Light Emitting Diode

Assembly and Handling Precautions for the Nichia 321 Series LEDs

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NC2W321x, NC3W321x, NC4W321x, and NC5W321x refer to Nichia 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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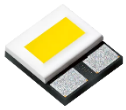
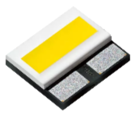
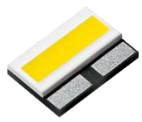
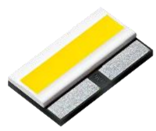
1. Overview

When handling LEDs, care should be taken to ensure that they are handled in a proper manner; if LEDs are improperly handled, it may cause damage to the LEDs and/or an adverse effect on their performance.
The Nichia 321 series LEDs use submounts and are specially designed to be mounted without soldering. The structure of this LED allows it to be directly attached to a heatsink/housing to achieve efficient thermal dissipation. These LEDs need to be handled and assembled in a proper manner to obtain excellent heat dissipation.
This application note provides the assembly and handling recommendations/precautions for the Nichia 321 series LEDs.

2. Applicable Part Numbers

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

Table 1. Applicable LED Part/Series Numbers

Category	Nichia 321 Series			
Part Number	NC2W321x	NC3W321x	NC4W321x	NC5W321x
Appearance				
Package Size (mm)	3.5×3.2×0.75	3.5×4.0×0.75	3.5×5.1×0.75	3.5×6.1×0.75

The x represents a letter that follows the alphanumeric code of the same LED type (e.g.: NC2W321x → NC2W321F, NC2W321G, etc. NCxW321G → NC2W321G, NC3W321G, NC4W321G etc.).

3. Storage

3.1 Storage Conditions

If the LEDs absorb moisture and are exposed to heat during the LED mounting process, it may cause the moisture to vaporize and the package to expand and the resulting pressure may cause internal delamination. To minimize moisture absorption in storage/transit, moisture-proof aluminum bags are used for the LEDs with a silica gel packet to absorb any air moisture in the bag.
Table 2 provides the required storage conditions before and after opening the moisture-proof aluminum bag.

Table 2. Storage Conditions

Conditions		Temperature	Humidity	Time	
Storage	Before Opening the Moisture-proof Aluminum Bag	≤30°C	≤90%RH	Within 1 Year from Delivery Date	
	After Opening the Moisture-proof Aluminum Bag	≤30°C	≤70%RH	NCxW321G	≤1 year
				NCxW321B NCxW321F	≤168 hours

The storage time after opening the moisture-proof aluminum bag may be different depending on the part number. Ensure that the LED mounting process is completed within the applicable storage time provided in Table 2. To store any remaining unused LEDs, use a hermetically-sealed container with silica gel desiccants. Nichia recommends placing them back to the original moisture-proof bag used for shipment and reseal it.

For the part numbers whose "After Opening" storage time is ≤168 hours, if the "After Opening" storage time has been exceeded, or any pink silica gel beads are found, ensure that the LEDs are baked before use at 65±5°C for ≤24 hours. Baking should only be done once.

These LEDs have aluminum-plated electrodes. If the LEDs are exposed to a corrosive environment, it may cause the plated surface to tarnish causing issues (i.e. electric connection failures).

3.2 Deformation of the Embossed Carrier Tape

Do not store the LEDs in a manner where excessive external force may be applied to the reel (e.g. the reel is stored using a vacuum seal in a manner where there is too little air left in the storage bag, heavy objects are stacked onto the reel, etc.) since it may cause the embossed carrier tape to deform; see Figure 1. If the embossed carrier tape deforms, the LEDs inside the pockets of the embossed carrier tape may tilt, causing damage to the LEDs and/or pick-up errors.

Before Opening the Bag with a Reel in it

Squashed Reel as a Result of Excessive Vacuum Sealing

Tilted LED in Pocket

Figure 1. Vacuum Storage and Deformation of the Embossed Carrier Tape due to Excessive Vacuum Sealing

3.3 Storage Environment

To avoid condensation, the LEDs must not be stored in areas where temperature and humidity fluctuate greatly. Also, ensure that the LEDs are not exposed to direct sunlight and/or an environment over a long period of time where the temperature is higher than normal room temperature, and are not stored in a dusty environment.

4. Design Consideration

4.1 Absolute Maximum Ratings

Absolute maximum ratings of the LEDs are the maximum values that must not be exceeded even for a short period of time. It must be ensured that the absolute maximum ratings are taken into consideration when designing a system/application using the LEDs and will not be exceeded in the conditions/environments in which the LEDs will actually be used even for a short period of time.
For the absolute maximum rating values for the LEDs, refer to the applicable specification.

4.2 Circuit Design Considerations

The circuit must be designed to ensure that the absolute maximum ratings are not exceeded for each LED. The LEDs should be operated at a constant current per LED. In the case of operating at a constant voltage, Circuit B is recommended. If Circuit A is used, it may cause the currents flowing through the LEDs to vary due to the variation in the forward voltage characteristics of the LEDs on the circuit.

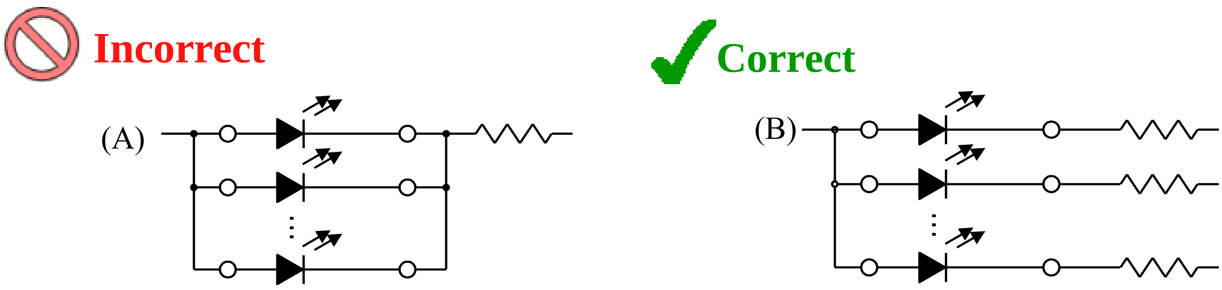


Figure 2. Examples of a Parallel Circuit

4.3 Operating Current

These LEDs are designed to be operated at a forward current. To stabilize the LED characteristics while in use, Nichia recommends that the LEDs are operated at currents ≥10% of the sorting current.
For the sorting current for the LED, refer to the applicable specification.

4.4 Precautions for When the LEDs are Off

Ensure that no voltage is applied to the LEDs in the forward/reverse direction while the LEDs are off. If the LEDs are used in an environment where reverse voltages are applied to the LEDs continuously, it may cause electrochemical migration to occur causing the LEDs to be damaged.

4.5 Volatile Organic Compounds (VOCs)

Materials present around the LEDs (e.g. housing, gasket/seal, adhesive, secondary lens, lens cover, grease, etc.) may contain volatile organic compounds (VOCs) . If VOCs that have been released from those materials penetrate into the LEDs and remain inside the LEDs, the VOCs can discolor after being exposed to heat and/or photon energy. This may cause the optical characteristics to be adversely affected (i.e. significant reduction in the brightness, significant color shift, etc.). When selecting parts/materials that will be used with the LEDs in the finished product, it must be ensured prior to use that there are no issues with the substances found in those parts/materials and/or that the expected performance for the finished product is maintained by performing a light-up test, sufficient verifications etc. taking into consideration the conditions/environments in which the chosen application will actually be used. Perform a light-up test, sufficient verifications etc. of the chosen application prior to use to ensure that the expected performance is maintained.
The adverse effect mentioned above may be improved by ventilating the environment (i.e. the LEDs are not used in a hermetically sealed environment) to prevent the VOCs from remaining inside the LEDs.

4.6 Corrosive Gases

To prevent substances/gases from affecting the plated surfaces of the LEDs, ensure that the parts/materials used around the LEDs (e.g. gasket/seal, adhesive, etc.) in the same assembly/system do not release corrosive gases (i.e. the parts/materials do not contain sulfur, halogens, etc.). If the plating becomes contaminated, it may cause issues (e.g. electrical connection failures). In addition, it has been confirmed that if a silicone resin is used in the LEDs the gases may accelerate degradation of the silicone resin. If a gasket/seal is used, silicone rubber gaskets/seals are recommended; ensure that this use of silicone does not result in issues (e.g. electrical connection failures) caused by low molecular weight volatile siloxane.
Perform a light-up test, sufficient verifications etc. of the chosen application prior to use to ensure that the expected performance is maintained.

4.7 Precautions for Environmental Conditions

Ensure that transient excessive voltages (e.g. lightning surge) are not applied to the LEDs. If the LEDs are used for outdoor applications, ensure that necessary measures are taken (e.g. protecting the LEDs from water/salt damage and high humidity).

5. Handling Precautions

5.1 Areas Where Contamination Must be Avoided

Avoid contamination of the LEDs, especially the surfaces of the electrodes and the light emitting areas (see Figure 3) and keep them clean. If the LED surfaces are contaminated, the optical characteristics and/or reliability may be affected.

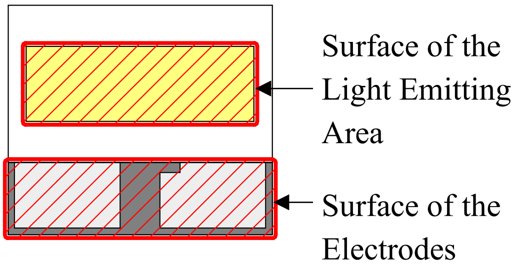


Figure 3. Areas where Contamination Must be Avoided

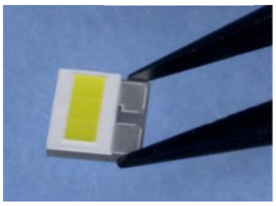
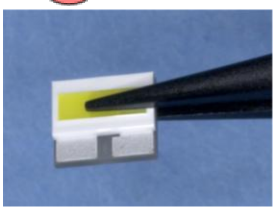
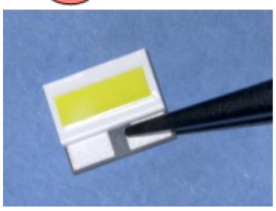
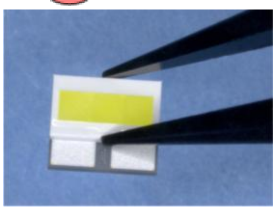
5.2 Handling with Bare Hands

Do not handle the LEDs with bare hands. This may contaminate the LED surface and have an effect on the optical characteristics and/or reliability.

5.3 Handling with Tweezers

Ensure that when handling the LEDs with tweezers, excessive force is not applied to the LEDs. Otherwise, it may cause damage to the light emitting area, the electrodes and/or the silicone resin (e.g. cut, scratch, chip, crack, etc.) and have an effect on the optical characteristics and/or the reliability.

Table 3. Correct/Incorrect Examples of Handling the LEDs

Correct Examples	Incorrect Examples		
(A) Correct 	(B) Incorrect 	(C) Incorrect 	(D) Incorrect 

For the LEDs with ceramic substrates, grab/hold the LEDs by the sides of the substrate. See the Correct Examples in Table 3. Do not apply excessive force to the emitting area, the electrodes, and/or the silicone resin as shown by the Incorrect Examples in Table 3.

5.4 Other Precautions

Do not drop the LEDs; this may cause issues (e.g. crack, chip, and/or deformation of the LEDs, and/or cut, scratch, etc. on the emitting area) causing the optical characteristics and/or the reliability to be adversely affected.

6. Precautions for Mounting the LEDs

6.1 LED Mounting

The LEDs are designed to be directly attached to a heatsink/housing with an adhesive; no soldering is required.

Nichia recommends using an adhesive with a high thermal conductivity when mounting the LEDs. If an adhesive with a poor thermal conductivity is used, the optical characteristics and/or reliability of the LED may decrease due to insufficient heat dissipation while the LEDs are operated. The recommended thermal conductivity of an adhesive used with the LEDs is 3W/m·K or higher. As stated in Sections 4.5 and 4.6, ensure that the adhesives used with the LEDs do not contain substances that have adverse effects on the LEDs.
When selecting an adhesive, perform a light-up test, sufficient verifications etc. of the chosen application prior to use to ensure that the expected performance is maintained. Nichia performed evaluations on how adhesive affects the heat dissipation performance of the LED modules. The evaluation results are provided in sections 7.4-7.9 for reference purposes.

6.2 Pick-and-Place Nozzle

When using a pick-and-place machine, select a pick-and-place nozzle that is appropriate for the 321 series LEDs. The nozzle is placed onto the emitting surface[1] and it suctions the surface to pick up the LEDs. If the size, shape, or material of the nozzle tip is not appropriate for the LEDs, this may damage the LEDs (i.e. scratch, chip, crack, etc.), affecting the optical characteristics and/or the reliability.

When setting the LED pick-up position, ensure that the center of the nozzle and the center of the emitting area of the LEDs are aligned. Do not apply excessive force to the emitting area when picking up the LEDs. If the nozzle does not pick up the LEDs at the center of the emitting area, and/or if excessive force is applied to the LEDs, this may damage the LEDs (i.e. scratch, chip, crack, etc.), affecting the optical characteristics and/or the reliability.

Table 4 shows examples of the pick-and-place nozzles that are appropriate for the 321 series LEDs.

[1] The material of the emitting area: Ceramics for the NCxW321G/NCxW321F LEDs and hard glass for the NCxW321B LEDs.

Table 4. Examples of the Pick-and-Place Nozzles that are Appropriate for the 321 Series LEDs

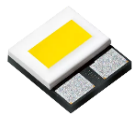
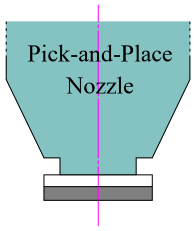
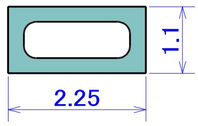
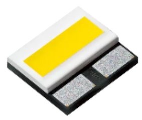
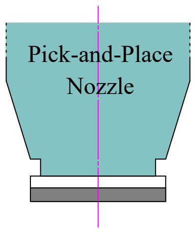
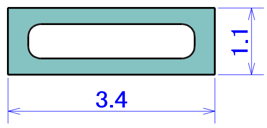
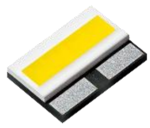
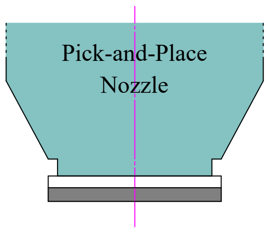
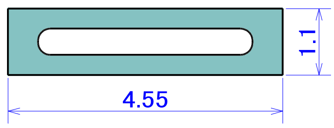
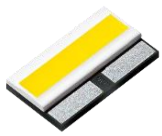
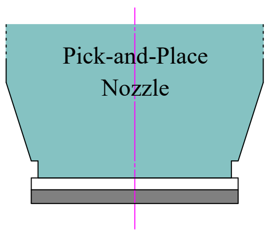
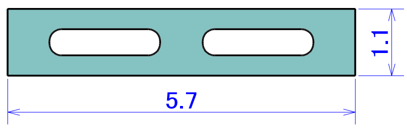
Part Number	Appearance (Dimensions of the Emitting Area: mm)	Cross-sectional view of the Nozzle when the LED is picked up	Example of the Shape of the Nozzle Tip (mm)
NC2W321x	 (1.15×2.3)		
NC3W321x	 (1.15×3.45)		
NC4W321x	 (1.15×4.6)		
NC5W321x	 (1.15×5.75)		

Figure 4 shows examples of LED pick-up positions for the NC3W321 series LEDs.

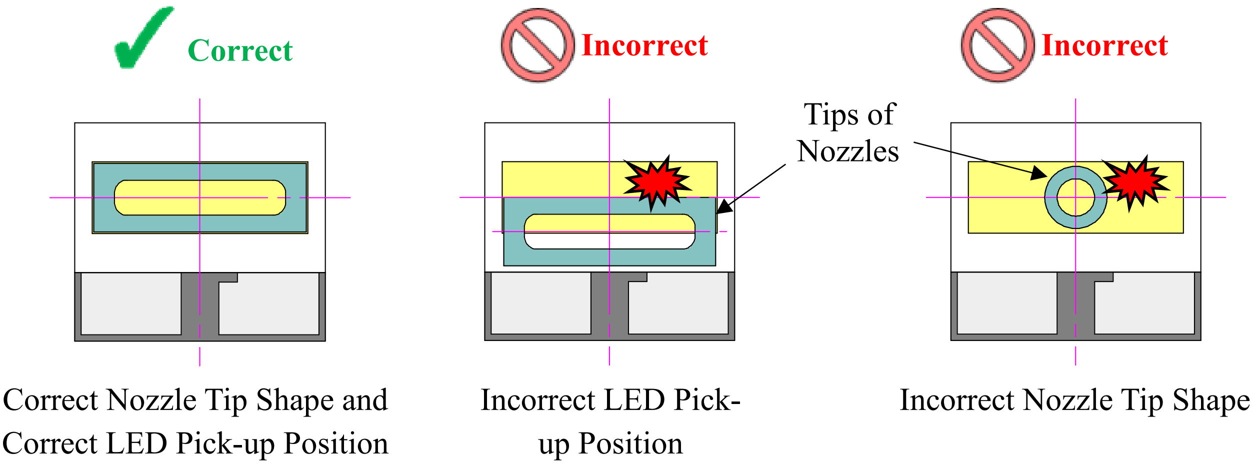


Figure 4. Examples of LED Pick-up Positions for the NC3W321 Series LEDs

6.3 Electrical Connection

The Nichia 321 series LEDs have aluminum-plated electrodes and are designed to have an electrical connection by bonding aluminum ribbons including aluminum wires. Materials other than aluminum such as gold wires are not suitable for these LEDs. To ensure an effective electrical connection, the surfaces of the electrodes should be free from contamination. Nichia recommends that plasma cleaning is done for the surfaces of the electrodes before bonding aluminum ribbons onto them.

Figure 5 shows the illumination area of the LEDs when the LEDs are lit. When an aluminum ribbon is bonded to the LEDs, consider the illumination area to ensure the loop shape/shadow of the aluminum ribbon or light reflected from the ribbon does not affect the LED optical design.

An electrical connection created by clamping the LED electrodes with a contact terminal such as a spring plate is not recommended because the input voltage may become unstable.

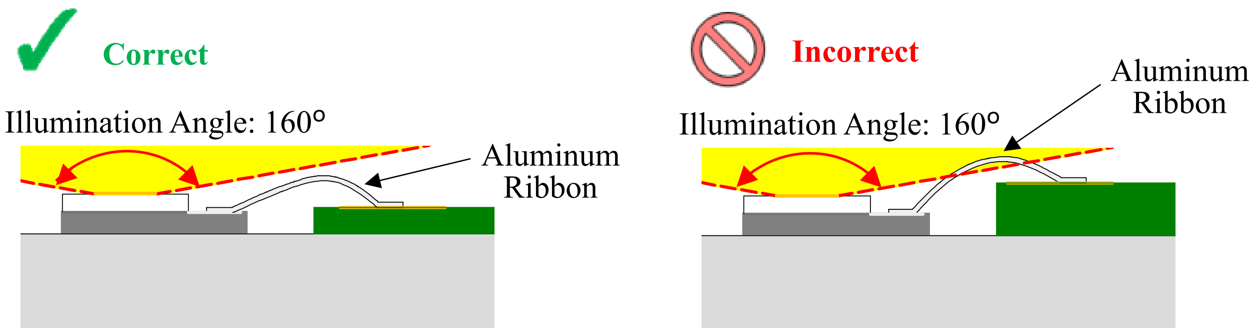


Figure 5. Illumination Area of the LEDs and a Correct/Incorrect Loop Shape of the Aluminum Ribbon

6.4 Bonding Conditions

A wedge bonding machine is used to bond an aluminum ribbon onto the surface of the LED electrode. In this bonding method, ultrasonic waves and loads are applied to the aluminum ribbon by using the wedge bonding tool. The ultrasonic output power, the load applied, and the duration will affect the bonding strength.

A suitable wedge bonding tool and appropriate bonding conditions are determined based on the specifications of the chosen aluminum ribbon (e.g. width, thickness, and wire diameter if an aluminum wire is used), the intended bonding area, etc. Since appropriate bonding conditions also depend on the material, roughness, etc. of the surface to which an aluminum ribbon is bonded, bonding conditions must be determined individually for the bonding surface of the LEDs and for that of the chosen heatsink/housing.

The shear test and pull test shown in Figure 6 are used to evaluate the bonding strength. Based on the resulting strength value and failure mode etc., select the setting conditions that are suitable for the ribbon bonding.

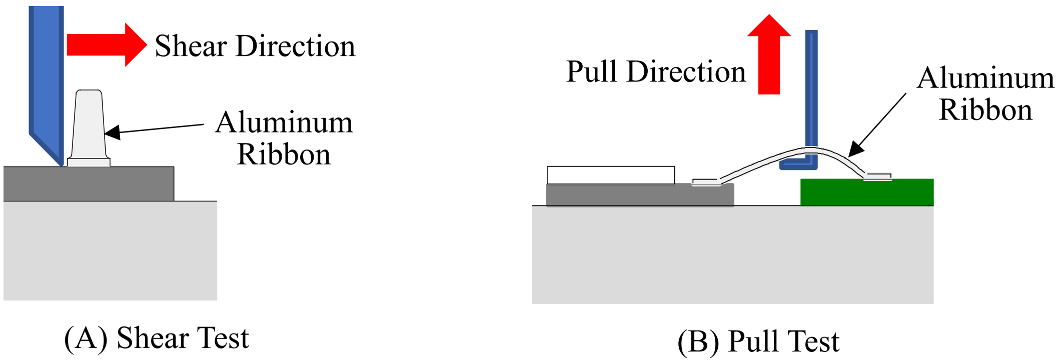


Figure 6. Evaluation Methods for the Ribbon Bonding Strength

Note that there is the mutual dependence between the ultrasonic output and load, and the combination of these setting values has a significant effect on the bonding strength. Figure 7 shows how the shear strength varies depending on the ultrasonic output and load.

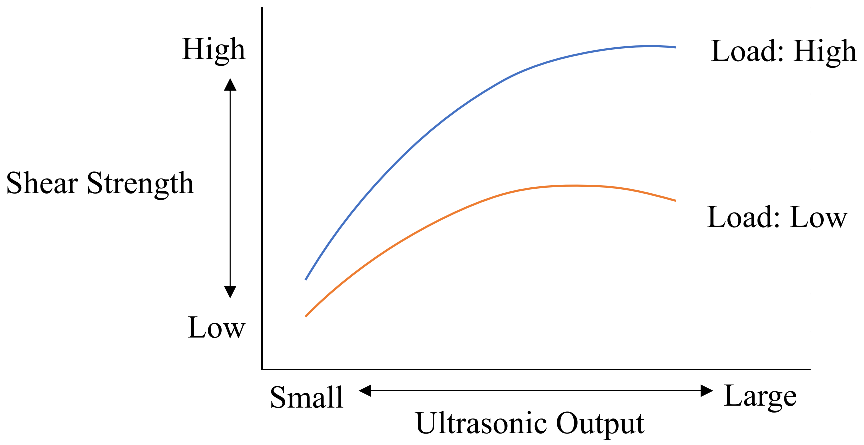


Figure 7. An Example of the Mutual Dependence Between the Ultrasonic Output and Load

6.5 Durability and Reliability of Aluminum Ribbons/Wires

In general, a larger cross-sectional area of a material results in a higher breaking load (i.e. able to withstand a greater load). The cross-sectional area also influences the fatigue of a material. Since stress is defined as load divided by cross-sectional area, the larger the cross-sectional area is, the smaller the stress experienced will be and the service life of a material is likely to be longer.
For an aluminum ribbon/wire, its cross-sectional shape also affects its strength. An aluminum ribbon has a thin, flat cross-sectional shape, making it stronger in the width direction and weaker in the thickness direction. For an aluminum wire, there is no difference in strength depending on the bending/twisting direction since it has a round cross-sectional shape. When bent/twisted in certain directions, an aluminum ribbon may be weaker than an aluminum wire of the same cross-sectional area.
If the LEDs that have an aluminum ribbon/wire attached to them are operated in environments with large temperature fluctuations, stress may be applied to the aluminum ribbon/wire due to the difference in the coefficient of thermal expansion between the LED package and the material onto which the LED is mounted (e.g. heatsink, housing, etc.). If large stress is applied over a long period of time, cracks may occur in the aluminum ribbon/wire causing the electrical connection to fail. In addition, stress caused by bending and/or twisting tends to concentrate on the bonding area; a high-quality bond must be created. Perform sufficient verifications using the final product under thermal conditions that reflect the chosen operating conditions and expected temperature fluctuations to ensure that there are no reliability issues prior to use.

6.6 Precautions After LED Mounting

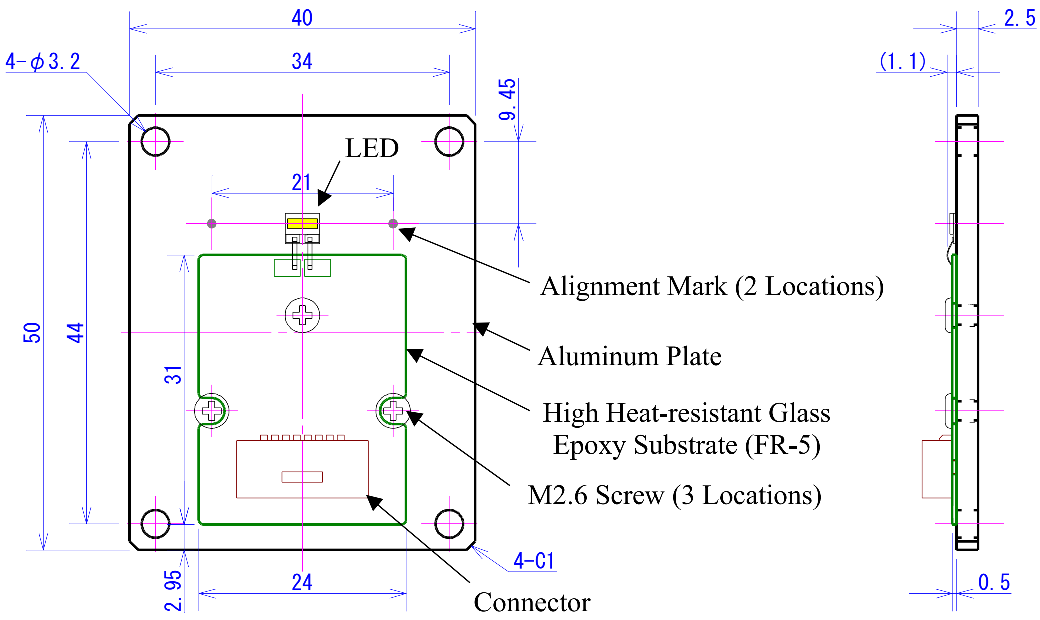
Do not stack assembled components together. Otherwise, it may cause damage to the emitting area, the resins, and/or the aluminum ribbons (e.g. scratch, chip, crack, deformation, cut, etc.) and have an effect on the optical characteristics and/or the reliability.

7. Examples of Modules Assembled with the Nichia 321 Series LEDs

Nichia prepared the module shown below and performed various evaluations to measure the characteristics at the module level.

7.1 Structure/Dimensions of the Module Used for the Evaluations

Figure 8 shows the structure/dimensions of the module used for the evaluations of the Nichia 321 series LEDs. In this module, a high heat-resistant glass epoxy substrate (FR-5: 31mm [L] × 24mm [W] × 0.5mm [H]) is fixed on an aluminum plate (50mm [L] × 40mm [W] × 2.5mm [H]) at three locations with M2.6 screws and the LEDs are mounted on the aluminum plate by using a high thermal conductivity adhesive (See Figure 9). An aluminum ribbon (0.5mm [W] × 0.1mm [H]) is used to create an electrical connection between the LEDs and the glass epoxy substrate.

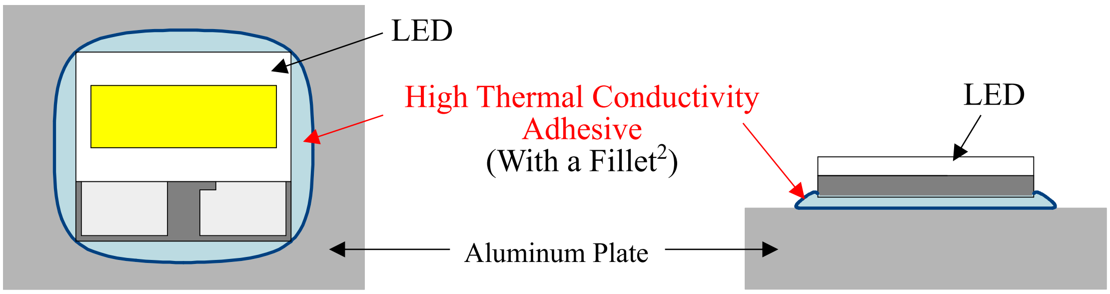


Aluminum Plate:

Surface Finishing: Anodic oxide coating (Black)

Surface Roughness: Ra=0.3μm

Figure 8. Structure/Dimensions of the Module Used for the Evaluations



Adhesive with High Thermal Conductivity:

Thermal Conductivity: 7W/m·K, Filler: Silver, Binder: Silicone Resin,

Applied Area: Approx. 130% Relative to the Area of the Bottom Surface of the LED,

Thickness: 10-15μm

Figure 9. Example of an Evaluation LED Bonded to the Aluminum Plate

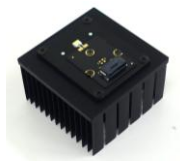
[2] Adhesive protruding beyond the LED

7.2 Characteristics of the Nichia 321 Series LEDs at the Module Level

Nichia evaluated the optical and thermal characteristics of the LEDs at the module level with heatsinks. The module is fixed to the heatsink at four locations with M3 screws, not with a heat-dissipating material such as thermal grease.

Table 5 shows the evaluation results at T_J=25°C when the LEDs were operated at 1000mA (sorting current) in pulse mode.

Table 5. Characteristics of the Nichia 321 Series LEDs at the Module Level with Different Heatsinks

LED Part Number	NC2W321F	NC3W321F	NC4W321F	NC5W321F
Color Rank	sw57	sw57	sw57	sw57
Appearance of the Module				
Heatsink[3]	Heatsink A	Heatsink A	Heatsink B	Heatsink B
Operating Current (mA)	1000 (Sorting Current)	1000 (Sorting Current)	1000 (Sorting Current)	1000 (Sorting Current)
T_J (°C)	25	25	25	25
Voltage[4] (V)	6.4	9.6	12.8	16.1
Input Power[4] (W)	6.4	9.6	12.8	16.1
Luminous Flux[4,5] (lm)	(812)	(1232)	(1587)	(2033)

3 Refer to Table 6 for the details of the heatsinks used.
4 The values are the averages of the measured values of three LEDs.
5 The values in parentheses are for reference purposes.

Table 6. Heatsinks Used for the Evaluations

<table>
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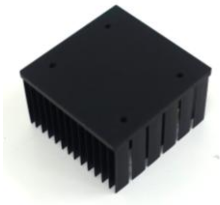
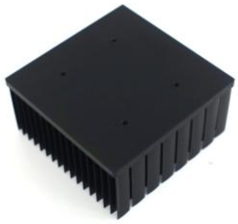
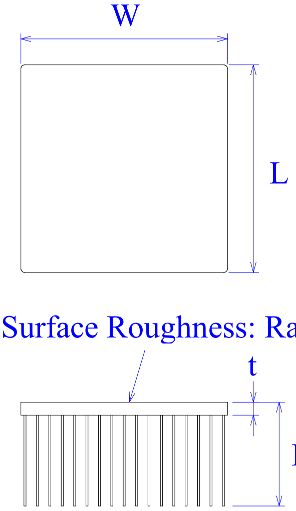
<tr><td colspan="2">Appearance</td><td></td><td></td><td rowspan="7">
</td></tr>
<tr><td rowspan="2">Size
(mm)</td><td>W×L×H</td><td>60×60×35</td><td>80×80×40</td></tr>
<tr><td>t</td><td>4</td><td>5</td></tr>
<tr><td>Surface Roughness
(μm)</td><td>Ra</td><td>1.6</td><td>1.6</td></tr>
<tr><td colspan="2">Thermal Resistance[6]
(°C/W)</td><td>(3.7)</td><td>(2.2)</td></tr>
<tr><td colspan="2">Material</td><td>Aluminum</td><td>Aluminum</td></tr>
<tr><td colspan="2">Surface Finishing</td><td>Anodic Oxide Coating
(Black)</td><td>Anodic Oxide Coating
(Black)</td></tr>
</table>

Figure 10 shows the junction temperatures (T_J) of the Nichia 321 series LEDs at the module level at different operating currents (I_F). The junction temperature (T_J) was measured when the saturation temperature at the junction was reached under the ambient temperature (T_A) of 50°C (the values are the averages of the measured values of three LED module). This measurement was performed with the emitting surface of the LEDs upward.

[6] The values in parentheses are for reference purposes.

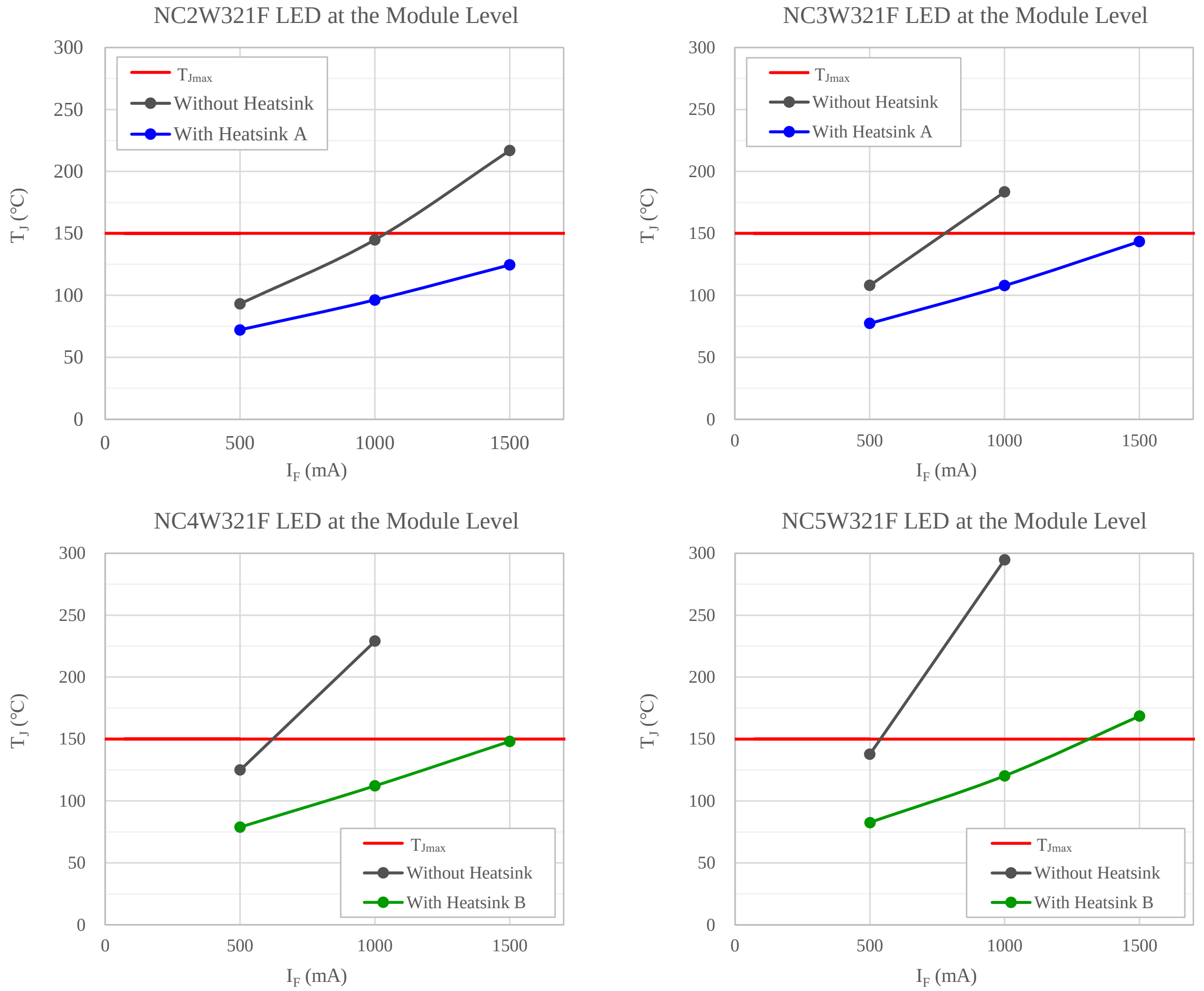


Figure 10. Relationship between the Operating Current and the Junction Temperature (T_A=50°C)

The chosen application must be designed to ensure that the maximum junction temperature (T_{Jmax}) of 150°C is not exceeded.

The T_J estimation of the LEDs at the module level can be calculated by using the temperature of the LED (T_{MP}) at the measurement point Nichia specifies, the thermal resistance ($R_{\theta JMP}$) from the LED chip to the T_{MP} measurement point, and the input power (W).

For the details of the T_J calculation, refer to the application notes “How to Calculate the Junction Temperature for the Nichia 321 Series LEDs” and “Thermal Resistance Values of the Nichia 321 Series LEDs”.

7.3 Placement Accuracy of the Nichia 321 Series LEDs

When designing the chosen application, the accuracy of the distance between the reference point (the optical component position) and the center of the LED emitting surface is important; however, the required accuracy varies depending on the application. For reference when designing the chosen application, Nichia evaluated the placement accuracy of the mounted LEDs based on the alignment marks on the evaluation module.

Figure 11 shows the evaluation of the LED placement accuracy. In the evaluations, one hundred NC3W321F LEDs were used and the target LED placement position was defined as the midpoint of the line connecting the two alignment marks on the aluminum plate. After a high thermal conductivity adhesive (i.e. the adhesive used for the evaluations detailed in Section 7.1) was applied to the aluminum plate, the pick-and-place machine placed the LEDs where the center of the emitting surface is aligned with the target LED placement position.
After the LED placement was completed, Nichia evaluated the placement accuracy (the amount of the deviation between the center of the LED emitting surface and the target LED placement position in the x and y directions is described as Δx and Δy, respectively). Nichia also evaluated the placement accuracy in the angular direction (the amount of the deviation between the center line of the emitting surface in the x direction and the line connecting the 2 alignment marks is described as $\Delta\theta$).

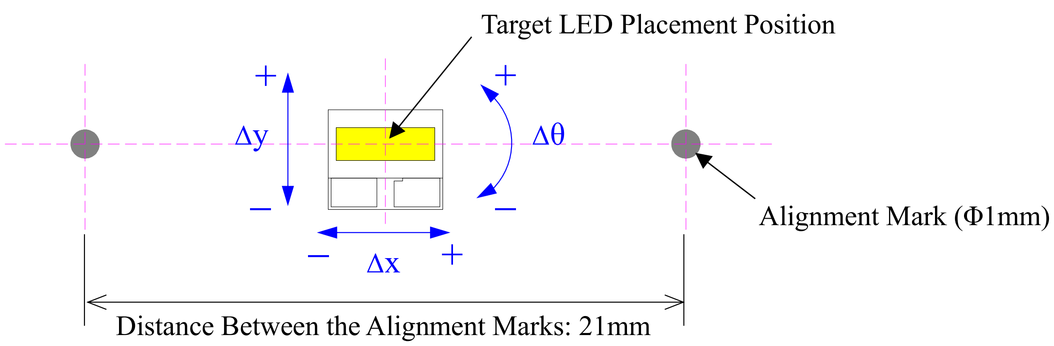


Figure 11. LED Placement Accuracy Evaluation

The evaluation results are shown in Table 7 and Figure 12. At an average value of $\pm 3\sigma$, the deviations from the target LED placement position in the x and y directions are both within ±15µm and the deviation in the angular direction is within ±0.1°.

Table 7. Evaluation Results of the LED Placement Accuracy (For Reference)

	LED Placement Accuracy		
	Deviations in x and y Directions (μm)		Deviation in the Angular Direction (°)
	Δx	Δy	Δθ
Average	-0.9	3.5	0.03
σ	3.6	3.9	0.02
Average -3σ	-12	-8	-0.03
Average +3σ	10	15	0.09
Min.	-12	-4	-0.02
Max.	6	15	0.08

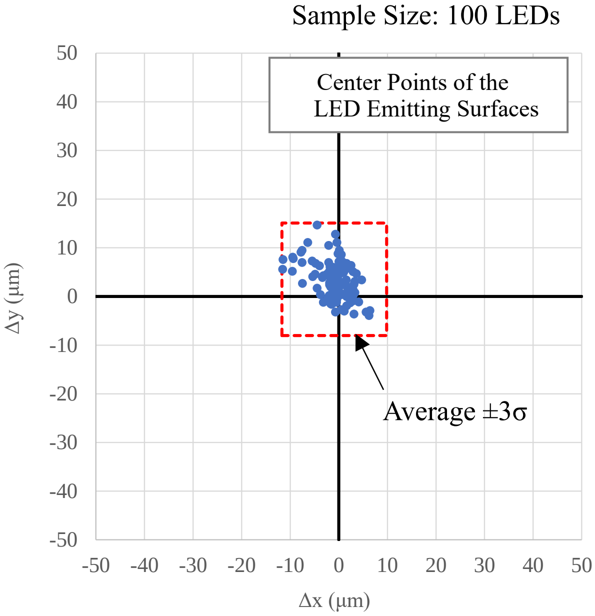


Figure 12. Distribution of the Center Points of the LED Emitting Surfaces (For Reference)

7.4 Relationship Between Adhesive Thermal Conductivity and LED Module Heat Dissipation

In general, the higher the thermal conductivity is for the adhesive used for LED mounting, the better the heat dissipation of the LED modules will be. Nichia performed evaluations as detailed below. LED modules were prepared using the NC3W321F LEDs. The specifications of the LED modules and the LED mounting conditions were the same as described in section 7.1; different evaluation adhesives were used to mount the LEDs onto the aluminum plate (see Table 8). Table 9 shows examples of the appearance of the LEDs mounted on the aluminum plate before aluminum ribbons were attached. Heatsink A was attached to the LED modules. The measurement was performed with the emitting surface of the LEDs facing upward.

Table 8. Adhesives Used for the Evaluations

Adhesive	Thermal Conductivity (W/m·K)	Thermal Conductive Filler	Binder Resin
A	7	Silver	Silicone
B	3	Aluminum Oxide	Silicone
C	1	Silver	Epoxy

Adhesive A is the adhesive that was used for the evaluations described in sections 7.1-7.3.

Table 9. Examples of the Appearance of the Mounted LEDs
Before Aluminum Ribbons were Bonded

Adhesive	A	B	C
Appearance			

Figure 13 shows the thermal resistance from junction to ambient ($R_{\theta JA}$) and the junction temperature (T_J) of the LED modules at T_A=50ºC, measured when the saturation temperature at the junction was reached (the values are the averages of the measured values of three LED modules). The evaluation results confirm that the higher the thermal conductivity is for the adhesive, the lower the $R_{\theta JA}$ and the T_J will be, indicating a better heat dissipation performance.

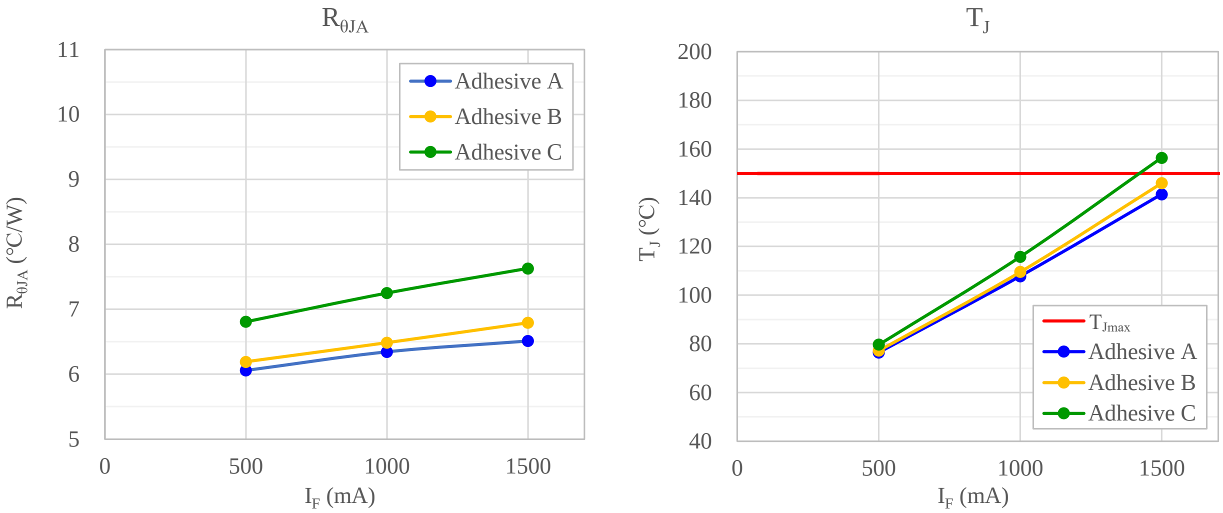


Figure 13. Thermal Resistance and Junction Temperature of the LED Modules
for Adhesives with Different Thermal Conductivities

7.5 Relationship Between Adhesive Application Area and LED Module Heat Dissipation

In general, the smaller the application area is for the adhesive, the lower the heat dissipation performance of the LED modules will be. Nichia performed evaluations as detailed below.
LED modules were prepared using the NC3W321F LEDs. The specifications of the LED modules and the LED mounting conditions were the same as described in section 7.4; different application areas of Adhesives A, B, and C were used to evaluate the heat dissipation performance of the LED modules (see Table 10). The evaluation results obtained for these adhesives exhibited similar trends; Nichia provides the results for Adhesive A as a representative example of the other adhesives, as shown below.

Table 10. Adhesive Application Areas Evaluated

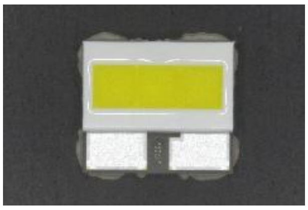
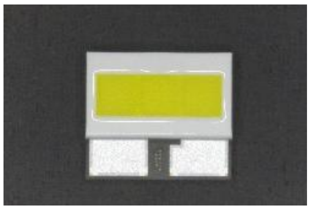
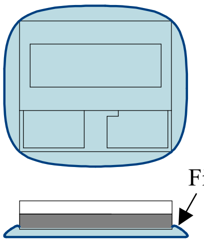
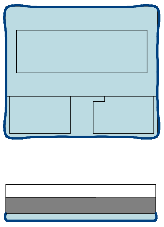
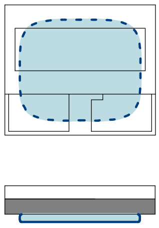
Application Area[7]	130%	100%	60%
Appearance (Before Aluminum Ribbons are Bonded)			
Reference Image			

Figure 14 shows the $R_{\theta JA}$ and the T_J of the LED modules at T_A=50°C, measured when the saturation temperature at the junction was reached (the values are the averages of the measured values of three LED modules). The evaluation results confirm that the smaller the application area is for the adhesive, the higher the $R_{\theta JA}$ and the T_J of the LED modules will be, indicating a poorer heat dissipation performance. The fillet also slightly contributes to improving the heat dissipation performance. In addition, Nichia has confirmed that a fillet improves the joint strength.

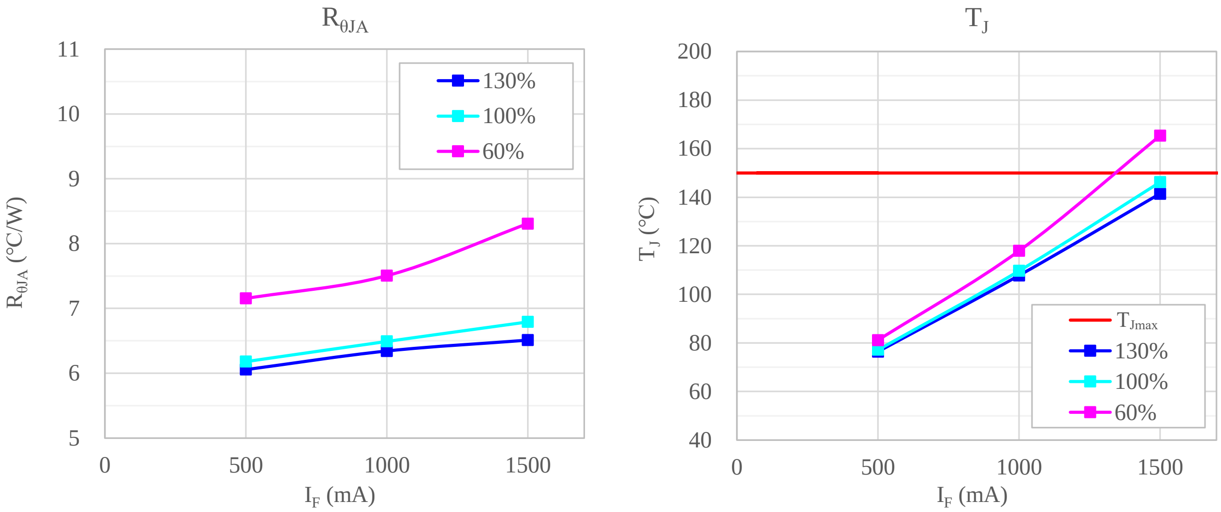


Figure 14. Thermal Resistance and Junction Temperature of the LED Modules for Different Adhesive Application Areas

7 The application area is the approximate adhesive application area expressed as a percentage of the bottom surface area of the LEDs, which is defined as 100%.

7.6 Relationship Between Adhesive Thickness and LED Modules Heat Dissipation

In general, when mounting the LEDs, the larger the thickness is for the adhesive used, the lower the heat dissipation performance of the LED modules will be. Nichia performed evaluations as detailed below.

LED modules were prepared using the NC3W321F LEDs. The specifications of the LED modules and the LED mounting conditions were the same as described in section 7.4; Adhesives A, B, and C were applied in different thicknesses to evaluate the heat dissipation performance of the LED modules. Only the evaluation results for Adhesive C exhibited significant differences among the thickness conditions; Nichia provides the results for Adhesive C only, as shown below.

Figure 15 shows the $R_{\theta JA}$ and the T_J of the LED modules at T_A=50ºC, measured when the saturation temperature at the junction was reached (the values are the averages of the measured values of three LED modules). The evaluation results confirm that the thicker the applied adhesive is, the higher the $R_{\theta JA}$ and the T_J will be, indicating a poorer heat dissipation performance.

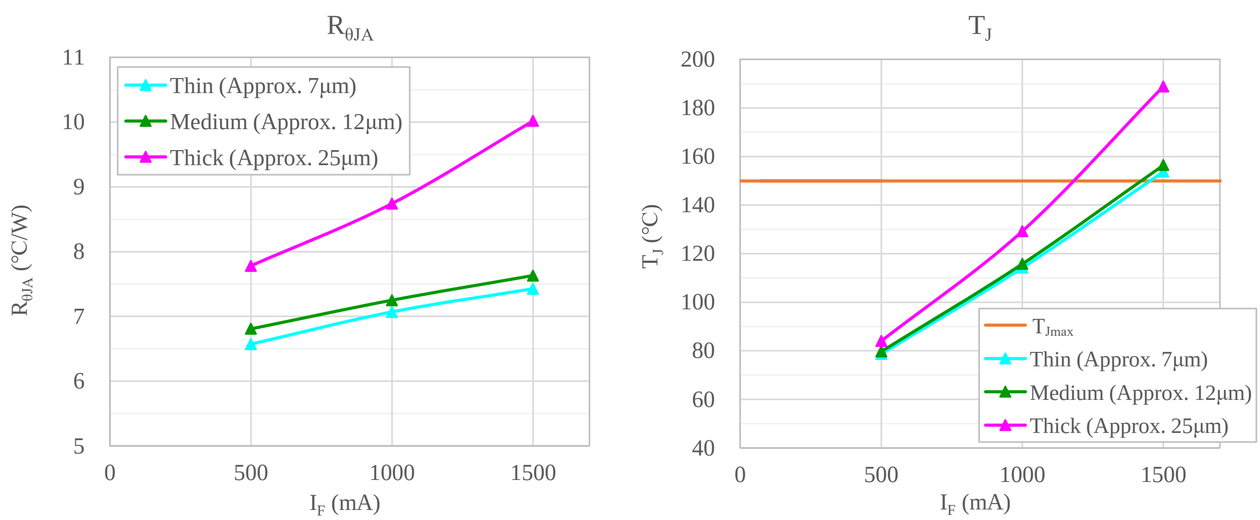


Figure 15. Thermal Resistance and Junction Temperature of the LED Modules for Different Adhesive Thicknesses

The results for Adhesives A and B showed little difference in the $R_{\theta JA}$ and the T_J up to the maximum evaluated thickness (i.e. approximately 25µm). This indicates that when an adhesive with a lower thermal conductivity is used, the heat dissipation performance of the LED modules is more strongly affected by the adhesive thickness.

7.7 Evaluation for the Heat Dissipation of the LED Modules and the Bonding Strength via Sulfur Corrosion Testing

Using the LED modules prepared as described in section 7.4, Nichia evaluated the heat dissipation performance of the LED modules and the bonding strength before and after a sulfur corrosion test. Table 11 provides the test conditions.

Table 11. Sulfur Corrosion Test Conditions

Temperature	Relative Humidity	Gas Concentration	Test Duration
40ºC	90%RH	H_2S: 15ppm	672h

Table 12 provides the appearance of Adhesives A, B, and C before and after the sulfur corrosion test. Adhesives A and C, which contain silver in the thermal conductive filler, showed discoloration (i.e. blackening) after the test; this is presumed to result from sulfidation of the silver. Adhesive B, which contains aluminum oxide in the thermal conductive filler, showed no visible change in appearance (e.g. no discoloration).

Table 12. Examples of the Appearance of the Adhesives
Before and After the Sulfur Corrosion Test

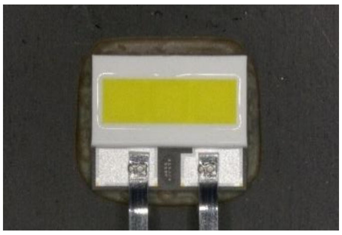
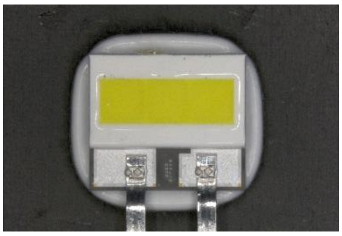
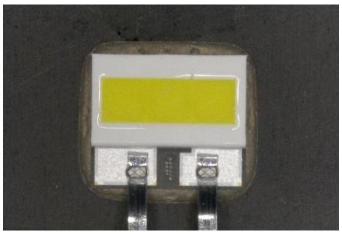
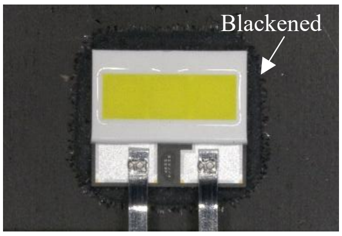
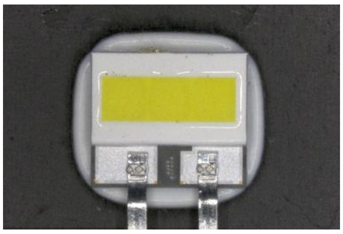
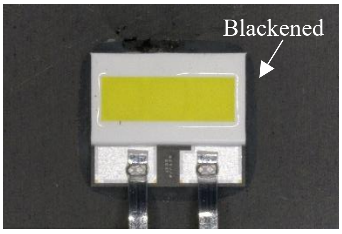
Adhesive	A	B	C
Before the Test			
After the Test			

Figure 16 shows the $R_{\theta JA}$ and the T_J of the LED modules at I_F=1500mA, T_A=50ºC, measured when the saturation temperature at the junction was reached before and after the sulfur corrosion test (the values are the averages of the measured values of three LED modules). The evaluation results show that for Adhesives A and C, while the adhesives discolored, the increases in the $R_{\theta JA}$ and the T_J were very small; this indicates that the corrosive gas hardly affected the heat dissipation performance of the LED modules with these adhesives under the test conditions. For Adhesive B, no effect on the heat dissipation of the LED modules was detected in the test.

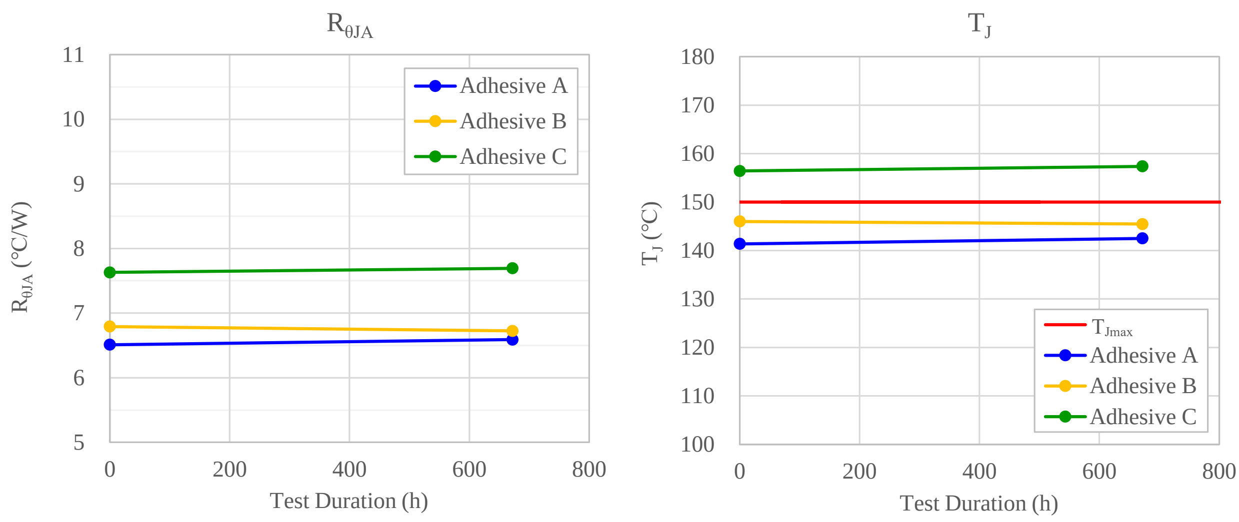


Figure 16. Thermal Resistance and Junction Temperature of the LED Modules Before and After the Sulfur Corrosion Test (I_F=1500mA)

Figure 17 shows the bonding strength between the LEDs and the aluminum plate before and after the sulfur corrosion test. The bonding strength was evaluated by shear testing using a bonding tester (the values are the averages of the measured values of three LED modules). The results show that for Adhesives A and B, the shear strength exhibited little decrease after the test. For Adhesive C, the shear strength decreased by approximately 10%; however, the value of the shear strength after the test remained higher than those of Adhesives A and B.

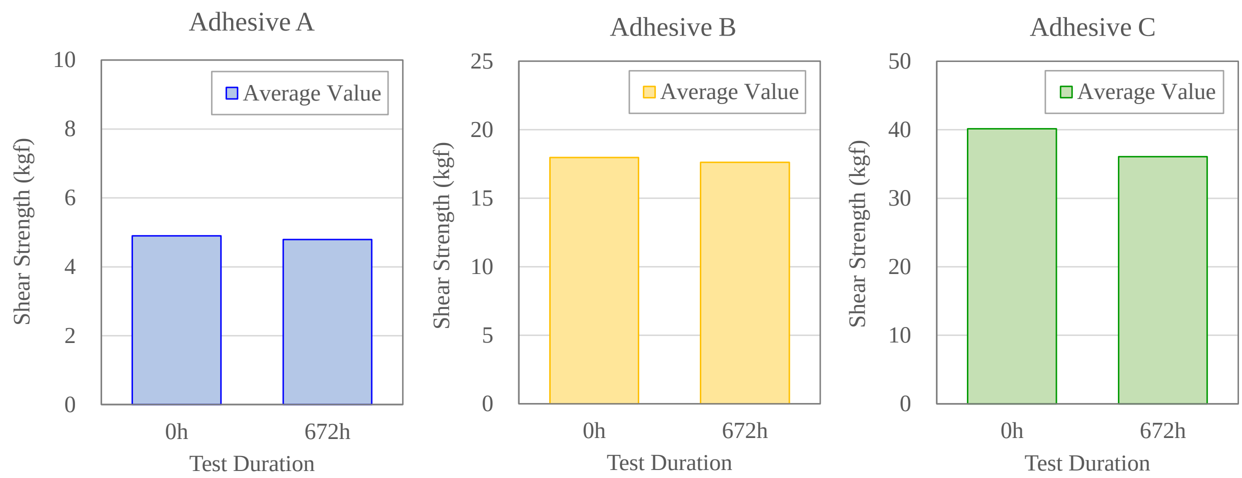


Figure 17. Shear Strength Before and After the Sulfur Corrosion Test

7.8 Evaluation for Heat Dissipation of the LED Modules and the Bonding Strength via Thermal Shock Testing

Using the LED modules prepared as described in section 7.4, Nichia evaluated the heat dissipation performance of the LED modules and the bonding strength before and after a thermal shock test. Table 13 provides the test conditions.

Table 13. Thermal Shock Test Conditions

Temperature Cycle	Number of Cycles Evaluated
-55ºC (15 min) ⇔ 150ºC (15 min)	560/1040/2000 Cycles

Table 14 provides the appearance of Adhesives A, B, and C before and after the thermal shock test. All the evaluated LEDs using adhesive C delaminated from the aluminum plate after 560 cycles. For Adhesives A and B, no delamination was observed at the completion of the 2000-cycle test, and there were no visible changes in the appearance.

Table 14. Appearance Examples of the Mounted LEDs Before and After the Thermal Shock Test

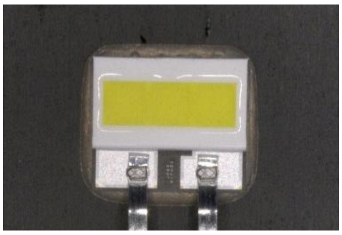
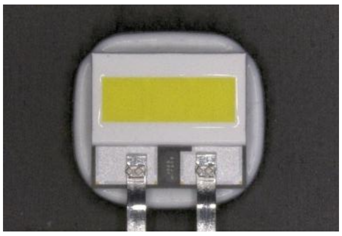
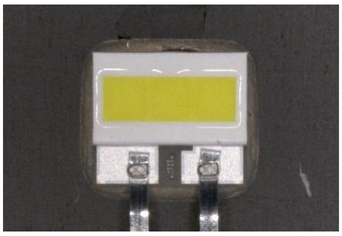
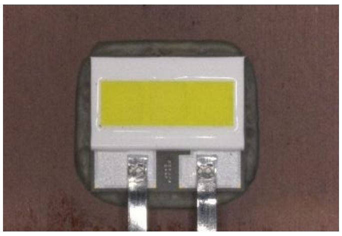
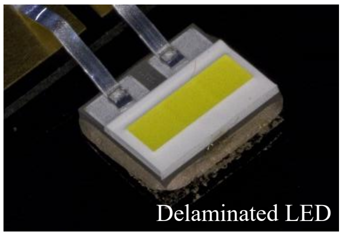
Adhesive	A	B	C
Before the Test			
After the Test	 After 2000 Cycles	 After 2000 Cycles	 After 560 Cycles

Figure 18 shows the $R_{\theta JA}$ and the T_J of the LED modules at I_F=1500mA, T_A=50ºC, measured when the saturation temperature at the junction was reached before and after the thermal shock test (the values are the averages of the measured values of three LED modules). The evaluation results show that for Adhesive A, the $R_{\theta JA}$ and the T_J slightly increased as the number of cycles increased. For Adhesive B, almost no change in the $R_{\theta JA}$ and the T_J was observed even after 2000 cycles. For Adhesive C, the LEDs delaminated after 560 cycles; no further measurements could be taken.

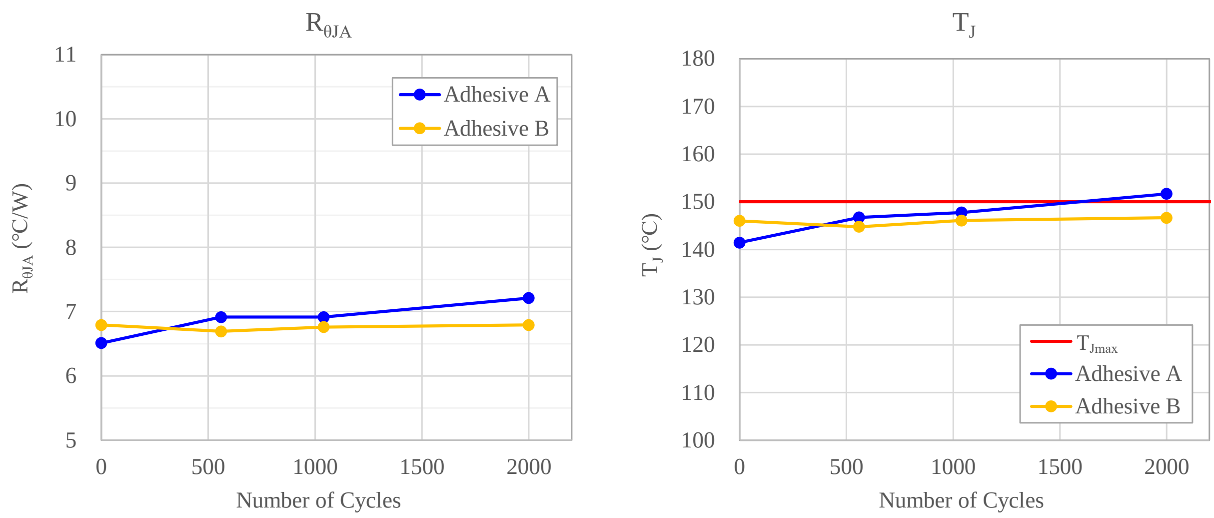


Figure 18. Thermal Resistance and Junction Temperature of the LED Modules Before and After the Thermal Shock Test (I_F=1500mA)

Figure 19 shows the bonding strength between the LEDs and the aluminum plate before and after the thermal shock test. The bonding strength was evaluated by shear testing using a bonding tester (the values are the averages of the measured values of three LED modules). The results show that for Adhesives A and B, the shear strength did not decrease significantly even after 2000 cycles under the test conditions. Almost no differences were seen in the rates of decrease for Adhesives A and B. For Adhesive C, the LEDs delaminated after 560 cycles; no further measurements could be taken.

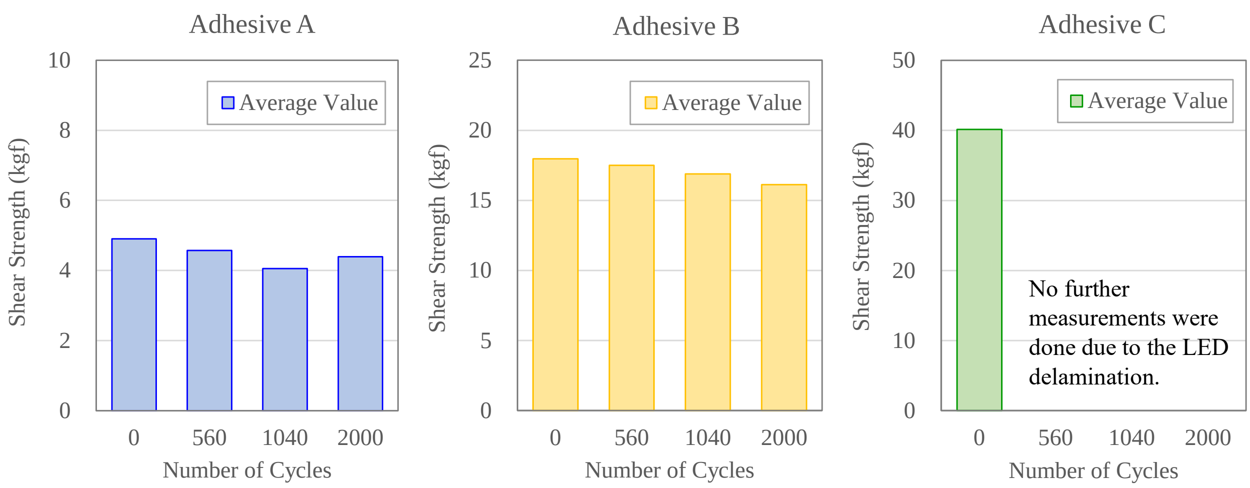


Figure 19. Bond Shear Strength Before and After the Thermal Shock Test

In the thermal shock test, the LEDs bonded with Adhesive C delaminated; Nichia assumes it was because the stress caused by a difference in the coefficient of thermal expansion between the ceramic LED packages and the aluminum plate was not adequately absorbed by the adhesive, whose binder resin was epoxy. In general, silicone-based adhesives are more flexible than epoxy-based adhesives and thus are better at absorbing differences in thermal expansion.

7.9 Cautions and Recommendations for Adhesives

Based on the evaluation results detailed in sections 7.4-7.8, Nichia provides cautions and recommendations for selecting and using adhesives in this section.

- The heat dissipation performance of the LED modules is affected by the thermal conductivity of the adhesive used to mount the LEDs. Select an adhesive with a high thermal conductivity. Nichia recommends a thermal conductivity of ≥3W/m·K, as explained in the previous sections.
- Nichia recommends applying the adhesive in a way that creates a fillet around the bottom surface of the LEDs. A fillet increases the bonding strength and improves the heat dissipation performance of the LED modules.
- The adhesive thickness affects the heat dissipation performance of the LED modules more significantly when the thermal conductivity of the adhesive is lower. Ensure that the adhesive is not thicker than necessary while meeting the chosen requirements for the bonding strength.
- If an adhesive containing silver in its filler is used, the silver may corrode due to sulfur in the environment resulting in reduced thermal conductivity and/or reduced bonding strength. For the silver-containing adhesives Nichia used for the evaluations, the heat dissipation performance of the LED modules and the bonding strength were not significantly affected by the sulfur corrosion test to a degree that would cause problems. However, reliability verification must be performed in corrosive environments containing sulfur.
- If the LED modules are used in an environment where the temperature fluctuates significantly, stress will be applied to the adhesive due to a difference in the coefficient of thermal expansion between the LED packages and the material onto which the LEDs are mounted (e.g. heatsink, housing, etc.). The stress may affect the quality of the bond, causing a reduction in the heat dissipation performance of the LED modules and/or the bonding strength. It is necessary to perform reliability verification considering the temperature fluctuations under the chosen operating conditions.
- The optical characteristics of the LEDs depend on the heat dissipation performance of the LED modules. Good optical characteristics and high reliability can be achieved by selecting a suitable adhesive and using it properly to create a high-quality bond. The evaluation results provided in this application note were obtained under Nichia's evaluation conditions and environments and thus, they are not guaranteed; use the evaluation results only as a reference. Perform sufficient verifications for the chosen application prior to use, considering the conditions/environments in which the LEDs will actually be used to ensure that the expected performance is maintained.

8. Thermal Management

When designing the chosen application using the LEDs, it is necessary to consider the heat generated from the LEDs during operation. The increase in the junction temperature (T_J) of the LEDs while in operation varies depending on the thermal resistances of the heatsink and housing, the thermal conductivity of the adhesive used, and how the adhesive is applied etc. Ensure that when using the LEDs for the chosen application, heat is not concentrated in an area and properly managed in the application and the Absolute Maximum Junction Temperature (T_J) is not exceeded under any circumstances.
The operating current should be determined by considering the temperature conditions surrounding the LEDs (i.e. T_A). Ensure that when operating the LEDs, proper measures are taken to dissipate the heat.

9. Electrostatic Discharge (ESD)

9.1 Measures Against ESD

The Nichia 321 series LEDs are sensitive to transient excessive voltages (e.g. ESD, lightning surge). If this excessive voltage occurs in the circuit, it may cause the LEDs to be damaged causing issues (e.g. the LEDs to become dimmer or not to illuminate [i.e. catastrophic failure]).
Ensure that when handling the Nichia 321 series LEDs, necessary measures are taken to protect them from an ESD discharge. The following examples are recommended measures to eliminate the charge:

- Grounded wrist strap, ESD footwear, clothes, and floors
- Grounded workstation equipment and tools
- ESD table/shelf mat made of conductive materials

Ensure that all necessary measures are taken to prevent the LED modules from being exposed to transient excessive voltages (e.g. ESD, lightning surge):

- tools, jigs, and machines that are used are properly grounded
- appropriate ESD materials/equipment are used in the work area
- the system/assembly is designed to provide ESD protection for the LED modules

9.2 Measures for When the Tool/Equipment Used is an Insulator

If the tool/equipment used is an insulator (e.g. glass cover, plastic, etc.), ensure that necessary measures have been taken to protect the LEDs from transient excessive voltages (e.g. ESD). The following examples are recommended measures to eliminate the charge:

- Dissipating static charge with conductive materials
- Preventing charge generation with moisture
- Neutralizing the charge with ionizers

9.3 Identifying ESD Damaged LEDs

To detect if an LED was damaged by transient excess voltages (i.e. an ESD event during the system's assembly process), perform a characteristics inspection (e.g. forward voltage measurement, light-up test) at low current (≤1mA). If the LED was damaged by transient excess voltages (e.g. ESD), it would cause the Forward Voltage (V_F) to decrease, the LED not to illuminate at a low current, etc.
For the failure criteria for the LEDs, refer to the applicable specification; the failure criteria for the V_F at the forward current of 0.5mA is specified.

10. Cleaning

Do not clean and/or wipe the emitting surface of the LEDs. If an area of the LEDs other than the emitting surface is contaminated (e.g. dust/dirt), use a cloth, swab, etc. soaked with a small amount of isopropyl alcohol (IPA) and wipe the LEDs with it in a manner that does not touch the emitting surface. If another solvent is used, it may cause the LED package/resin to be damaged causing the optical characteristics and/or the reliability to be affected; ensure that sufficient verification is performed prior to use.
Do not clean the LEDs with an ultrasonic cleaner. This may cause the optical characteristics and/or the reliability to be affected.

11. Eye Safety

There may be two important international specifications that should be noted for safe use of the LEDs: IEC 62471:2006 Photobiological safety of lamps and lamp systems and IEC 60825-1:2001 (i.e. Edition 1.2) Safety of Laser Products - Part 1: Equipment Classification and Requirements. Ensure that when using the LEDs, there are no issues with the following points:

- LEDs have been removed from the scope of IEC 60825-1 since IEC 60825-1:2007 (i.e. Edition 2.0) was published. However, depending on the country/region, there are cases where the requirements of the IEC 60825-1:2001 specifications or equivalent must be adhered to.
- LEDs have been included in the scope of IEC 62471:2006 since the release of the specification in 2006.
- Most Nichia LEDs will be classified as the Exempt Group or Risk Group 1 according to IEC 62471:2006. However, in the case of high-power LEDs containing blue wavelengths in the emission spectrum, there are LEDs that will be classified as Risk Group 2 depending on the characteristics (e.g. radiation flux, emission spectrum, directivity, etc.)
- If the LEDs are used in a manner that produces an increased output or with an optic to collimate the light from the LEDs, it may cause damage to the human eye.

If an LED is operated in a manner that emits a flashing light, it may cause health issues (e.g. visual stimuli causing eye discomfort). The system should be designed to ensure that there are no harmful effects on the human body.

12. Summary

The LEDs need to be handled and assembled in a proper manner to obtain the required characteristics and reliability. Follow the cautions/suggestions detailed in this application note and the applicable specification for the LEDs to ensure that the LEDs are used properly.
In addition, when selecting the parts/materials to be used with the LEDs, effects of VOCs and corrosive gases from the parts/materials (e.g. sulfur, halogens, etc.) must be carefully considered and sufficient verifications with the conditions/environments in which the chosen application containing the LEDs will actually be used must be performed to ensure that the characteristics and/or the reliability for the LEDs are not adversely affected.

Light Emitting Diode

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