB materials

LED		PCB	
Package Material	**CTE(1/℃)**	**Material**	**CTE(1/℃)**
Ceramic	7×10^{-6}	Ceramic	8×10^{-6}
Resin	16×10^{-6}	Iron (Fe)	12×10^{-6}
		Glass-reinforced epoxy laminate material (FR-4)	14×10^{-6}
		Copper (Cu)	17×10^{-6}
		Aluminum (Al)	21×10^{-6}
		Composite epoxy material (CEM-3)	25×10^{-6}

Note:

[1] The linear expansion coefficient described in the table is only a typical value.

2.2. The Mechanism that Causes Solder Cracks

Step 1: Attaching a SMD LED to a PCB by reflow soldering

Both the SMD LED and PCB are exposed to high temperatures during the reflow soldering process. They expand according to their linear expansion coefficients. Although further stress is applied to the solder joint as the heated SMD LED and PCB cool down and shrink, as long as there is no change in the ambient temperature, solder cracks are not created immediately after the reflow soldering process (see Figure 1).

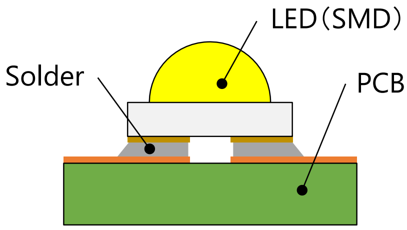


Figure 1. Step1

Step 2: Using the assembly in an environment with large temperature difference

The linear expansion coefficients of the SMD LED and the PCB are different, these different expansion rates creates stress which is applied to the solder joint (see Figure 2).

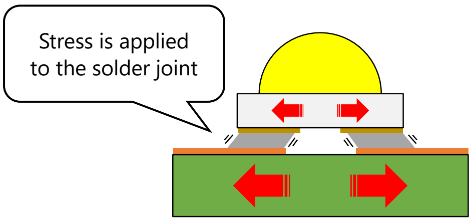


Figure 2. Step2

Step 3: The occurrence of solder cracks

Due to the continuous stress applied to the solder connection in Step 2, part of the solder begins to crack (i.e. solder crack begins to occur). Eventually, the solder crack occurs across the solder joint and the SMD LED is no longer able to be energized and will not emit light (see Figure 3).

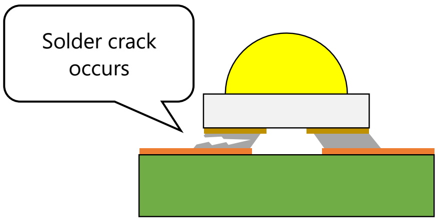


Figure 3. Step3

3. How to Reduce the Occurrence of Solder Cracks

This section will cover the best-known methods and industry practices to reduce the occurrence of solder cracks or minimize the resulting damage.

3.1. Select an LED and PCB combination with a small difference between the linear expansion

As noted in section 2.2, the smaller the difference between the linear expansion coefficients of the SMD LED and the PCB, the smaller the occurrence of solder cracks, and the less severe the damage (i.e. size of solder cracks) is even if solder cracks occur.
For example, if the combination is a resin package SMD LED with a glass epoxy PCB (i.e. FR-4), the difference in the linear expansion coefficient is $2x10^{-6}$, whereas if the combination is a ceramic package SMD LED and an aluminum-core PCB, the difference in the linear expansion coefficient is $14x10^{-6}$. If the goal is to reduce the potential of solder cracks, the combination of a low/middle-power SMD LED with a resin package and a FR-4 (Glass Epoxy) PCB is more effective than a combination of a high-power SMD LED a ceramic package and an aluminum-core PCB.

3.2. Use an LED with a smaller package size

As the temperature increases, so too does the influence of the difference between the linear expansion coefficients of the SMD LED and the PCB (i.e. the expansion between the electrodes increases) leading to an increase in the occurrence of solder cracks. Since small packages are more likely to have a smaller distance between the electrodes than large packages, the occurrence of solder cracks may be able to be reduced by using a SMD LED with a small package size.

3.3. If the LED package size is the same, select a SMD LED with a small distance between the electrodes

As discussed in 3.2, as the temperature increases so too does the influence of the difference between the linear expansion coefficients of the SMD LED and the PCB (i.e. the expansion between the electrodes increases) leading to an increase in the occurrence of solder cracks. Using a SMD LED with a small distance, the occurrence of solder cracks may be able to be reduced.

3.4. If the LED package size is the same, select a SMD LED with a larger electrode area

The strength of the solder joint can be increased by using an LED with a larger electrode area and the influence of solder cracks on the SMD LED performance/reliability may be able to be reduced after a solder crack begins to occur. This may also extend the life of the solder joint, which may help avoid a lighting failure.

3.5. Other considerations

This application note does not cover all potential factors (e.g. solder paste, PCB components/materials other than the base metal material, etc.); these factors may be able to reduce solder cracks. Nichia recommends that customers select the right materials for the chosen application and intended usage environment.

4. Solder Crack Evaluation (Temperature Cycling Test)

Nichia performed a temperature cycling test to verify the cause described in section 2 (i.e. the difference in linear expansion coefficient between the SMD LED and PCB) and the effectiveness of the best-known methods and industry practices described in section 3. If there is a solder crack, the electrical resistance of the solder joint tends to increase and the VF value tends to rise; as a result the VF value is used as an indicator for solder cracks.

4.1. Evaluation Conditions/Method

Evaluation Conditions:

Cycle test conditions: -40°C (15 minutes) ⇔ 100°C (15 minutes), 2000 cycles (non-energized)
LED: 10 pieces each of 3.5mm sq. ceramic package with either 2 or 3 electrodes (see Table 2, Figure 4)
PCB: 5pcs each of Fe, FR-4, and Al (see Table 3, Figure 5,6)
Solder: Senju Metal M705-298C-42-11 (Sn 96.5 / Ag3.0 / Cu 0.5), solder thickness: 0.1 mm

Evaluation Method:

Nichia performed a complete lighting check every 500 cycles, and checked for a 10% rise in the V_F value[2], and performed a cross-section observation of the LEDs to compare.

Table 2. LED part number and the linear expansion coefficient

LED	Base Material	CTE(1/℃)	Number of Electrodes	Total Electrode Area(mm^2)
NVSL119B-V1	Al_2O_3	7×10^{-6}	2	8.3
NVSL119C	AlN	4×10^{-6}	2	8.3
NVSL219B-V1	Al_2O_3	7×10^{-6}	3	6.2
NVSL219C	AlN	4×10^{-6}	3	6.2

Table 3. LED recommended soldering pad pattern

PCB Material	PCB Thickness (mm)	Copper Foil Layer(μm)	Insulating Layer [μm]	CTE(1/℃)
Fe	0.5	35	120	12×10^{-6}
FR-4	1.0	35	なし	14×10^{-6}
Al	1.0	35	120	21×10^{-6}

Note:
[2] The V_F rise of 10% is based on the standard judgment value of Nichia's reliability test per the part specifications.

NICHIA 119 series (two-electrode configuration) NICHIA 219 series (three-electrode configuration)

Figure 4. LED part number electrode layout

NICHIA 119 series (two-electrode configuration) NICHIA 219 series (three-electrode configuration)

Figure 5. LED recommended soldering pad pattern

Figure 6. Example of how the LEDs were mounted on the PCB

4.2. Evaluation Results

As shown in Table 4,5 below, both the NICHIA 119 and 219 series SMD LEDs did not fail (i.e. no light emission) up to 2000 cycles with any of the combinations. However, the combination of the NICHIA 219 series LEDs (both part numbers using an aluminum oxide [Al_2O_3] ceramic material and an aluminum nitride [AlN] ceramic material for the package) and the aluminum-core PCB caused a 10% increase in the V_F value (i.e. possible indication of solder cracks) after 1000 cycles.
The difference between the NICHIA 119 and 219 series LEDs is the electrode configuration and size; the NICHIA 219 series LEDs were designed based on the NICHIA 119 series LEDs (i.e. SMD LEDs with a two-electrode configuration) to have a three-electrode configuration compatible/similar to other companies' products, resulting in a smaller electrode size than the NICHIA 119 series. From these facts and findings, it can be concluded that the best-known methods and industry practices noted in section 3 are efficient in preventing solder cracks.

Table 4. Evaluation results (No Light Emission)

PCB Material			Fe				FR-4				Al			
Cycles			500	1000	1500	2000	500	1000	1500	2000	500	1000	1500	2000
LED	NVSL119B-V1	2 electrodes	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
	NVSL119C		0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
	NVSL219B-V1	3 electrodes	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
	NVSL219C		0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10

Table 5. Evaluation results (V_F Increase of 10%)

PCB Material			Fe				FR-4				Al			
Cycles			500	1000	1500	2000	500	1000	1500	2000	500	1000	1500	2000
LED	NVSL119B-V1	2 electrodes	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
	NVSL119C		0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
	NVSL219B-V1	3 electrodes	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	**1/10**	**7/10**	**7/10**
	NVSL219C		0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	**5/10**	**7/10**	**8/10**

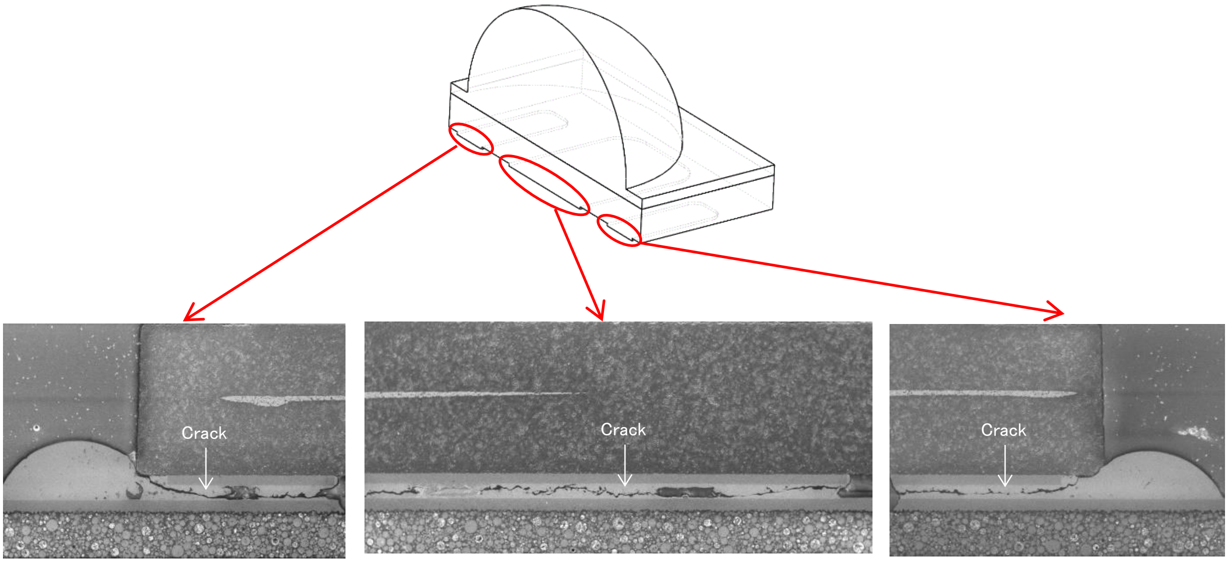
Table 6. Combination of LED and various PCBs[3]

LED	Number of Electrodes	Total Electrode Area(mm^2)	CTE(1/℃)		
			Fe	FR-4	Al
NVSL119B-V1	2	8.3	5×10^{-6}	7×10^{-6}	14×10^{-6}
NVSL119C		8.3	8×10^{-6}	10×10^{-6}	17×10^{-6}
NVSL219B-V1	3	**6.2**	5×10^{-6}	7×10^{-6}	**14×10^{-6}**
NVSL219C		**6.2**	8×10^{-6}	10×10^{-6}	**17×10^{-6}**

For reference purposes, in order to confirm the condition of the solder crack at 2000 cycles for the combination of where the V_F value 10% rise was seen (i.e. NVSL219C and aluminum-core PCB), Nichia performed a cross-section observation (see Figure 7). Note that this combination has the largest difference in linear expansion coefficient (i.e. aluminum nitride [AlN] ceramic package [4 x 10^{-6}] and aluminum-core PCB [7 x 10^{-6}]), and the NVSL219C has three electrodes resulting in a smaller electrode size.

Note:

[3] V_F rise of 10% occurred for the cases shown in red within the table.



Cathode Die Heat Sink Anode

Figure 7. Cross section observation (NVSL219C 3 electrodes and Al PCB) after 2000 cycles

5. Summary

As shown in this application note, Nichia found that using an appropriate SMD LED package (i.e. package material and size, and electrode configuration and size) and appropriate PCB (i.e. base material) together, the combination can have a certain resistance against solder cracks. However, when designing for the chosen application, in addition to solder cracks there will be other elements/issues to take into consideration. For example, consider:

- the thermal management of the LED (e.g. how to dissipate the heat effectively)
- selecting an LED that matches the intended/designed optical performance
- designing/selecting a metal solder stencil that optimizes the amount/shape of the applied solder paste to prevent other soldering issues (e.g. insufficient coverage of solder, void, shear strength, etc.)
- the position accuracy of the LED during the reflow process

Nichia recommends that customers ensure the design is well-balanced for all necessary considerations for the chosen application.

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