Light Emitting Diode

Reducing the Occurrence of Solder Cracks for the Nichia 170, 131, or 121 Series LEDs

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The "Nichia 170/131/121" collectively refers to Nichia part numbers listed in the table in Section 2 Applicable Part Numbers. These Nichia part numbers within this document are merely Nichia's part numbers for those Nichia products and are not related nor bear resemblance to any other company's product that might bear a trademark.

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1. Overview

If the Nichia 170/131/121 Series are subjected to thermal stress after soldering, it may cause cracks on the solder joints between the LED and PCB due to the different thermal expansion coefficients of each component (see Figure 1). When the solder crack grows, it may cause a solder joint failure; in the worst case, it could cause the LED to not emit light. When the LEDs are used with metal-core PCBs, sufficient verification must be done prior to use to ensure there are no issues for the chosen application.

This application note shows the evaluation results for anti-solder crack solutions performed using the NC5W121A. This Nichia LED was chosen for the evaluations since it has the largest dimensions for the Nichia 170/131/121 Series, and therefore would have the highest possibility of solder cracks.

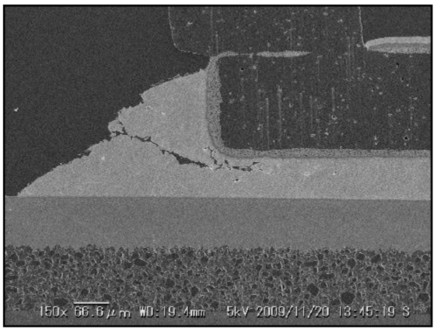


Figure 1. Example of a Solder Crack

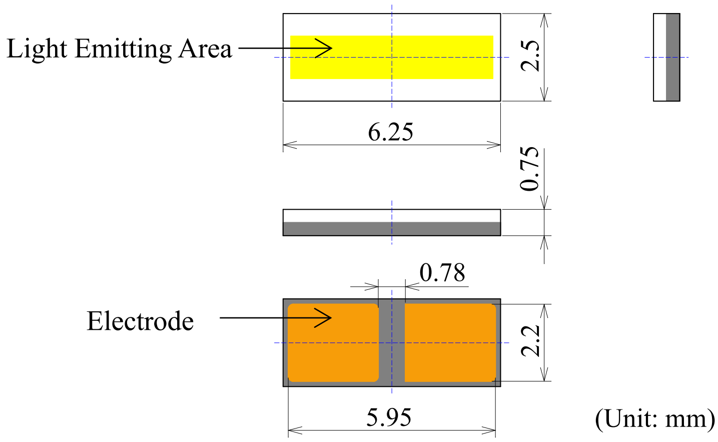
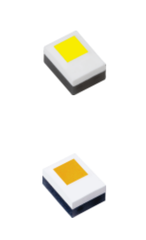
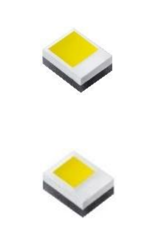
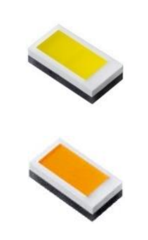
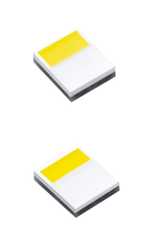
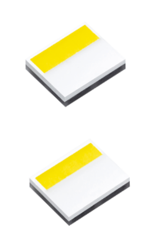
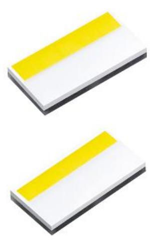


Figure 2. Top, Side, and Back of the NC5W121A LED

2. Applicable Part Numbers

This application note applies to the LEDs shown in Table 1.

Table 1. Applicable LED Part/Series Numbers

Category	Nichia 170/131 Series[1]			Nichia 121 Series			
Part Number[2]	NJSx170x	NCSx170x NCSx131x	NC2x170x NC2x131x	NC2W121x	NC3W121x	NC4W121x	NC5W121x
Examples of Package Appearance							
Package Size (Unit : mm)	1.6×1.2×0.75	1.8×1.45×0.75	3.0×1.6×0.75	3.1×2.6×0.75	3.1×3.75×0.75	3.1×4.9×0.75	3.1×6.05×0.75

Note:

[1] The electrode pattern on the back of the package for the Nichia 170 Series and Nichia 131 Series is different.

[2] The x represents a letter that follows the alphanumeric code of the same LED type.
(Ex: NCSx170x → NCSW170C, NCSW170D, NCSW170D-PCA, NCSA170D, NCSW170F, NCSA170F, etc.)

3. Main Cause of Solder Cracks

3.1 How Solder Cracks Occur

Figure 3 below shows an LED soldered to an aluminum-core PCB.

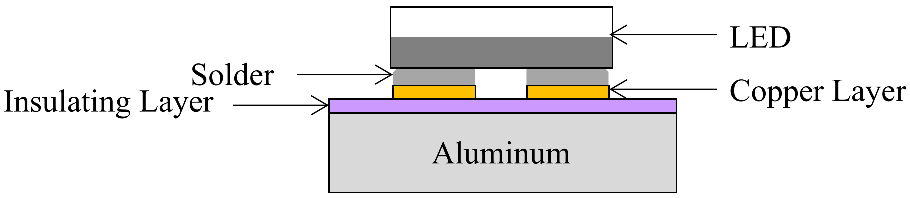


Figure 3. Step 1: Soldering an LED to an aluminum-core PCB

Since there is a difference in the coefficient of thermal expansion (CTE) between the LED and the aluminum-core PCB, using this assembly in an environment where the temperature fluctuates significantly causes them to expand/contract at different rates and the resulting stress will be applied to the solder joints (see Figure 4).

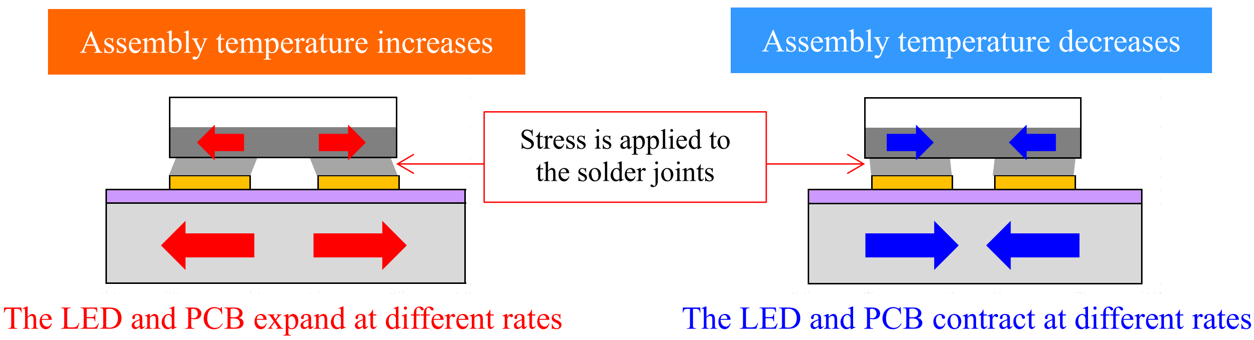


Figure 4. Step 2: The LED and PCB expand and contract at different rates

If these solder joints are exposed to repeated stress, it will cause a minor crack to occur in the solder joint. Then when it is exposed to additional stress, if the crack turns into a complete fracture, it stops the flow of electrical current supplied to the LED, the LED will fail to illuminate (see Figure 5).

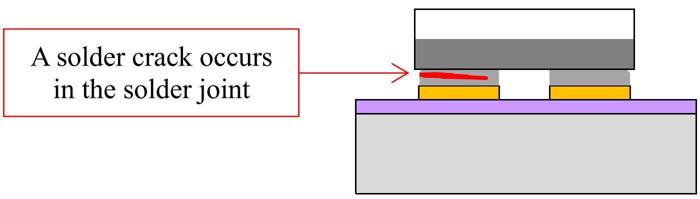


Figure 5. Step 3: Solder cracks occur

3.2 Effect of the difference in the CTE between the LED and the PCB

Solder cracks are more likely to occur when the difference in the CTE between the LED and the PCB is large. The CTE or coefficient of thermal expansion describes how the size of an object changes with an increase in temperature per degree of Celsius (i.e. /°C). Table 2 below shows the CTE of the ceramic substrate (i.e. Aluminum Nitride [AlN]) for the Nichia 170/131/121 Series and the CTEs of typical PCB materials[3].

Table 2. The CTE of the Nichia 170/131/121 Series LEDs
and the CTEs of typical PCB materials

Nichia 170/131/121 Series	
Material of the Ceramic Substrate	CTE (1/°C)
Aluminum Nitride (AlN)	approx. 5×10^{-6}

PCB	
Material	CTE (1/°C)
Ceramic	8×10^{-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}

For example, if the Nichia 170/131/121 Series LEDs are used with an aluminum-core PCB, the difference in the CTE between the LED and the PCB will be 16×10^{-6}/°C; if those LEDs are used with a copper-core PCB, the difference will be 12×10^{-6}/°C. This indicates that using a copper-core PCB is a better option than an aluminum-core PCB to reduce the possibility of solder cracks.

Note:
[3] The CTEs listed in the table are only the typical values of the materials.

4. Insulating Layer Comparison

A metal-core PCB has an insulating layer between the copper layer and the base metal (see Figure 6). This section shows thermal shock tests conducted on aluminum substrates with different insulation layers (i.e. low modulus elasticity vs. standard) to investigate the lighting failure rate for the NC5W121A (see Table 3). Nichia confirmed that the use of a substrate containing an insulation layer with a low elastic modulus is effective in reducing the rate of lighting failures (see Figure 7).

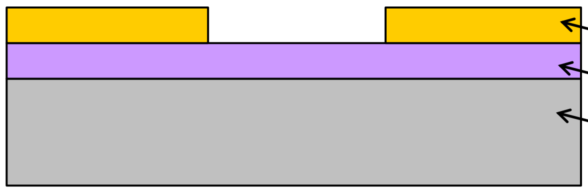
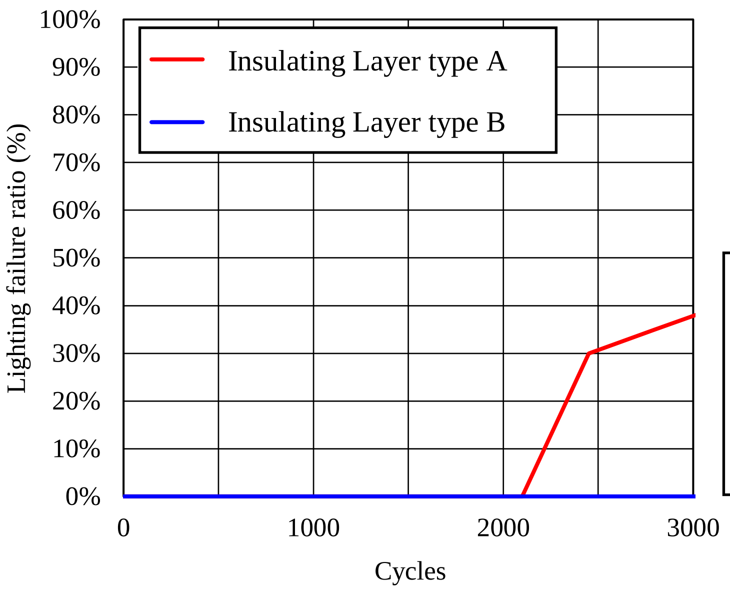


Figure 6. Structure of the metal-core test PCB

Table 3. Physical properties of the insulating layers

Property	Insulating Layer type	
	A (Normal)	B
Modulus of Elasticity (MPa)	22000	490
Thermal Expansion Coefficient (1/°C)	21×10^{-6}	121×10^{-6}



NC5W121A

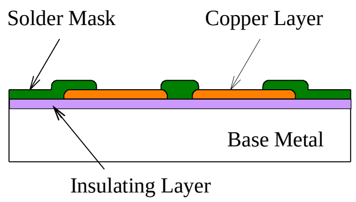
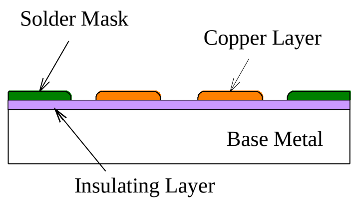
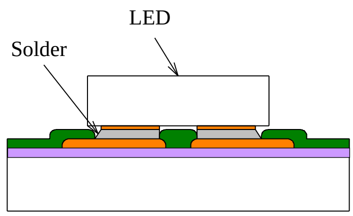
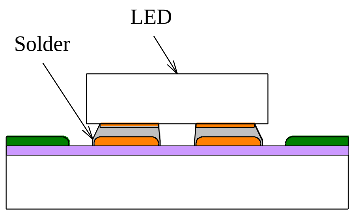
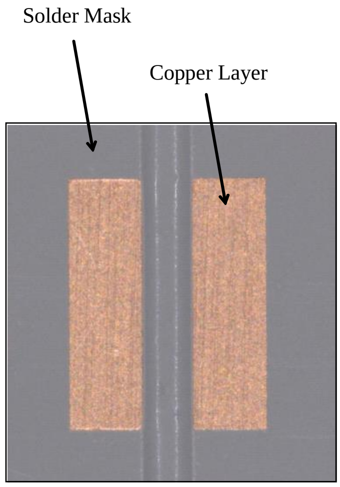
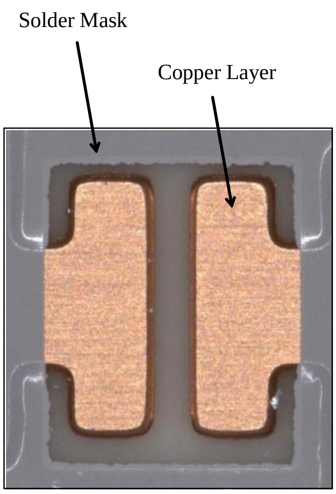
Data Details:
- LED: NC5W121A
- PCB Copper Layer: SMD (see Section 5)
- Solder Paste: SAC305 (Sn-3.0Ag-0.5Cu)
- Test Condition: -40°C to 150°C, 1min. dwell

Figure 7. Lighting failure comparison via thermal shock test

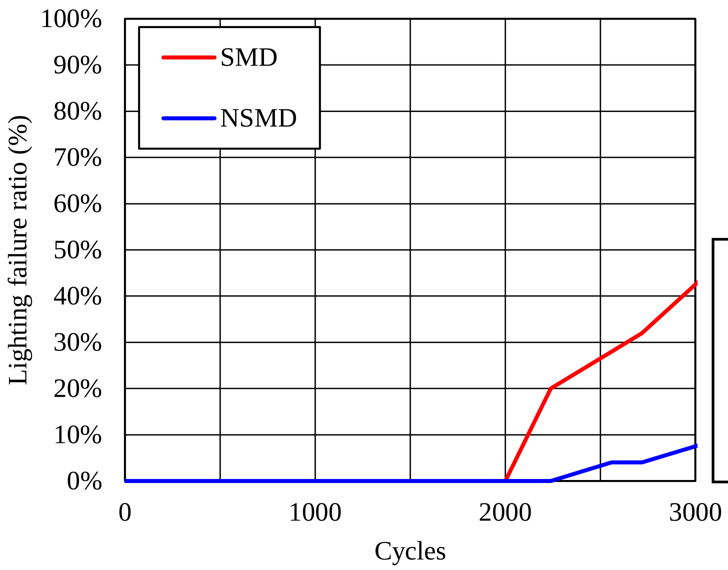
5. Copper Layer Design Comparison

There are two types of copper layer designs: Non-Solder Mask Defined (NSMD) and Solder Mask Defined (SMD). NSMD is when the solder mask does not cover the copper layer around the soldering pad (see Table 4). There are two types of copper layer designs: Non-Solder Mask Defined (NSMD) and Solder Mask Defined (SMD). The SMD type have soldering pads defined by the apertures of the solder resist, and the NSMD type have soldering pads defined by their shape, in other words the solder resist does not cover the copper layer around the soldering pad (see Table 4).

Table 4. Copper layer design comparison (NSMD vs. SMD)

	SMD	NSMD
Solder Resist Structure		
PCB Populated with an LED		
Appearance Overview of the Soldering Pad		

This section shows thermal shock tests conducted on aluminum substrates with those two different solder resist structures to investigate the lighting failure rate for the NC5W121A. Nichia confirmed that the Non-Solder Mask Defined (NSMD) structure is more effective in reducing the occurrence of lighting failures (see Figure 8).



NC5W121A

Data Details:
- LED: NC5W121A
- PCB Insulating Layer: B (see Table 3)
- Solder Paste: SAC305 (Sn-3.0Ag-0.5Cu)
- Test Condition: -40°C to 125°C, 15min. dwell

Figure 8. Lighting failure comparison via thermal shock test

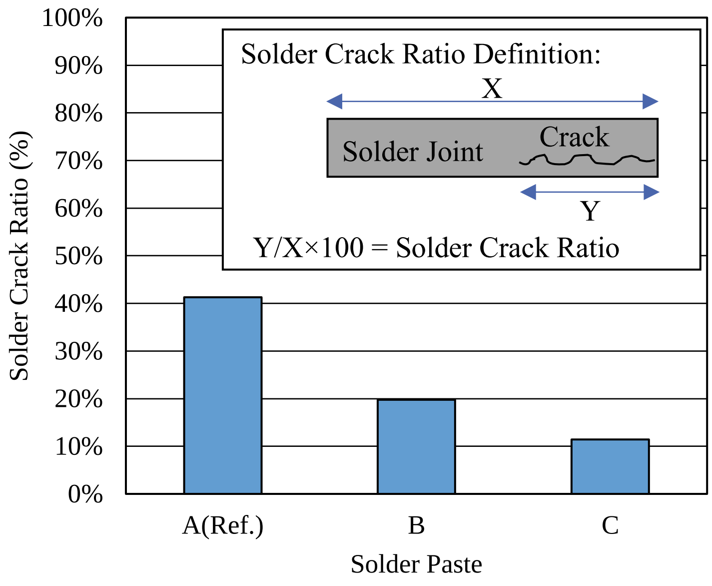
6. Solder Paste Comparison

This section shows thermal shock tests conducted with different types of solder paste to compare the crack resistance for the NC5W121A (see Table 5). The crack resistance was evaluated by the incidences of cracks from a cross-sectional observation of the soldered area (see Figure 9). Nichia confirmed that the type of solder paste that is used can potentially be a solution for reducing the occurrence of solder cracks.

Table 5. Solder paste overview

Solder Paste	Composition
A (Standard/Ref.)	Sn-3.0Ag-0.5Cu
B	Sn-3.9Ag-0.6Cu
C	Sn-3.4Ag-0.7Cu-3.2Bi-3.0Sb-Ni-X

The evaluation results show that compared to solder paste A (Standard/Ref.), B and C have better crack resistance (see Figure 9). It is possible to improve the crack resistance by changing the type of solder paste.



NC5W121A

Data Details:
- LED: NC5W121A
- PCB Insulating Layer: B (see Table 3)
- PCB Copper Layer: SMD (see Section 5)
- Test Condition: -40°C to 125°C, 15min. dwell

Figure 9. Solder crack resistance via thermal shock test

7. Summary

As a result of the evaluation, Nichia makes the following summary/recommendations:

- PCBs with low modulus elasticity insulating layers are effective to prevent solder cracks.
- The Non-Solder Mask Defined (NSMD) type is also an effective option for solder crack resistance.
- The solder crack resistance does vary depending on the type of solder paste that is used; solder paste “C” was the most effective as shown in the evaluation results.

Although Nichia provides the results and recommendations from the evaluation above, those may vary depending on the manufacture of the chosen component (i.e. PCB, solder paste), customers are advised to perform sufficient verification within the chosen application before selecting components for production use.

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